The Economics of Infrastructure Investment: Beyond Simple Cost Benefit Analysis

Arthur Grimes

Motu Working Paper 10-05
Motu Economic and Public Policy Research

August 2010

Author contact details

Arthur Grimes
Motu Economic and Public Policy Research and University of Waikato
arthur.grimes@motu.org.nz

Acknowledgements

This paper has been prepared with the assistance of the Centre for Advanced Engineering New Zealand (CAENZ Infrastructure Project) and the Foundation for Research, Science and Technology (FRST grant MOTU0601, Infrastructure). Helpful comments have been received from George Hooper, John Boshier, Ernest Albuquerque and Len Starling, but none of the above individuals or organisations is responsible for the views expressed.

Motu Economic and Public Policy Research

PO Box 24390
Wellington
New Zealand

Email info@motu.org.nz
Telephone +64 4 9394250
Website www.motu.org.nz

ISSN 1176-2667 (Print), ISSN 1177-9047 (Online).

Abstract
This non-technical 'think-piece' examines aspects of infrastructure project evaluation, concentrating on circumstances that may render a standard cost benefit analysis (CBA) inappropriate. It is designed to make infrastructure investors and planners think deeply about their assumptions and to broaden the range of issues that are taken into account. Issues considered include: the role of CBA; network effects (increasing returns to scale) and the endogeneity of resources within an economy; the valuation of productive versus consumptive benefits; the value of traded versus non-traded sector production; the role and choice of the discount rate; and the importance of considering option values when making infrastructure investment and disinvestment decisions.

JEL codes
H54

Keywords
Infrastructure, cost benefit analysis, evaluation

Contents

Executive Summary

This non-technical 'think-piece' examines aspects of infrastructure project evaluation, concentrating on circumstances that may render a standard cost benefit analysis (CBA) inappropriate. It is designed to make infrastructure investors and planners think deeply about their assumptions and, in some circumstances, to broaden the range of issues that are taken into account. Key findings of the paper can be summarised as follows:

- CBA is a useful tool for making comparisons between alternative projects designed to produce similar benefits. It makes explicit the nature, size and timing of a project's costs and benefits, covering both tangible and intangible items plus wider economic benefits (e.g. agglomeration externalities).
- A CBA makes an explicit trade-off between present and future net benefits through its choice of discount rate. There is no single "correct" discount rate that covers all project types.
- Where returns from a project can be reinvested at the same rate and risk profile as the project under consideration, and where the project could be undertaken equally by another agent, a cost of capital (incorporating a market-derived risk premium) constitutes an appropriate discount rate for the project.
- Even here, the choice of risk premium is far from trivial, and circumstances exist where a negative risk premium may be appropriate.
- Where the benefit stream in part comprises intangible consumption benefits, the cost of capital is generally no longer the appropriate discount rate; inter-personal value judgements arise between benefits for current versus future agents. An 8% p.a. real discount rate (New Zealand Treasury's current standard rate) means that, for the same tax flows and liability structure, policy-makers prefer to have one unit of consumption benefit now in place of six units of benefit in 25 years time.
- A conventional CBA is inappropriate where an initial project within a sequence of projects creates options for investment in future projects with uncertain returns, and where: (a) information about those returns is forthcoming only after the initial project is completed, or (b) potential returns from the future projects diminish over time.
- In these cases, investment in the initial project creates an *option* to reap high returns through prospective future investments, without imposing an obligation to invest in those projects where circumstances indicate that returns will instead be low.
- The prospective investment opportunities include those that may be undertaken by future agents (e.g. new migrants, start-up firms or international firms not yet present in the country) as well as by the initial infrastructure provider or other current agents.
- Investment in the initial project may be optimal even when the initial project and the combined set of projects both have a negative net present expected value.
- The importance of options created by some infrastructure investments means that a standard needs analysis may, on occasions, need to be supplemented by an "opportunities analysis".

- A corollary of the options approach is that disinvestment decisions must account for future opportunities that may be lost if existing infrastructure were scrapped.
- Network effects are a potential source of discontinuity and/or increasing returns to scale arising from infrastructure investments; a suite of complementary investments can produce greater returns than the sum of returns to each individual investment.
- A coordinated approach to infrastructure investment is therefore sometimes required. Coordination may be required for diverse investments at a spatial level (e.g. a spatial plan) or may relate to several investments of the same type (e.g. road networks) or to complementary investments (e.g. investments in fibre plus IT skills).
- Infrastructure that raises New Zealand's productive potential will attract labour and capital to the country; one region's gain should not, in general, be considered another's loss.
- Some classes of infrastructure investment have favourable long-term economic effects relative to others. Infrastructure that produces returns for the internationally traded productive sector delivers greater long-term national benefit than does a project with commensurate immediate benefit related to domestic consumption.
- Accordingly, a national infrastructure strategy may concentrate on prioritising projects that: (i) service the internationally traded productive sector; (ii) exhibit network complementarities; and/or (iii) create new opportunities for value-enhancing investments that take advantage of the initial investment project.
- These considerations, which are largely absent from a conventional CBA evaluation, may be combined with the choice of a lower discount rate in order to prioritise projects that boost the productive base of the New Zealand economy for a future generation.

1. Introduction

Infrastructure investment is an important contributor to economic growth (OECD 2006, 2007 and 2008; Nijkamp & Poot 2004). Investments in infrastructure are generally characterised by large capital items that can be accessed by multiple users, for prolonged time periods. In many instances, large-scale long-lived infrastructure projects are provided and/or funded by (central or local) government (e.g. roads), although some items (e.g. cell-phone towers) are provided privately.

Our concentration is on how a government body should approach the prospective evaluation of a major infrastructure investment. While many New Zealand government agencies are involved in some form of infrastructure, it is the Treasury that acts as the "guardian" of the evaluation process. Its *Cost Benefit Analysis Primer* (New Zealand Treasury, 2005) provides a succinct and clear introduction to the methods it regards as appropriate for such prospective project evaluation.[1] The *Primer* emphasises the benefits of Net Present Value (NPV) analysis and Benefit Cost Ratios (BCRs) as tools to evaluate prospective investments within a cost benefit analysis (CBA).

For many (especially small-scale) projects, the methods discussed within the *Primer* are excellent tools to use when analysing whether a project should proceed or not. In some cases, however, advances in economic theory - and in other cases, unresolved puzzles - make the application of the Treasury's preferred methods less clear-cut. This paper analyses some of these complications. It does so in a context where for two decades, New Zealand had low levels of infrastructure investment relative both to its own history and to investment rates in other advanced countries (Grimes, 2009a); this situation is only now being rectified (New Zealand Government, 2010).

The issues analysed here have implications both for the overall quantum of infrastructure investment and for the nature of chosen investments given an investment funding envelope. Different methods give different rankings for alternative projects, and the optimal timing of investments may differ across approaches. We make no claim that one approach is necessarily better than another. Rather, the purpose of the paper is to elucidate the complexity of some of the issues at hand and to encourage a deep scrutiny of the assumptions used when evaluating major infrastructure investment proposals.

[1] NZTA (2010) provides a much more substantial manual targeted at CBAs of transport projects. See also Infrastructure Australia (2009) and HM Treasury (2010).

The next section of the paper outlines a simple baseline case that we use as our departure point in subsequent analytical sections. The baseline case follows the preferred methodology used in the Treasury's *Primer* in relation to NPV and BCR analyses. Each subsequent section analyses a particular departure from the baseline assumptions. Section 3 examines the treatment of seemingly unrelated projects that, if conducted together, would create an increasing returns to scale network (examples may be a broadband network or conversion of multiple inter-city roads into a national highway). The section also examines the endogeneity of resources to the domestic economy. Section 4 examines how uncertainty with regard to benefits affects the analysis, raising the need to treat option values explicitly within an appraisal. As we will see, this may reduce or increase the propensity to invest in certain types of infrastructure. Section 5 examines the treatment of productive versus consumption benefits, where the latter are assumed to be intangible and incapable of storage. Unlike the standard treatment, this case implies favouring some types of benefits over others. In section 6 we examine the rationale behind the use of alternative measures of the discount rate and the sensitivity of outcomes to discount rates. All these sections involve some use of simple intertemporal economic theory and/or simple examples. Section 7, which examines the treatment of infrastructure investments that service traded versus non-traded productive sectors, differs in method by utilising a recent model (Grimes, 2009) designed to analyse the relative importance of these two sectors at a macroeconomic level.

Conclusions are stated in section 8. These conclusions are not designed to propose a single optimal analytical method to be used in place of the Treasury's *Primer*. Instead, they summarise key issues that complicate the use of any single method, and alert the reader to cases where more complex analytical tools or insights are required in order to reach more nuanced, and hopefully more appropriate, infrastructure investment decisions.

2. Standard NPV and BCR Approaches

After specifying the nature of the economic problem to be addressed and outlining the range of potential measures, the most basic approach when conducting a cost benefit analysis (CBA) of a potential long-lived project is to:

a) calculate all anticipated costs associated with the project, allocating them to specific years;
b) calculate all anticipated benefits associated with the project, allocating them to specific years;

c) discount each year's costs and benefits by an appropriate discount factor (that embodies the chosen discount rate which in turn reflects the risk of the project[2]);
d) sum all discounted benefits less discounted costs to give the project's net present value (NPV); and/or
e) take the ratio of the sum of the project's discounted benefits to discounted costs to give the project's benefit-cost-ratio (BCR);
f) if funds are available (i.e. in the absence of non-price rationing) approve the project if NPV>0 or, equivalently, if BCR>1; if multiple solutions to the same issue are being considered, then choose the project with the highest BCR.

An important distinction is made in the *Primer* between 'financial analysis' and 'economic cost benefit analysis'. CBA considers all (tangible and intangible) benefits and costs accruing to agents within the economy no matter whether they are public or private; benefits and costs are therefore not limited just to those relating to the specific agency undertaking the project. By contrast, financial analysis considers only costs and benefits as they accrue to the relevant agency. For instance, CBA includes the benefits accruing to private car users arising from a new road whereas these benefits are not included in a financial analysis (other than, perhaps, through the extra excise taxes raised on the petrol used by additional traffic). CBA therefore provides the appropriate approach for including all economic benefits when considering a major infrastructure project.

An important corollary is that comparable CBAs must be used when evaluating potentially competing projects. For instance, the same categories (and valuations) of intangible benefit included in a roading CBA must also be included in a rail CBA; otherwise one transport mode may be privileged over another leading to a sub-optimal allocation of investment resources. A key implication of this insight is that the rail agency's accountability should be based on the identical approach to the accountability used for the roading agency, rather than being assessed in standard financial terms.

In CBA calculations (and for the purposes of this paper), all costs and benefits are calculated in real (i.e. CPI-adjusted) terms. Correspondingly, the discount rate is specified in real terms (i.e. the real discount rate is approximately equal to the nominal discount rate less the CPI inflation rate). The *Primer* sets a standard discount rate of 10% real p.a., but this standard rate has since been reduced to 8% (New Zealand Treasury, 2008). The *Primer* notes other possible specific rates and indicates that sensitivity analysis of projects should be carried out using different discount rates. Except where the discount rate is being analysed, the treatment in this paper adopts the standard 8% rate.

---

[2] Note that risk should be in terms of the 'beta' of the project (i.e. its correlation with the market portfolio) rather than its volatility (standard deviation).

The period of analysis is taken to correspond to the economic lifetime of the project (or assets) being considered, although a shorter time-span with consideration of residual value, or a longer time-span incorporating sequential projects could be considered in equivalent fashion. The *Primer* (p.13) advises that given its standard discount rate "the recommended approach is to use an analysis period of 20 years, because impacts beyond 20 years tend to be insignificant after the time value of money (discounting) is taken into account."

In addition, the *Primer* states (p.10): "Ideally CBA will demonstrate that the expected benefits of a given proposal exceed the expected costs. That is, to determine if there is a *net benefit*. If the net benefit is greater than zero then the proposal may be worthwhile pursuing." As we demonstrate later in this paper, the decision criterion may, however, be more complicated than giving the go-ahead (respectively, putting a stop) to a proposal that has positive (respectively, negative) net benefit. Indeed, the *Primer* indicates a number of items that may complicate the analysis, including:

a) difficulties in assigning values to certain (intangible) benefits, while noting that intangibles should be explicitly included where they can be reliably measured (or at least be itemised and included qualitatively);
b) difficulties in assessing the "strategic value" of a project (although this term is not defined);
c) the risk of 'optimism' bias – i.e. understating costs and/or over-stating benefits (however, other research suggests that, in some situations, there may be an opposite tendency to understate potential benefits)[3];
d) the ability to "provide assurance" that "all significant benefits and costs … will be realised" (p.10), while also including contingencies (p.17);
e) the need to include deadweight losses due to taxation,[4] although no distinction is made in the *Primer* between investments that are funded by taxation relative to those funded by users (the latter case does not incur the deadweight loss associated with taxation).

The *Primer* makes the standard assumption (for a long-lived project) that all resources in the economy are otherwise fully utilised. The potential for large-scale investments to influence the available pool of resources (e.g. by affecting international migration flows and/or international capital investments) is not addressed. Such increases in resources available to the economy raise economic activity. Similarly, existing resources may be used more effectively as a

[3] For example, see Grimes (2009a) and Grimes and Liang (2010).
[4] The *Primer* (p.18) recommends multiplying public expenditures by 1.2 prior to discounting to incorporate deadweight loss effects (in addition to using its recommended discount rate; thus indicating that the discount rate is not set so as to include deadweight loss impacts).

result of infrastructure investments that produce agglomeration externalities or other forms of increasing returns to scale in the economy.[5]

Ignoring the complications discussed above, we begin with a baseline CBA for a notional long-term (101 year) project and adopt the basic CBA methodology. The key parameters of this baseline project, deliberately chosen to highlight some of the complexities examined in this paper, are shown in Table 1.

The project outlined in the table has an initial five years of known capital costs and, for simplicity, requires no subsequent outlays. Benefits do not begin to accrue until 5 years after the commencement of the project, and then accrue at a constant (undiscounted) known rate for 96 years; no benefits accrue thereafter. While the accrued benefits are over nine times the accrued costs, once discounting occurs the project only just has a positive NPV (BCR≈1). Hence the judgement that follows from this baseline CBA is that society is virtually indifferent to whether this project should proceed or not.

Table 1: Baseline Project*

Year	Costs ($million)	Benefits ($million)
0	100	0
1	100	0
2	100	0
3	100	0
4	100	0
5	0	47
6	0	47
7	0	47
…	…	…
100	0	47
101 …	0	0
SUM (Undiscounted)	500	4,512
SUM (Discounted at 8% p.a.)	431	432
NPV	**0.4** (≈ 432 - 431)	
BCR	**1.0008** (≈ 432/431)	

* All numbers in this and subsequent tables are in real terms; figures are rounded to the nearest whole number unless confusion would otherwise arise.

Subsequent sections vary key parameters within this model to show how the reasoning that lies behind the parameters can significantly alter the outcomes.

[5] The box on pp.13-14 of the *Primer* discussing benefits typically considered for roading proposals includes no such benefits; however, NZTA (2010) does now incorporate wider economic benefits of these types.

3. Network Benefits and Resource Availability

3.1. Network Effects

In many cases, infrastructure projects are considered in the context of the existing environment with allowance made for likely developments. The latter may include regional demographic developments based, for instance, on Statistics New Zealand's medium population projections for affected regions.[6] However it is unusual, at least in New Zealand practice, to undertake a CBA of multiple seemingly-unrelated projects that together exhibit increasing returns to scale.

Increasing returns may occur through at least two mechanisms. The first is through network effects that occur by virtue of a series of linked projects of the same type. Examples may include a telecommunications network in which the effectiveness of a single telecommunications device is magnified by other users joining the network, or a roading network in which firm or household location decisions may be dependent on a fast road being available for the full distance between two locations rather than a series of fast and slow patches of road between those locations.

A second situation in which there may be increasing returns is where complementary investments (of different types) are made in a specific area. Local "master-planning" for large-scale urban extensions exemplify the issues. A new settlement requires multiple types of infrastructure – roads, public transport networks, telecommunications, electricity supplies, water supply, sewerage, schools, health services, community facilities, etc. If any one of these infrastructures is lacking, the entire project may be rendered infeasible or lose significant value, but each investment project can only be evaluated in the context of all others also taking place. For instance, if the existing population of the locality is 100, none of these infrastructure investments may be worthwhile, but if the population is expected to increase to 10,000 as a result of a coordinated master-plan development, all services may not only be feasible, but also necessary for the development to occur. Analysis of a specific infrastructure project in isolation of all others would, in this case, be inappropriate.

We illustrate the issues with an example exhibiting the former type of increasing returns, but the analysis applies just as readily to the latter type. Consider ten potential roading investments, each a fifth the size of our baseline case (i.e. with expenditures of $20 million p.a.

[6] In the next sub-section, we examine cases where the resources (including population) of the region may be affected by the infrastructure investment decision, thereby rendering inappropriate the use of a standard projection that does not incorporate the prospective investment.

for years 0-4). Five of the projects are scattered around the country and have a benefit profile exactly one-fifth that of the baseline project (i.e. $9.4 million p.a. for years 5-100). Together, these five projects equate to the baseline case and so all would be undertaken on the same basis as for the baseline case in Table 1.

The other five projects each involve upgrading a separate portion of a local road between two cities to motorway standard. Considered by itself (i.e. in the absence of the other four upgrades) the benefit profile for each project is $9 million p.a. for years 5-100. As shown in the first Benefit column of Table 2, each of these projects - considered as specific isolated projects - would be uneconomic with a negative NPV and a BCR of less than one.

Table 2: Network Effects of Five Related Projects

Year	Sum of Costs ($million)	Sum of Benefits: Project-specific ($million)	Sum of Benefits: Network ($million)
0	100	0	0
1	100	0	0
2	100	0	0
3	100	0	0
4	100	0	0
5	0	45	50
6	0	45	50
7	0	45	50
…	…	…	…
100	0	45	50
101 …	0	0	0
SUM (Undiscounted)	500	4,320	4,800
SUM (Discounted)	431	413	459
NPV		**-18**	**28**
BCR		**0.9582**	**1.0647**

Now consider the case where all five projects were treated as a single project and built together. The cost profile of all five projects remains as before but the total benefit is now $50 million p.a. (for years 5-100), i.e. 11.1% higher than the total benefits if considered as five isolated projects. The final column of Table 2 summarises the outcomes, revealing that the combined project would now not only be undertaken (since the NPV is positive) but also be undertaken in preference to the baseline projects (the BCR for the linked motorway project of 1.0647 exceeds that of the baseline case). The latter situation may be relevant where investment funds or contracting resources are limited.

The example illustrated above may appear to be either contrived (where do the extra benefits arise from?) or obvious (who could object to considering the network impacts of the projects?). Let us take these two points in turn.

Network effects are quite obvious in the master-plan example discussed above. A new settlement without a specific key piece of infrastructure (for instance, a school or an electricity supply) may fail, whereas it would be highly successful if all relevant infrastructure elements are built. Consideration of each element by itself (i.e. ignoring the concurrent placement of other infrastructures) could lead to a decision to build none of the infrastructures rather than the optimal decision to build all.

At the larger regional level, the move towards a regional spatial plan for Auckland (incorporating the regional infrastructure investment plan), as part of the formation of the Auckland Council, reflects a need to consider interactions between separate infrastructure investments. For instance, CBD development plans cannot be adequately considered without consideration also of public and private transport links from outer suburbs to the CBD (both for workplace location and for entertainment/shopping choices): CBD development may fail if transport links from the rest of the urban area to the CBD are poor. Conversely, projected benefits of transport upgrades may not be sufficiently high for a project to proceed unless CBD upgrades (e.g. to the harbour-front) also occur, in which case the network benefits may exceed the sum of benefits attributed to each of the projects.

The importance of long-term infrastructure planning incorporating network effects has long been recognised within the development economics literature.[7] Recently, the Secretary of the Australian Treasury, Ken Henry (2010), has followed this line of argument noting that an important element for government to consider is "the need for infrastructure investment to take place in carefully designed and planned networks … Government has an important role to play in enabling planning and providing a coordination and organising function" (p.15). He notes the importance of metropolitan level planning and development functions, citing international examples and the advent of Australia's Capital City Strategic Plans which provide a way "to facilitate cooperation between tiers of government." By contrast, New Zealand's *National Infrastructure Plan* (New Zealand Government, 2010) places less emphasis on strategic planning or on consideration of network effects.

[7] Lakshmanan (2010) cites the contributions of Rosenstein-Rodan (1943) and Hirschman (1958) that stress the importance of coordinated investments where opportunities are available to invest in increasing returns to scale technologies and where investment in a single project is unprofitable.

3.2. Resource Availability

At the national level, almost no spatial planning (or even coordination) is undertaken explicitly, despite New Zealand being smaller in population than moderate sized international cities. One reason for eschewing such an approach at the national level – apart from the major information and coordination problems – is that, for some types of investment, one region's gain may be offset by another region's loss (e.g. a new stadium may shift test matches from one city to another but not increase the overall number of test matches played in New Zealand).

This raises an important issue regarding the relationship between investment in new projects, especially those exhibiting increasing returns to scale, and the endogeneity of resource supply within the economy. Many firm and household location decisions are made in an international context; for New Zealand, the trans-Tasman context is particularly important. A spatial equilibrium approach (Roback, 1982; Haughwout, 2002; Glaeser and Gottlieb, 2009) indicates that resources (including people) flow across regional and national boundaries so as to equalise returns from producing and living in different regions. Land prices and wages adjust to equate returns after consideration of amenity and productivity values associated with certain locations and their infrastructures.

Consider a hypothetical case where a firm wishes to establish a facility close to a major university that has strong agri-tech capability and is near a major international airport. It can locate in Sydney, employ 100 people at an average salary of $100,000 per person[8] and make an annual profit of $10,000,000; thus total value added is $20,000,000 p.a. We assume that 25% of each of salaries and profits (i.e. $5,000,000 p.a.) is paid to government in tax, leaving $7,500,000 for employees and the same amount for owners of capital.

Within New Zealand, the same firm could locate either in Hamilton (close to agri-tech research facilities) or Auckland (close to an international airport) but, based on current infrastructure, it cannot locate close to both facilities. Its definition of "being close to an airport" may include uninterrupted motorway access from (near) the research facility to the airport (with an additional maximum journey time constraint, which we assume is met were there to be a motorway link between Hamilton and Auckland).

Without a motorway link, the facility will be located in Sydney and some portion of the 100 employees will migrate from New Zealand to Sydney to work in the facility (either directly to access specific jobs or indirectly as job opportunities in Sydney are seen to be superior to Auckland/Hamilton). Their existing salaries will be lost to the local community, and – in

[8] All sums are in New Zealand dollars for simplicity.

particular – the New Zealand government's tax revenues will decrease in line with the lost incomes. By contrast, the firm (and others like it) may locate the facility in Hamilton if the motorway link is built, thereby providing a step jump in returns provided the full roading upgrade is completed.

Importantly, since the choice is between locating the facility in Sydney versus Hamilton/Auckland, there is no case for arguing that the gain to Auckland/Hamilton is at the expense of another region in New Zealand. Instead, the quantity of resources available to New Zealand – including the $5 million to the New Zealand government through additional tax revenue – is increased by virtue of the new motorway link. In other words, the link results not just in a productivity improvement relating to existing resources, but also in additional resources being made available to both the private and public sectors.

The example given above is not restricted to the case of network effects – it could also arise in the case of an individual project. However, from an international firm's viewpoint, a coordinated set of infrastructure investments that lifts the capability of a particular region provides both an explicit signal and a concrete inducement to invest in New Zealand rather than in Australia or elsewhere. Again, the master-plan example provides the intuition: a resident or commercial enterprise is more likely to locate in a new settlement where it is apparent that coordinated services are available than in one where there is no apparent coordination of multiple services.

The endogeneity of resource location (i.e. the ability of resources to migrate across spatial boundaries) in response to a set of infrastructure investments has another corollary: it provides a counter-example to the standard treatment of deadweight costs associated with tax-financed infrastructure investments. Traditionally, it has been argued that the deadweight costs associated with taxation should be added to the cost side of a CBA. In the example above, however, because resources are internationally mobile, the pool of tax revenues available to government can increase as a result of a tax-financed investment, thus enabling a marginal reduction in tax rates (and hence in deadweight costs or 'excess burdens'). The potential for an increase in tax revenues and/or a decrease in tax rates therefore also needs to be incorporated into a CBA.

4. Uncertainty and Options

4.1. Options Overview

Most projects involve an inherently uncertain stream of benefits; costs may also be uncertain although they are generally more certain than the benefit steam. Henceforth we concentrate on issues of benefit uncertainty, though the same insights apply equally to cost uncertainties.

The Treasury's *Primer* (p.10) recommends that analyses are able to provide assurance that all significant benefits and costs will be realised. This approach implies that uncertain benefits should not be included in the CBA or, perhaps, should have some discount applied to their expected value prior to incorporation in the analysis (an approach that also mitigates the potential for optimism bias). Contingency scenarios with alternative outcomes for the benefit streams can also be used.

Laird et al (2009) note that option values have hitherto been largely absent as a component of transport appraisals. Building on the environmental literature they define option value in a transport sense as: "the willingness-to-pay to preserve the option of using a transport service for trips not yet anticipated or currently undertaken by other modes over and above the expected value of any such future use."[9] In this sense, the option value is equivalent to a risk premium that an individual would pay to ensure that a service is provided. They find that the few rail appraisal studies that have included option values exhibit a pattern: option values are typically highest for rail lines where current user benefits (and patronage) are low and/or where commuting opportunities (e.g. opening/closing stations) are concerned.

The modern approach to investment under uncertainty (e.g. Dixit and Pindyck, 1994) provides some rigour for conceptualising the nature of option values. Instead of treating benefits in an expected value sense or discounting benefits to reflect their uncertainty as in standard CBA approaches, the modern approach treats the inherent uncertainties explicitly within a "real options" framework that builds on the financial options approach of Black and Scholes (1974). This framework takes into account the option value involved in the timing of investment decisions. In some cases, delay has positive option value whereas, in others, investing early creates option value. We provide examples demonstrating how consideration of option values can change the timing and outcomes of decisions with regard to infrastructure investment.

4.2. Baseline Variants

Consider our baseline case with one variation. Instead of having a certain stream of benefits of 47 from year 5 onwards, we now have a certain stream of benefits of 30 p.a. plus an uncertain stream of benefits of 34 p.a. (also starting in year 5). The probability of the uncertain

[9] Note that this concept of an option differs, at least in nuance, from the meaning in the project appraisal literature where the appraiser may evaluate a range of options (i.e. alternatives) for the same project.

stream of benefits being realised is 'p' with probability 1-p that that stream will not occur (i.e. will be zero).

If p=0.5, the expected stream of benefits at the start of the project is 47 (=30+0.5x34) which is identical (in expected value terms) to the benefit stream in the baseline case. If one were to follow a pure expected value approach to the CBA, the decision to undertake the project would therefore be identical to that in the baseline case. Any $p \geq 0.5$ would result in the project proceeding (if funding is fully available at the baseline discount rate); any lower p would result in rejection of the project.

If one were to apply any discount to the uncertain returns (since one cannot "provide assurance" that "all significant benefits and costs … will be realised"), the project's NPV would become negative and the project would not proceed even with p=0.5. In this case, i.e. if there were an aversion to treating the uncertain returns in an expected value framework, p may have to be very much higher than 0.5 in order for the project to proceed.[10]

Now consider what the optimal investment decision would be if it was known at time t that the uncertainty surrounding project returns would be completely resolved in year 1 (i.e. one year later). There are now two alternatives: (1) invest, as before, in year zero; or (2) wait until year 1 and then decide whether to undertake the project based on the then known streams of all benefits.[11] The expected net present value for alternative (1), with p=0.5 is fractionally positive, as shown in Table 1. The middle column of Table 3 shows the NPV for varying values of p if the project is begun in year 0.

If the project planner were to wait until year 1 and then make a decision on the project in light of the new information on benefits (i.e. whether they will be 64 p.a. (=30+34) or 30 p.a.), the effects of uncertainty are removed, but time will be lost in accruing the benefits of the project in the case where the project is beneficial. The discounted stream of net benefits will therefore be reduced (as viewed from year 0).

In year 1, the project will only be undertaken if the uncertain stream of benefits materialises. In this case, the stream of benefits exceeds the baseline level, and we know from the prior analysis that the project should (just) be undertaken given the baseline benefit stream. If the stream of benefits does not materialise, the benefits fall well below the baseline level and so the project will not be undertaken.

[10] Such an approach, if generalised, could result in significant loss of value if a series of unrelated projects with uncorrelated returns were rejected owing to a discount being applied to each of their uncertain benefit streams.
[11] In this case, we assume that once the project has been started it will continue as planned for the full period. Sequential project investments, with the ability to halt the project part-way through, are examined in the next sub-section.

By waiting until year 1, therefore, the value of the project (viewed from year 0) will equal p multiplied by the discounted value of the project in year 1 (if it proceeds) plus 1-p multiplied by the discounted value of the project in year 1 (if it does not proceed). The second part of the sum is zero since the project will not proceed if the uncertain benefits do not materialise; hence the NPV in that case is zero. Thus, by waiting until year 1, the value of the project (as viewed in year 0) is $d*p*NPV_1$ where d is the discount factor (which in our example is $0.9259 = 1.08^{-1}$) and NPV_1 is the project's NPV as measured in year 1 if the uncertain benefits materialise. Column 3 of Table 3 indicates the project's NPV (viewed from year 0) if the decision is delayed to year 1.

Comparison of columns 2 and 3 shows that an immediate start to the project (in year 0) should only proceed if p>0.93, in which case the costs of waiting balance the benefits of resolving the uncertainty. In all cases with p<0.93, it is optimal to delay the investment. In these circumstances, the result is that the project planner who incorporates option values will take a more conservative investment stance than does one who operates on the basis of traditional CBA frameworks using expected values.

Table 3: Options and the Effects of Uncertainty

Probability of uncertain benefits	Expected value if begin project in Year 0	Expected value if decision is delayed to Year 1
P	**NPV**	**NPV**
0.45	-15	65
0.5	0.4	73
0.6	32	87
0.7	63	102
0.8	94	116
0.9	125	131
0.93	135	135
0.95	141	138

The favouring of a conservative investment stance is a standard result from the investment under uncertainty literature. As the length of time until resolution of the uncertainty increases (for a given p), the required degree of certainty with regard to the positive outcome that is required to delay the project falls, since the cost of delay increases with the number of years that the project is delayed.

A corollary of the conservative investment approach is that, given the same assumptions, a conservative disinvestment (i.e. scrapping) policy also applies. For instance, if our example applied to an operational but loss-making rail line, a decision-maker would require a higher degree of certainty that material future benefits would not arise if the rail line were retained than he would under an expected value analysis. In the presence of large sunk costs, an existing loss-making line may be retained for a significant period if the magnitude of future demand has considerable uncertainty (provided that operating losses are not "too large"). This may occur, for instance, in the presence of major uncertainty about future fuel and/or carbon prices.

Now consider a second case for the resolution of uncertainty. In this case, the uncertainty is not resolved until the completion of construction (i.e. end of year 4 if construction starts in year 0). In this case, the analysis is identical to the expected value case since the project must be evaluated, *ex ante*, without any ability to resolve the uncertainty until after construction has ended. No amount of waiting will help to resolve the uncertainty, and any delay reduces the net present value of the project (if expected NPV is positive). Thus, using the benefit flows considered above (certain benefits of 30 p.a. and uncertain benefits of 34 p.a., with p=0.5), the project should just proceed in year 0 despite the uncertainty.

An example of this type of uncertainty is where it is difficult to gauge the actual usage of a projected infrastructure investment, and the only way of resolving that uncertainty is to build it and find out. Some major new roads may fit this category (e.g. the Lane Cove tunnel in Sydney) as well as new technologies (e.g. fast broadband based on fibre-optic cable).

4.3. Sequential Investment Decisions and Learning

Previous examples considered investment projects that, once begun, had to be finished in their entirety. Some infrastructure projects (e.g. a tunnel) are of this nature, but others can be broken down into a sequence of inter-related projects (as discussed in relation to infrastructure networks). Furthermore, for some investments, the process of undertaking initial steps reveals information about the benefits (or costs) of further stages in the development that cannot otherwise be gained. As an example, a pilot fibre broadband roll-out to certain locations may help reveal the actual market demand for potential new services. Another example is where a 'back-bone' investment by a public entity (such as the electricity transmission grid) leads to private sector investors evaluating the potential pay-offs of future investments (in electricity generation and/or electricity usage) that require the back-bone already to be in place.

Dixit and Pindyck (1994; chapter 10) show that in these circumstances, the initial investment steps have information value over and above their direct contribution to the NPV of the investment programme. This information value, coupled with the ability to make subsequent decisions based on this information, means that part of the value gained from the initial investments is equivalent to the purchase of an option to proceed with further investments, and that this option has positive value.

Use of this real-options framework reveals that value can be created through the development and exercise of sequential projects, with option values attached to each successive project (Miller and Lessard, 2008). The key requirements for a project to create positive option value are: (a) project cash flows are made sequentially; (b) there exists uncertainty or volatility concerning the value of a project; and (c) flexibility is retained about whether successive projects are undertaken or not, with decisions on those projects reflecting new information that comes to hand after completion of earlier projects in the sequence. Under these circumstances, the *ex ante* economic value of a sequence of projects can be greater than the discounted present value of the expected future cash flows. The reason is that value is increased through the creation of options for subsequent sequential choices through the completion of initial projects.

We illustrate the nature of these option values through a simple example. We consider an infrastructure programme comprising multiple projects in which each project has its own pay-off with or without completion of subsequent projects within the programme. Examples may include an upgrade to an existing major road route, a sequence of fibre (broadband) investments or upgrade of the national transmission grid with the possibility of extra investments either in generation facilities or by new electricity users (i.e. extra firms or households) in the region.

Our illustration adopts a simple three-period model (periods 0, 1, 2) as detailed in Table 4. The full infrastructure programme comprises two projects: A and B. Project A, built in year 0, must be completed prior to project B if project B is to be undertaken. If project B is undertaken, it is built in year 1. The investor has the option of undertaking project A only and then deciding not to proceed with project B. The cost of each project (discounted to year 0) is $100 million in its year of construction.

If only project A is built, the benefit is known to be $60 million (which accrues in year 2). At the outset of the programme, the benefit that may accrue from project B is uncertain. There is a probability, p, that it will add nothing over and above project A, and so the overall benefit in year 2 would remain at $60 million. With probability, 1-p, the additional benefit from completion of project B is $240 million resulting in total benefit of $300 million in year 3. In our examples below we adopt p=0.5.

Consider a standard CBA conducted at the outset of year 0 solely for project A (i.e. ignoring project B). The discounted benefit is $60 million, the cost is $100 million, so the project's NPV = -$40 million. The decision stemming from a standard CBA is therefore not to proceed with project A by itself.

Table 4: Sequential Investment Projects

	Period		
	0	1	2
	All values in $ million (discounted to year 0)		
Cost: Project A	100	0	0
Cost: Project B	0	100	0
Benefit: Project A (by itself)	0	0	60
Benefit: Combined projects (poor outcome)	0	0	60
Benefit: Combined projects (good outcome)	0	0	300
Probability of poor outcome	0.5		
NPV: Project A only (without option value)	-40		
NPV: Combined projects (without option value)	-20		
NPV: Programme (including option value)	30		

Now consider a standard CBA conducted at the outset of year 0 for the combined programme of project A and project B. The expected discounted benefit is now the average of $60 million (if project B adds no value) and $300 million, i.e. $180 million. The total discounted cost is $100 million (project A) plus $100 million (project B), i.e. $200 million. Thus the combined projects' NPV = -$20 million. Again, the decision stemming from this CBA is not to proceed with the combined projects. Since neither project A not the combined projects yields a positive NPV, the overall programme would be declared uneconomic on the basis of a standard CBA.

Now consider how this result changes when the uncertainty about the magnitude of benefit resolves itself at the end of year 0. At this stage, the investor can choose whether to proceed with project B or not; by that stage, project A is irreversible.

If, at the end of year 0, it becomes known that the unfavourable outcome will occur (i.e. total benefit remains at $60 million) there is no return to undertaking project B and the overall programme will be capped at project A – even though project A, considered by itself, is uneconomic. (The cost of project A is sunk at this stage so the benefit will still accrue and it is not worth scrapping it.) Thus the NPV of the programme is -$40 million as shown earlier for project A by itself.

If, instead, it becomes known at the end of year 0 that the favourable result will occur, then project B will be undertaken since the marginal discounted benefits of the project will be $240 million compared with the marginal discounted cost of $100 million, an NPV (discounted to year 0) for project B (given project A) of $140 million. The NPV for the combined projects is now $100 million ($300 million benefits less $200 million costs).

Knowing that there is a p=0.5 chance of undertaking project B, an investor at the outset will calculate the NPV of the combined programme as the average of the two NPVs (i.e. -$40 million and $100 million). The overall NPV for the programme is therefore $30 million. Since this value is positive, the programme should be undertaken; i.e. project A, at least, should be undertaken.

How is it that a standard CBA of project A rejects the project, and a standard CBA of the two projects combined rejects the joint projects, yet project A, at least, should optimally proceed? The key is that by completing project A, the investor is gaining an option to proceed with project B, but he does not have that option if project A is never begun. The crucial assumption that yields value is that the knowledge about final benefit is crystallised only as a result of undertaking project A. Part of the return to completing project A is therefore the value of the option to proceed with project B that is created by first investing in project A.

If we consider real world examples, electricity planners may only learn about potential industrial demand for electricity in a region if the capacity to supply that power already exists; otherwise electricity-intensive firms will not consider the merits of establishing themselves in that region, and so will never communicate their potential regional electricity demand to the suppliers. Similarly, if fibre broadband access is not already available in a city, telecommunications providers may not know of the potential location choices of international firms wishing to situate themselves where high-speed broadband is already available. A roading planner may not know of the demand for new subdivisions in areas beyond the current highway if reasonable road access is currently unavailable. By creating the raw capacity to deliver electricity, information and/or vehicles, these investments can then induce private sector agents to reveal their valuations of newly available services, leading to further investments that may be undertaken privately (e.g. industrial plants, new firms in high-tech services, etc).

These examples indicate a further complication that arises with infrastructure investment: the initial investor is often (or generally) not the party that accrues the benefits arising from subsequent investments. In many case, project A in our illustration is the infrastructure investment, while project B is the aggregate of many smaller firm-specific investments, the benefits of which accrue to those firms, and/or to local landowners that benefit through an increase in their property prices (Grimes and Liang, 2010). The planner of project A does not have the information to accurately assess the marginal benefits flowing from project(s) B since the latter information is decentralised and may not even be within the knowledge base of existing firms. Firms may only develop that knowledge in response to project A's completion. Yet ignoring the potential benefits – even where these benefits are uncertain as in our illustration – results in under-investment. In particular, treating potential benefits within an expected value framework (as in a conventional CBA) or, even worse, in a risk averse manner, may result in under-investment where the project itself helps to elicit the nature and quantity of benefits that may arise.

4.4. Additional Option-Related Considerations

The option value in the previous example arises, in part, because the act of investing in the first stage project reveals information about the pay-offs in subsequent stages that would not otherwise be revealed. In addition to the examples already cited, research facilities (including both public good and private research facilities) are of this nature; commercialisation opportunities (i.e. second stage projects) only become apparent once the initial, more basic, research has been undertaken.

Another type of uncertainty is where the potential uncertain benefits may dissipate over time (or even disappear entirely if an early-mover advantage is lost). Consider, for instance, investment in fibre for fast broadband. If New Zealand were to invest now, it may capture (or at least retain) firms that require fast broadband services but if it were to delay the fibre investment, these firms may move offshore or fail to become established as the opportunity to be at the vanguard of new ventures is lost. In this case, contrary to the more standard situation with uncertainty, delay incurs a significant cost (in addition to the cost represented by the discount rate). While waiting may resolve uncertainty, the act of waiting in this example diminishes the size of the prospective uncertain benefits.[12]

Furthermore, there may be a game-theoretic element here. Consider two jurisdictions that compete for the opportunity to attract firms requiring fast broadband. Neither jurisdiction knows, with certainty, the size of the potential benefits that new fibre will bring, but both have a positive NPV for the project. The catch is that only the first investment will capture the benefits since firms agglomerate to the location of the early-mover. In this case, it pays to bring forward construction as much as possible so as to establish one's location as the dominant player in the field, as opposed to being relegated to a backwater. This situation is another example where the infrastructure investment, if undertaken early, effectively includes the purchase of an option with positive value. The uncertainty in this situation results in an optimal policy of fast-forwarding investment rather than delaying it.

---

[12] This result is related to the analysis of the *intensive margin* versus the *extensive margin* in the international trade literature. For instance, exports of existing firms may increase following a reduction in transport costs (the intensive margin) but the magnitude of this effect may be less than the extra exports arising from new firms entering exporting as a result of the cost reduction (the extensive margin). See Hummels and Klenow (2005) and Chaney (2008) for additional details.

Now consider a further type of uncertainty that interacts with the network effects discussed in the prior section. Take a project A, that is identical to our baseline case; from analysis of that case we are essentially indifferent as to whether this project proceeds or not (BCR=1.0008). Now introduce a project B that like our first variation considered in this section has a certain stream of benefits of 30 p.a. plus an uncertain stream of benefits of 34 p.a. The probability of the uncertain stream of benefits being realised is $p>0.5$, and uncertainty for this stream cannot be resolved until after construction is completed. From the previous analysis, this project should proceed.

However, the uncertain benefit stream can only be realised if a complementary project (project A that has NPV=0) is also undertaken. In this case, while we would be indifferent to undertaking project A by itself, proceeding with that project is now the equivalent of purchasing an option that has value to capture the expected value of the uncertain benefit stream from project B. Project A should therefore also be undertaken since its value needs to reflect the positive value of the option that relates to Project B. This conclusion would remain even if the conventionally-calculated NPV of Project A were negative but where the option value relating to Project B outweighs the negative NPV associated with Project A alone.

How might such a situation arise in practice? Consider a fibre investment (in this case Project A) plus an investment in a technology park attached to a university or research institute (Project B). Without the fibre investment, Project B cannot recoup its costs, but with that investment it has the potential (with probability p) to capture an uncertain stream of benefits from new technology start-up firms. In this case, the investment in Project A is crucial to creating the option value relating to project B.

4.5. Options Insights

The analysis in this section demonstrates that uncertainty about future benefit (and cost) flows raises major complexities that are not dealt with appropriately by standard CBA approaches. In some circumstances, uncertainty leads to a more conservative investment stance that results in an optimal decision to delay an investment (relative to the standard CBA methodology).

In other cases, especially where learning may occur within a sequential investment process or where there may be international competition for firms to locate around new technologies, uncertainty can lead to investments optimally being fast-tracked. In addition, complementarities across projects may lead to investment in a project with zero or even negative

NPV where investment in that project is essential in order to realise option value associated with benefits attached to a separate project.

5. Production and Consumption Benefits

Conventional CBA treats all types of benefits symmetrically. For instance, the benefits of a new road that reduces congestion for business traffic, so raising value added, is conceptually treated the same as a new road that reduces congestion for holiday traffic, so raising the quantity or quality of leisure time.[13] As another example, conceptually the benefits that people may derive from consumption-related uses of a new fibre roll-out (e.g. access to free websites) are treated equally to the additions to firms' value added that may occur as a result of a similar roll-out.

The issue addressed in this section is whether equal treatment is appropriate. To focus the analysis, we concentrate on cases where the consumption benefit is intangible and non-storable, but nonetheless demonstrably positive (e.g. hip replacements for the elderly). Productive benefits are assumed to be tangible, leading to extra income (for firms or employees) that can in turn be reinvested.

In order to analyse these issues, we return to our baseline example. The costs of that project are $100 million p.a. for 5 years. The assumption lying behind the conventional CBA approach is that, instead of investing in that project, the government or other investor could alternatively have invested the funds in another investment with the same risk profile and earn 8%. If it did so, at the start of year 101, the $500 million investment (spread over years 0 to 4) would be worth $1,024,450 million; when this sum is discounted back to the start of year 0 (at 8%) the value is $431 million, identical to the discounted sum of costs shown in Table 1.

If all benefits (of $47 million p.a.) from years 5 to 100 were reinvested into a fund earning an 8% return, the resulting fund would be worth $1,025,282 million; when this sum is discounted back to the start of year 0 the value is $432 million, identical to the discounted sum of benefits in Table 1. Thus government is essentially indifferent between investing in the specific infrastructure project or in another investment opportunity with the same risk profile that is expected to earn 8%. In other words, government could invest $431 million now in the chosen project and reproduce the same sum accruing to the populace in 101 years' time that

[13] We frame this discussion in terms of conventional CBA approaches rather than the more nuanced specifics adopted by NZTA in New Zealand. In practice, NZTA (2010) judges that rural travel time cost savings are worth approximately 40% more per hour than urban travel time cost savings (NZTA, 2010, Table 1 of page SP3-8). This estimate in turn is based on three types of use: (i) work travel purpose; (ii) commuting to/from work; (iii) other non-work travel purposes. For a car driver, categories (ii) and (iii) are valued at 33% and 29% respectively of work travel time savings. For a cyclist or pedestrian, the equivalent ratios are 30% and 20% respectively (NZTA, 2010, Table A4.1).

could be achieved by instead investing in the alternative project. Correspondingly, the population in 101 years' time will be indifferent to the choice by government between the two projects.[14]

The rationale underlying this application of CBA methodology is therefore based on the rate of return of a similar project (opportunity cost). It has nothing to do with any individual's (or society's) rate of time preference. Appendix 1 discusses the conceptual difference between the rate of return and the rate of time preference in more detail within the context of an individual's inter-temporal consumption choice.[15]

Now divide the benefits in the baseline case into two different groups: tangible benefits resulting in higher incomes for firms and/or workers (e.g. hip replacements for manual workers) that can be reinvested, and intangible consumption benefits (e.g. hip replacements for the elderly who otherwise could not afford surgery), the benefits of which cannot be reinvested. We assume that the $47 million in benefit each year is split into $30 million of tangible benefits and $17 million of intangible benefits. The discounted value of the costs remains $431 million; the discounted values of tangible and intangible benefits are $275 million and $156 million respectively.[16]

With the split of benefits into tangibles and intangibles, we find that an investment of $431 million now produces a sum for the population 101 years hence that is only 64% of the sum that could have been earned by investing in the alternative project. Over the century, the population has enjoyed intangible benefits (that comprise the other 36% of total benefit) but none of these intangible benefits is available through reinvestment to the population in 101 years time. They are left 36% poorer as a result of the choice to invest in the chosen project as opposed to the alternative investment.

Justification for treating intangible benefits as equivalent to tangible benefits in the CBA therefore cannot rest on an opportunity cost (rate of return) argument. Instead, a value judgement must be imposed that treats benefits to proximate generations more highly than those to future generations; moreover, the trade-off rate used to compare future relative to current generations must be identical to the rate of return earned from the particular risky investment that is being evaluated.

This result has the corollary that if a different rate of return is applicable across projects, reflecting differing project risks ('betas'), then the weight given to future relative to current

[14] In this example we assume that each alternative produces the same set of opportunities, so there are no extra embedded options in one alternative relative to the other.
[15] We do so since many discussions on the use of discount rates in CBA appear to confuse the two concepts.
[16] Prior to rounding, the sum of these two figures is $432 million to the nearest million, as in the baseline case.

generations differs from project to project. This corollary, however, has no logical justification: there is no reason that can be used to justify discounting the utility of a future generation differently when considering a range of projects with different risk.

The conclusion that follows from this analysis is that conventional CBA analysis is not a sufficient tool for evaluating a project that has intangible benefits and where inter-generational comparisons are involved. However, in practice, CBA analysis is frequently applied in these situations. For instance, road investments are typically long-lived (so requiring a consideration of benefits for future generations) and typically have major benefits that cannot be reinvested (e.g. reduced congestion costs for leisure users). This demonstration of the inadequacy of CBA in such circumstances leads us into a deeper discussion of inter-generational (discounting) issues in the next section.

6. Discount Rates

The discussion in section 5 demonstrated that considerable care must be taken in interpreting and using discount rates. In particular, the reasoning behind the use of a chosen rate (e.g. a real rate of return - potentially with different risk premia, versus a rate of time preference) needs to be consistent with the assumptions built into the analysis. The choice of discount rate involves both (i) a conceptual decision as to which discounting concept to apply, and (ii) a numerical decision as to the appropriate rate given the chosen concept.

In order to illustrate the importance of these issues, we examine an example that demonstrates the sensitivity of decisions based on standard CBA criteria to the choice of discount rate. We follow this discussion with a more in-depth discussion of appropriate concepts and rates. There has been much discussion of related topics in treatments elsewhere[17] but many of the issues surrounding correct choice of discount rates are, at best, still unresolved.

Table 5 summarises the NPV and BCR of our baseline project for differing real discount rates varying from 1% to 10% p.a. The choice of discount rate for a long-lived project makes an enormous difference to the estimated viability of the project. For instance, if funding constraints mean that only projects with a BCR > 2 are undertaken, the baseline project would be undertaken if a discount rate of 4% were used, but it would not be undertaken with a higher discount rate. Furthermore, if the New Zealand government's former standard discount rate of 10% were adopted, the baseline project would drop from being a marginally acceptable

[17] See, for example, the extensive literature surveyed by Young (2002), Cowen (2007), Parker (2009) and Harrison (2010).

development to one in which benefits are calculated at only three-quarters of the costs of the project.

Table 5: Baseline & Alternate Projects with a Range of Discount Rates

	Baseline*		Alternate**	
Discount Rate (Real)	**NPV ($ million)**	**B:C Ratio**	**NPV ($ million)**	**B:C Ratio**
1%	2,289	5.6691	724	2.4768
2%	1,366	3.8410	572	2.1901
3%	839	2.7781	446	1.9453
4%	518	2.1191	340	1.7354
5%	312	1.6854	252	1.5546
6%	172	1.3844	178	1.3982
7%	73	1.1658	115	1.2624
8%	0	1.0008	62	1.1440
9%	-54	0.8724	17	1.0403
10%	-96	0.7698	-21	0.9491

* Baseline parameters are as per Table 1.
** Alternate costs are as per baseline; benefits are $67 million p.a. (undiscounted) for years 5-25 inclusive, and 0 in all other years.

The discount rate is important not only for determining whether a particular project should proceed but also for prioritising project options. Suppose two projects have the same cost structure but the benefits follow different time-paths. As an illustration, compare the baseline project with an alternate project that has (undiscounted) benefits of $67 million p.a. in years 5 to 25 inclusive, and no benefits thereafter. The second project is an alternative way of constructing the same project as the baseline, with identical cost structures; it has larger up-front benefits but those benefits last for only a comparatively short time.

The alternate (shorter-term) project is preferred to baseline for any discount rate of 6% or above; at lower discount rates, the baseline project is preferred. The arithmetic reason for the switch in preference is that the longer term benefits (e.g. benefits over 25 years) of the baseline project are discounted heavily using higher discount rates whereas the alternate project has no benefits accruing beyond 25 years, so the higher discount rate does not reduce the value of longer term benefits in the alternate case.

The conceptual reasoning behind choice of appropriate discount rate, and hence between choice of project, in part relates to the issues raised in the previous section about the nature of benefits that are expected to accrue across the two projects. If: (i) both projects have the same risk profile, and (ii) all benefits are tangible and will be reinvested in a project with the same risk and return over the full term of evaluation (i.e. through to year 100) then the analysis of the last section indicates that the cost of capital represents the appropriate discount rate. If either of these two assumptions does not hold perfectly, there is no conceptual reason to consider that the cost of capital is the appropriate rate to use to discount benefits.

The previous section indicated one situation in which a discount rate that differs from the cost of capital is appropriate. That situation is where some of the benefits are not capable of being reinvested in a project with the same risk and return over the full term of evaluation. Intangible benefits fall into this category.

There are numerous other cases in which the cost of capital is unlikely to represent the appropriate discount rate for an infrastructure investment. Parker (2009) provides an excellent survey of the issues surrounding choice of discount rate in various circumstances; a comprehensive summary will not be repeated here. He contrasts two principal approaches: setting the discount rate at the social opportunity cost (SOC) rate – which equates to the cost of capital concept discussed above – versus setting the discount rate using the social rate of time preference (SRTP). As discussed in Appendix 1, these are entirely different concepts and there is no reason that they should be equal.

The SOC approach has been described in section 5. Conceptually, it is the more straight-forward of the various approaches. Even so, Parker notes that the concept of risk (which is central to the choice of risk premium within the SOC-based discount rate) is tricky to define. For instance, what is the appropriate discount rate to use if the up-front costs are risky but the longer term benefits are certain (or, more generally, follow a different risk profile)? In that case, should the costs be discounted using a standard SOC-based discount rate while the benefits are discounted at a risk-free rate?

More generally, how should the risk premium be calculated for projects that have national implications. The workhorse model to determine the cost of capital for individual projects is the capital asset pricing model (CAPM; Sharpe, 1964 and Lintner, 1965). The CAPM determines a project's risk premium (relative to the risk-free rate) by virtue of its 'beta' which in turn reflects the sensitivity of the project's returns to those of the overall market (the market portfolio). A project that is expected to record high returns at the same time as the market is doing poorly (and vice versa) will have a low risk premium, since that project provides useful diversification properties within an investment portfolio. Likewise, a project with strongly pro-cyclical returns will have a high risk premium (no matter what its individual variance of returns).

At a broader economic level, the workhorse model to determine risk premia is the consumption capital asset pricing model (CCAPM; Breeden 1979). At this level, a project that is expected to record high returns at the same time as the broader economy (and consumption) is doing poorly will be accorded a low risk premium, since that project provides useful diversification properties for the wider economy. A project with strongly pro-cyclical returns relative to the broader economy will be accorded a high risk premium.

A major irrigation scheme is an example where the CCAPM may imply a low risk premium. Treasury research (Buckle et al, 2007) indicates that rainfall is a material determinant of New Zealand's cyclical economic outcomes, with drought negatively affecting each of national production (GDP), domestic demand (GNE) and exports. An irrigation scheme has its highest payoffs precisely when the economy is at a low ebb due to drought; thus the CCAPM determines that irrigation schemes should be accorded a low risk premium. Indeed, if the returns to an irrigation scheme are counter-cyclical (i.e. a negative consumption beta) the appropriate discount rate would be below the risk free (government borrowing) rate.

From a government's perspective, why might this make sense? If a government is concerned with having a moderately stable revenue stream, it will value highly a scheme that produces tax revenues at times when other tax revenues are declining. An irrigation scheme that meets this requirement acts to offset other risks to the government's revenue stream, thus having a risk-reducing role for government's overall revenues. This risk-reducing role implies that the risk premium is negative for the scheme; thus the appropriate SOC-based rate is below government's risk-free borrowing rate.

Choosing an appropriate discount rate under the SOC-based approach is essentially a technical decision relating to risk. More difficult issues arise when the assumptions justifying this approach are not fully met. In situations where some benefits are intangible and/or we cannot be certain that the tangible returns will be reinvested in a project with the same risk and return over the full term of evaluation, the SOC-based approach is incomplete as a descriptor of the appropriate discount rate.

Consider a situation in which the current generation cares about the welfare (consumption) of both the next generation (children) and the one after that (grand-children) but there is a risk that the children may be profligate and may not act to protect the living standards of the grand-children.[18] The current generation could save now (at a market rate of return) to provide resources for both future generations. The amount saved for future generations will be determined by the market rate of return relative to the current generation's inter-generational rate of time preference (i.e. the rate at which it values the welfare of future generations relative to its own).

[18] This is the simplest case; the argument follows if the current generation cares about great-grandchildren, but the children may not care about their grandchildren, etc.

Once the amount set aside for future generations is determined, the SOC-based approach would allocate the investments according to market rates of return, since once the quantum of savings is determined, the task becomes a technical one to invest in projects that produce the best risk-adjusted return for each of the next two generations. However, the grand-children have no control over the decisions of the children. If government (or individuals) allocate all savings into a financial vehicle (e.g. a government investment fund) there is nothing to prevent the children's generation from expropriating some or all of the investments intended for the grand-children's benefit and leaving the grand-children with fewer resources than intended by the current generation.

This is a classic time consistency problem. One way around this time consistency problem is for the current generation to invest in assets that provide a return to the grandchildren and which cannot be expropriated by the children. Long-lived infrastructure investments may be of this type. For instance, a concrete based road may last with little maintenance for 50 years, whereas a bitumen road may require substantial maintenance to still be operating in peak condition in 30 years time. If there is concern that a future generation may not allocate resources to maintain infrastructure for a future generation (noting that for a generation after 1984 there was significant deferred maintenance in relation to many infrastructure assets), then the current generation may choose to invest in "future-proofed" infrastructure that mitigates the potential for infrastructure decline through the next generation. In this situation, a concrete-based road may be preferred to a bitumen-based road even though the conventional BCR for the latter is higher than for the concrete road.[19]

The key element of this example is that the discount rate applied to long-lived projects must take account not only of what projects could *theoretically* be invested in over time, but what projects will *actually* be invested in over time. If actual returns to public investments in future are expected to fall below the theoretical optimum, then current investments should build in the expected future return to alternative investments, which is lower than the optimum return.

A counter-argument to this latter point is that if the private sector could achieve the optimum return on its investments then this is the appropriate required rate of return since an alternative for the current generation is simply not to proceed with a certain infrastructure investment (that may yield only 7% return) when leaving the funds with the private sector instead returns 8%. Nevertheless, in this situation there is still no guarantee that the

---

[19] Another argument favouring a concrete-based road relates to the issue of intangibles. Future maintenance of a bitumen-based road will cause extra congestion during long periods of road works; the saving of this extra congestion is a benefit of a concrete road but conventional BCR discounts this intangible saving at the cost of capital rather than the rate of time preference, whereas it is the latter that is theoretically appropriate.

grandchildren's generation will benefit from the private sector's expenditure choices. Its investments may provide a larger return for the children but that may not be available for subsequent generations. For instance, a future government may tax the children's returns to provide short-term election-driven consumption benefits. If the current generation cares about future generations and has concerns that the private or public sectors over coming decades may be profligate (relative to the current generation's concerns for the future) then locking in long-lived infrastructure investments is one method it can use to protect the welfare of future generations.

Caplin and Leahy (2004), Cowen (2007) and Creedy (2007) formalise some of these issues. In each case, the point is made that applying an inter-generational discount rate (i.e. valuing a future generation's welfare relative to our own) involves an inter-personal welfare comparison that is of the same type as trading off the welfare of one member of the current generation with that of another. Economists are typically reluctant to make inter-personal welfare comparisons within a generation, leaving these decisions to political decision-makers.[20] In turn, this implies that it is futile to search for a single "correct" estimate of the social rate of time preference. Nevertheless, application of an inter-temporal discount rate to the welfare (consumption) of individuals across generations is routinely practiced, inevitably valuing the trade-off between the welfare of future generations and that of the current generation. The question is whether the rate that is used (whether it be the cost of capital or some other rate) accords with decision-makers' rate of time preference.

Creedy discusses such issues in detail, noting that inter-personal value judgements are being made whether one advocates use of a discount rate based on a market interest rate or one advocates a (near) zero rate of time preference. The latter rate is argued for in relation to climate change effects within the Stern Review (2007).[21] Creedy argues from first principles that these value judgements should be made explicitly and debated rather than being hidden behind technical complexities.[22]

Caplin and Leahy run the thought experiment of testing whether inter-generational trade-offs are time consistent in the sense that the next generation will agree with the decisions made

[20] Curiously, however, typical CBA treats the marginal dollar received by each individual as having equal impact on overall welfare whether it accrues to a starving individual or to a multi-millionaire. In the absence of lump-sum taxes, this approach accords with no known philosophical school of thought (see: Blackorby and Donaldson, 1990; Sen, 2009).

[21] The Stern Review deals with catastrophic risk; i.e. where, because of climate change, there is a chance of mass deaths or even (near-) extinction of the human race and/or many other biological organisms. In this case, as stressed also by Cowen, the economist's typical marginal analysis is not an appropriate tool. These issues are dealt with in more detail in Appendix 1.3.

[22] Technical arguments include approaches by Weitzman (1998 and 2001) and Lowe (2008).

by the current generation. For instance, from today's viewpoint are we happy that the infrastructure deficit built up since the early 1980s was optimal, or do we instead consider it would have been preferable for the last generation to provide more infrastructure investment than actually occurred? If, *ex ante*, the deferred investment (coupled with high social expenditures) was an optimal strategy but, *ex post*, that strategy is viewed as sub-optimal, then there is a disagreement between the two generations about the rate of time discount. When this situation occurs, there is no single objective rate of time discount; we wish that the last generation had paid more heed to our generation when it was taking its expenditure decisions than it chose to.

Cowen elaborates on this point. He notes that processes of substantial economic reform often involve a significant loss of production while the reform process is undertaken. The loss is accepted given an expectation of higher subsequent growth rates once dislocation and reorganisation of the economy has run its course. This was the experience of New Zealand after 1984, and was also the experience of many transition countries in Eastern Europe. Significant economic reform is generally only undertaken if the longer term growth benefits of reform are considered to outweigh the transitional costs. The inter-temporal discount rate materially affects this calculus.

For instance, consider the New Zealand reforms. Grimes (1996) shows that over the seven years prior to the 1984 reforms (i.e. 1978-1984), New Zealand's GDP growth rate was 0.9% p.a. below that of the OECD average for the same period. For the following seven years (i.e. 1985-1991) during the transition period, New Zealand's GDP growth rate was 2.4% p.a. below that of the OECD. After 1991, the New Zealand growth rate was expected to increase. If it was known at the outset of the reforms that this transition would occur but that the New Zealand economy would henceforth grow at the OECD average rate from 1992 onwards (i.e. at a rate 0.9% p.a. above New Zealand's pre-reform growth rate), would the reforms have been considered worthwhile *ex ante*?

Imagine that the policy-makers had a fifty year time horizon at the start of the reforms, and that they discounted future incomes back to 1984 dollars using an 8% real discount rate. By 2034, fifty years after the start of the reforms, the New Zealand economy would be producing 32% more *per annum* than in the baseline (no reform) case. However, once future production is discounted back to 1984 with an 8% discount rate, discounted total production over the first fifty years with the reforms would be less than if the reforms had never occurred. This result is despite the New Zealand GDP growth rate being 0.9% p.a. higher with the reforms for the final 43 years of the evaluation period.

Cowen makes the point that use of a high intertemporal discount rate rarely makes economic reform worthwhile. In other words, with a high discount rate, low growth policies that are already in place are preferred to an economic policy that favours greater future economic growth. The reason for this result is that near-term transitional costs (accruing to the current generation) are discounted very lightly while benefits for future generations are discounted heavily. Cowen's insight with regard to economic reform programmes applies more specifically to long-lived infrastructure investments: applying a high discount rate to infrastructure investments that are designed to increase the productive potential of the economy results instead in a policy that locks in a consumption-oriented low-growth economy rather than one with a higher GDP growth rate and higher future living standards.

On the other hand, if all government investment projects used a low discount rate, the result would be a severe crowding out of private sector investment. Cowen's analysis therefore applies to projects that have clear long-lived benefits that will accrue to a future generation and that would not otherwise be pursued by the private sector.[23]

Use of a high discount rate for productive projects becomes of greater concern if: (a) citizen's welfare ("utility") at any point in time is shaped at least in part with reference to living standards in other countries,[24] (b) comparator countries use a lower discount rate for their productive long-lived infrastructure projects, and (c) the current generation cares about the relative living standards of future generations in New Zealand.

Consider, for instance, if New Zealanders compare their living standards with Australia; they are happy if they can keep pace with their neighbour but feel increasingly unhappy the further they fall behind. Furthermore, imagine the case where – taken in isolation – the optimal discount rate to apply to like infrastructure projects in each country is 8%, but that Australia chooses instead to adopt a 6% discount rate. It increases taxes in the near-term to fund the increased number of projects that are thereby commissioned. The result will be that Australia will have reduced short-term consumption and will invest more in long-lived infrastructure projects than New Zealand. The returns to that investment will induce a higher standard of living across the Tasman in future years relative to New Zealand.

In this case – even if New Zealand were to adopt the "optimal" discount rate policy viewed from an isolationist perspective – New Zealanders would in future feel worse-off because

[23] This is a similar set of projects to those referred to by Henry (2010) as falling within scope for government decisions within Australia.
[24] The empirical evidence (i.e. the "Easterlin Paradox") is that national measures of absolute wellbeing in developed countries tend not to increase over time; instead, *relative* living standards are more prominent determinants of individuals' (and countries') happiness (Easterlin, 1974).

their living standards had dropped below those of Australia. With free labour mobility, the result will be migration of New Zealanders to Australia to take advantage of its higher relative infrastructure stock, higher productivity and higher living standards (an example of resource mobility as considered in section 3).

Parker (2009) summarises the observed choices of discount rates for major long-lived infrastructure projects across OECD countries. Within Europe (including the United Kingdom) most countries use rates within the 3-5% range; the United States appears to use a rate at the bottom end of this range for long-lived projects. Rates across Australia vary by State, but appear to be centred on the 6-7% range; however Henry (2010) notes that in certain circumstances, government in Australia may nevertheless approve projects that fail a CBA using a conventional discount rate. Henry states (p.13): "There remains an important role for public investment in infrastructure. There may be infrastructure projects that are of strategic importance and that may not pass a private cost-benefit analysis; perhaps because the costs and benefits need to be amortised over too many decades or for other reasons."

In New Zealand, the Treasury[25] recommends a default rate of 8% for infrastructure except for "telecommunications, media and technology IT and equipment" for which it recommends a 9.5% rate; general purpose office buildings have a recommended discount rate of 6%. Treasury states that it anticipates these rates "will be appropriate for most public sector expenditure proposals that involve an expectation of benefits in a later time period". However they are careful to note: "Different rates may be adopted in cases where it can be justified on objective opportunity-cost grounds."

The use of discount rates for differing types of investment indicate that the recommended rates are not based on a (single) rate of time preference; rather they are explicitly related to a market cost of capital across sectors (based on the CAPM). These market costs are used to discount "benefits in a later time period" across all classes of benefit. This formulation therefore adopts an opportunity cost approach. As discussed above, this approach is only valid in very specific circumstances that do not generally hold for long-lived infrastructure projects.

By comparison, many of the European countries cited by Parker adopt an explicit (low) social rate of time preference to trade off future relative to current benefits when considering infrastructure investments. In these circumstances, New Zealand, with an 8% real discount rate, will tend to be "infrastructure-capital-shallow" relative to other developed countries. As discussed in Appendix 1.2, this result fully incorporates the funding (liability) side of the

[25] See Treasury Circular 2008/13.

investment project. At the simplest level, the irrelevance of funding choices is most obvious when investment choices are being made within a given fiscal expenditure envelope. In this case, taxes and debt liabilities are unaltered by the choice of expenditure options, but the timing of benefits does differ across generations.

By choosing the current approach, New Zealand policy-makers have signalled that they favour current consumption over future production, relative to the choices made in other countries. This choice may be optimal viewed from the perspective of an individual current consumer, but a future resident will favour the choices made by government agencies in other countries and accordingly will opt to migrate to those countries to enjoy their higher future living standards.

7. Traded versus Non-Traded Sector Issues

Traditional neoclassical analysis incorporates an equilibrium result that, at the margin, an extra dollar invested in one sector is as productive as an extra dollar invested in any other sector.[26] While this result holds for any individual firm, the analysis in Grimes (2009b) calls this result into question at the aggregate economy level. That model incorporated two sectors, a traded goods sector and a non-traded goods sector. The traded good can be conceptualised as exports (or as a consumption good that competes directly with imports) while a non-traded good cannot be traded internationally (e.g. haircuts). Production in each sector is undertaken using labour and capital, where the capital good is imported.

The original paper made the conjecture that, at the margin, an infrastructure investment that boosted productivity in the traded goods sector would have greater economy-wide payoffs than an identical infrastructure investment that boosted productivity in the non-traded sector. In Appendix 2, we develop the model further to examine conditions under which this conjecture is borne out. The only changes made to the original model of Grimes (2009b) are that productivity in each of the traded goods and non-traded goods sectors is related positively to the quantity of government infrastructure investment servicing that sector (denoted G_N and G_T respectively).[27] A lump sum tax is levied on individuals sufficient to meet the capital costs and depreciation relating to the two sets of infrastructure.

---

[26] Optimally, this should hold for both private and public sector investments.

[27] While the model can make a conceptual distinction between infrastructure that services the traded and non-traded sectors respectively, in practice much infrastructure will support both sectors. Nevertheless, some infrastructure favours one sector more than the other; for instance fibre to the home may favour the non-traded sector more than a road to an export port. Note that the infrastructure itself is not being conceptualised as being in one or other sector; it is a capital good that services either/both sector(s).

As outlined in Appendix 2, we analyse the impacts of increasing G_N and G_T individually by 1% on the following variables: non-traded sector production (Y_N), traded sector production (Y_T), total production ($Y=Y_N+Y_T$), total consumption ($C=C_N+C_T$, where non-traded goods consumption, $C_N=Y_N$), and utility of the representative agent (U). The last of these variables is the appropriate measure of 'welfare' in this model; as we will see, welfare and production (i.e. GDP) may move quite distinctly in our simulations.

The model is run with two separate economic structures. The first, which mirrors that in the original paper, has symmetric consumption; i.e. in the baseline (prior to increasing either G_N or G_T) consumption of non-traded goods equals consumption of traded goods. In this configuration, production of traded goods exceeds production of non-traded goods with the extra traded goods production used to finance the required imports of capital goods (to meet the depreciation of the private and public capital stock). The second configuration sets production of traded goods equal to the production of non-traded goods; in this case, consumption of non-traded goods exceeds consumption of traded goods (again so that exports can finance the importation of capital goods).

Table 6 summarises the results of the four simulations (i.e. increases to each of G_N and G_T with each of the two model configurations). With equal consumption shares (in which traded goods production exceeds non-traded goods production), an increase in infrastructure for the traded goods sector (G_T) has a greater impact on overall production (Y) than does an increase in infrastructure for the non-traded sector (G_N). An arithmetic reason for this is that the traded sector is initially larger than the non-traded sector, but this is not the full story. The key difference is that the greater traded sector productivity engendered by the increase in G_T enables purchase of extra capital equipment funded by the extra traded sector exports. This capital effect can be seen through the much greater increase in Y (0.23%) than C (0.07%) in column 2.

Table 6: General Equilibrium Effects of Government Infrastructure Investments*

	Equal consumption shares		**Equal production shares**	
	G_N ↑ 1%	**G_T ↑ 1%**	**G_N ↑ 1%**	**G_T ↑ 1%**
Y_N	0.08	-0.03	0.08	-0.03
Y_T	0.06	0.36	0.12	0.42
Y	0.07	0.23	0.10	0.19
C	-0.02	0.07	0.02	0.02
U	-0.02	0.07	0.02	0.02

* The figure in each cell is the % change in the variable listed in the first column caused by a 1% increase in the type of infrastructure listed across the top. "Equal consumption shares" and "Equal production shares" correspond to the two model configurations; see Appendix 2. G_N is infrastructure servicing the non-traded goods sector; G_T is infrastructure servicing the traded goods sector; Y_N is non-traded sector production; Y_T is traded sector production; Y is total production, C is total consumption; U is utility (welfare) of the representative agent.

Utility increases with the increase in G_T as the benefits of the extra production outweigh the loss in income via extra taxation to pay for the infrastructure. By contrast, the increase in non-traded sector infrastructure, G_N, leads to a reduction in overall welfare since the cost to the agents through taxes to fund the extra infrastructure capital is not recouped by a sufficient increase in production. In this situation, residents are made worse off by government increasing its (non-traded sector) infrastructure investment.

With the second model configuration (equal production shares, in which non-traded consumption considerably exceeds traded consumption) the effects are more finely balanced. An increase in G_T again increases output by more than would a commensurate increase in G_N, for the same reason as before – that the greater traded goods productivity enables greater imports of private sector capital. Now, however, the welfare effects of the two policies are identical, reflecting the assumed much greater consumption of non-traded goods in the baseline case.

The parameter assumptions in this latter case imply that consumption of traded goods (imported goods and goods capable of being exported) represents only 27% of total consumption, which is an under-estimate of the actual traded goods share of consumption in the economy. This case therefore appears to be a limiting one that is unlikely to arise. In practice, one may conclude that utility is likely to increase more with an investment in infrastructure that raises traded sector productivity relative to a same-sized investment that raises non-traded sector productivity.

The results from this general equilibrium model imply two key conclusions with respect to the targeting of infrastructure investment. First, an infrastructure investment in the traded sector has a greater impact on aggregate production than does an *ex ante* identical infrastructure investment for the non-traded sector. This effect arises, in part, because of the greater scope for importing capital goods that arises when traded sector expands, an effect that does not occur with an increase in non-traded sector production.

Second, aggregate production effects differ from overall welfare effects. Measuring benefits solely by increases in production may lead to a miscalculation of the overall net benefits of a project. One factor that affects the relationship between production and welfare outcomes is changes in relative prices between traded and non-traded goods that arise as productivity of one sector increases relative to another. As explained in Grimes (2009), an increase in non-traded sector production causes a decrease in the relative price of non-traded goods since domestic consumers are the only source of demand for those goods; by contrast, the price of traded goods is determined by world demand. An increase in infrastructure for the traded sector has no adverse price effect on New Zealand producers whereas an infrastructure investment that boosts productivity of non-traded producers leads to a partially offsetting income drop through falling prices. In this case, domestic producers benefit more from a boost to infrastructure investment that supports the traded sector than a commensurate infrastructure investment supporting the non-traded sector.

8. Conclusions

Cost benefit analysis (CBA) is a useful tool for many project investment applications. It is especially useful for making comparisons between alternative specifications that are designed to produce similar benefits. It makes explicit the nature and size of projected costs and benefits of a project, as well as the timing of those costs and benefits. Ideally, both tangible and intangible benefits and costs are included in the calculations. Wider economic benefits that may arise, for instance, from agglomeration externalities within cities, are also included. Furthermore, a CBA makes explicit how future values for costs and benefits are traded off against current values. The discipline involved in making these comparisons results in far better project evaluation than would occur if there were no formal model for comparing the worth of alternative investments.

Within any CBA, there are some crucial judgements that must be made. These judgements can materially alter the perceived worth of an individual project and can alter the ranking of alternative projects. Estimation of the scope and scale of wider economic benefits is an example of one such judgement that is required. Another important judgement that affects the worth of long-lived projects is the choice of discount rate. The analysis in this paper, and elsewhere, shows that considerable thought needs to be applied to the discount rate choice. There is no single "correct" discount rate choice that covers all project types.

In certain circumstances, a cost of capital (incorporating an appropriate risk premium derived from market prices for commensurate risks) constitutes an appropriate discount rate for a project. Circumstances where this choice is most appropriate include where returns from the proposed project can all be reinvested at the same rate (and with the same risk profile) as the project under consideration, and where the project could be undertaken equally by another agent (e.g. by both the private and public sectors).

Even within this approach, the choice of risk premium within the cost of capital is not trivial. A standard capital asset pricing model (CAPM) approach would measure the project's "beta" which places priority on the project's *covariance* of returns with the aggregate market return. Under this (standard) approach, riskiness is *not* measured by the *volatility* (e.g. standard deviation) of project returns or by measures of return uncertainty. Individual infrastructure projects could therefore have quite different costs of capital (and hence discount rates) from one another. For instance, a project with returns that had zero covariance with the market return would have a cost of capital set at the risk-free (government borrowing) rate.

If government is concerned about stability of aggregate GDP or aggregate tax flows, the measure of the appropriate risk premium changes. A project that yields high returns at a time when aggregate GDP and/or tax-flows are falling would have a negative risk premium according to the Consumption CAPM, which is the appropriate model in these circumstances. For instance, an irrigation project that delivers its highest returns in times of drought (and associated cyclical economic decline) should have a cost of capital that is below the risk-free rate. This variation in discount rates, even where a cost of capital approach is used, demonstrates the care that must be adopted when choosing a particular discount rate for an infrastructure investment.

Where the benefit stream in part comprises intangible consumption benefits (that are not fully substitutable for other privately financed consumption benefits) the cost of capital no longer necessarily constitutes the appropriate discount rate for an infrastructure project. The reason is that intangible consumption benefits cannot be reinvested at the chosen cost of capital. In these circumstances, investment versus consumption choices inevitably arise, and involve an inter-personal value judgement between benefits for current agents versus those in the future. The analysis in this paper demonstrates that adoption of an 8% p.a. real discount rate (the New Zealand Treasury's current standard rate) means that - for the same tax flows and liability structure - policy-makers prefer to have one unit of benefit now in place of six units of benefit in one generation's (25 years) time.

For instance, one hip operation today is preferred to having the wealth in 25 years to deliver six hip operations at that time. At the Treasury's former preferred 10% p.a. real discount rate, one hip operation today would have been preferred to having the wealth to deliver nine hip operations in 25 years time. Because we are dealing with inter-personal comparisons of benefit, we cannot say that these value judgements are necessarily "wrong". They reflect a policy choice that current consumption is strongly preferred to investment and hence to future consumption. Citizens of countries that make such a choice can have a higher level of current benefit than citizens of countries in which policy-makers choose to invest for a future generation. Conversely, future citizens in the initial high consumption country will be worse off than future citizens in a country that consumes less initially and invests more in long-lived projects.

Where citizens have an option to migrate from the "consumer country" to the "investment country" it could be argued that an optimal policy is for the current generation to consume today in the former country and for the next generation to migrate to the latter country, taking advantage of that country's infrastructure capital that its previous generation built up. However, if current citizens care about the welfare of future citizens domiciled in their own country, and have a wish to see future generations largely remain in the home country, this strategy can no longer be considered optimal. In those circumstances, current citizens need to give greater priority to investments in projects that yield long-term returns and spend less on policies that deliver near-term consumption benefits.

While complicated, the choice of discount rate is essentially a technical choice within a standard CBA. There are more complex circumstances in which a standard CBA approach may be inadequate, or even inappropriate. Potentially the most important characteristic that may render a conventional CBA inappropriate is where a potential project opens up options for investment in future projects with uncertain returns and where: (a) information about those returns is forthcoming only after the initial project is completed, or (b) potential positive returns from the future projects diminish over time.

In case (a), the initial project must be undertaken in order to find out whether or not to proceed to the next stage within a sequence of projects. Examples may include investment in a fibre broadband network (the initial project) where the subsequent projects are in the form of potential private sector investments that utilise the greater speed and bandwidth that fibre affords. Other examples may include: investments in basic research (with potential commercialisation of research findings constituting the subsequent projects); improved (public and private) transport networks that open up new possibilities for firm and household location and trade; minerals exploration, opening up opportunities to extract any reserves that are found; and the electricity transmission grid, opening up opportunities for new generation plants and/or new major users of electricity.

In case (b), returns to investment are time dependent. A notable example may be where countries are competing for the location of major firms that, once their location is chosen, incur substantial sunk costs and so are reluctant to move again. Another example may be where agglomeration externalities combine with path dependence to establish a cluster for a new industry that may be reliant on a particular form of infrastructure and/or technology. The fibre example is again relevant here, with a cluster of high-tech firms potentially locating in countries or centres that are early adopters of large-scale fibre provision.

The potential importance of options created by particular infrastructure investments means that a standard "needs analysis" may be an insufficient basis from which to begin an ex ante evaluation of a potential investment. In the cases discussed above, an "opportunities analysis" also needs to be included prospectively. Furthermore, it is important not to restrict opportunities to those that may be exercised (or even internalised) just by the infrastructure provider or by existing agents. Future agents (e.g. new migrants, start-up firms or international firms not yet present in the country) may be the agents that take advantage of opportunities that are created. A corollary of this approach is that disinvestment decisions need to take account of future opportunities that are potentially lost through a decision to scrap existing infrastructure. The opportunity (or option) approach may be particularly important where discontinuities are possible. For instance, a decision to close (large parts of) the rail network owing to its inability to pass a conventional CBA may turn out to have a large negative outcome if fuel prices were to surge massively, in which case the option to increase rail traffic would no longer be available. Of course, this option value must be weighed against the costs of ongoing operational deficits in determining the closure decision.

Similarly, if fibre becomes a "must-have" business attribute, a decision not to invest could have discontinuous consequences on the location decisions of firms (at least in information-rich sectors). In the fibre case, this option effect must be weighed against a competing option effect: a ubiquitous fibre network represents a large sunk cost, and it may turn out that future mobile technologies offer a much cheaper, but equally effective, delivery mechanism. In this case, the standard investment under uncertainty result would favour delaying fibre investments until more is known about the benefits of the alternative technologies. A decision therefore needs to be taken about the potential for returns to be time dependent when choosing whether to delay or bring forward a major fibre investment.

Network effects are another potential source of discontinuity arising from infrastructure investments. A single investment project may produce limited returns in the absence of other complementary investments. However the experience of master-planning at the regional level demonstrates that a suite of complementary investments can produce much greater returns than the sum of the returns to each investment where each of those investments was considered by itself.

This observation, which has long established roots in the economic development literature, means that a coordinated approach to at least some infrastructure investments is required. For instance, it indicates the advisability of coordinating transport investments, land use control decisions, energy reticulation, plus schooling and other social investments at a spatial level. At a broader level, it has implications for national strategic investment choices. For instance, a decision to invest heavily in fibre may logically be coordinated with a decision to favour training in information-related skills; a decision to substantially upgrade Auckland's passenger transport network may logically be complemented by ensuring that opportunities to expand the housing and commercial building stocks are enhanced, while ensuring that each of electricity, gas and water provision is secure for a potentially much larger city.

In making these judgements, the endogenous flows of resources across regions must be considered. Capital and labour both flow across regional and national boundaries to where earnings opportunities (plus amenity values) are highest. For a small country such as New Zealand with open labour and capital markets, this means that an investment in one region should be considered within an Australasian, rather than a New Zealand-specific, context. For an instance, an investment that boosts Christchurch's productive potential will reallocate resources across Australasia (of which Australia forms the bulk) rather than primarily constituting a foregone benefit for other parts of New Zealand.

The importance of an over-arching national strategic approach to infrastructure provision is highlighted by findings that certain classes of infrastructure investments have favourable long-term economic effects relative to others. The importance of infrastructure investments which produce returns that are capable of being reinvested, rather than consumed immediately, is one such class of favoured investment. A standard CBA treats a dollar produced for intangible consumption today equally with a dollar produced through servicing an export industry, but the consumption benefit is lost immediately whereas the productive benefit can be reinvested. Using the fibre example, equivalent fibre investments to the home and to the firm respectively may produce equal initial gains to those recipients. However, returns from the latter investment (i.e. to the firm) can be reinvested for the future whereas the former return (to the consumer) may produce only a fleeting intangible benefit.

Furthermore, the analysis indicates that where a differentiation can be made, an infrastructure investment that services the export sector (or, more generally, the traded goods sector including import substitution activities) provides a greater overall benefit to the economy than one that services the non-traded productive sector (i.e. goods and services that are not traded internationally). This is the case even where the marginal returns to equivalent firms from equal sized investments are the same. The reasoning here is twofold: First, in a capital-importing country such as New Zealand, export receipts are required to purchase the capital goods that produce both traded and non-traded goods and services. Second, exports can generally be increased without causing prices to fall since New Zealand producers form only a small proportion of all suppliers of the commodity. By contrast, an increase in non-traded goods production causes the price to move against producers of those goods since domestic demand for these goods is limited.

The combined effect of these various findings is that a national infrastructure strategy may concentrate on supporting infrastructure investments that: (i) service the internationally traded productive sector; (ii) exhibit network complementarities with other infrastructure investments; and (iii) create new opportunities for further value-enhancing investments that take advantage of the initial investment project. These considerations are all largely absent from a conventional CBA evaluation of a single prospective project.

In many cases, the considerations just outlined will not be material, and a conventional CBA will form an appropriate prospective evaluation tool. However where some or all of the above considerations are germane, conventional CBA tools need to be supplemented by analysis that incorporates the larger strategic aspects of a project. Furthermore, the essence of a strategic approach is that a "bottom up" aggregation of one-off projects will not be optimal; network benefits and new opportunities will be missed under such a regime. Some over-arching investment principles and strategies, emphasising production in internationally traded sectors combined with network effects and the creation of option values, are required. If adoption of these strategies were combined with a decision to place greater weight on the value of future production relative to current consumption, an increasingly productive New Zealand economy might evolve that competes on more equal terms with its advanced neighbours.

9. References

Black, Fischer & Myron Scholes (1974) "From Theory to a New Financial Product", *Journal of Finance* 29(2), 399–412.

Blackorby, Charles & David Donaldson (1990) "A Review Article: The Case against the Use of the Sum of Compensating Variations in Cost- Benefit Analysis", *The Canadian Journal of Economics* 23(3), 471-494.

Breeden, Douglas (1979) "An Intertemporal Asset Pricing Model with Stochastic Consumption and Investment Opportunities", *Journal of Financial Economics* 7, 265-296.

Buckle, Robert, Kunhong Kim, Heather Kirkham, Nathan McLellan & Jarad Sharma (2007) "A Structural VAR Business Cycle Model for a Volatile Small Open Economy", *Economic Modelling* 24(6), 990-1017; earlier version published as Treasury Working Paper 02/26.

Caplin, Andrew and John Leahy (2004) "The Social Discount Rate", *Journal of Political Economy* 112(6), 1257-1268.

Chaney, T. (2008). Distorted gravity: The intensive and extensive margins of international trade. *American Economic Review* 98(4), 1707-1721.

Cowen, Tyler (2001) *What is the Correct Intergenerational Discount Rate?*, mimeo, George Mason University.

Cowen, Tyler (2007) "Caring about the Distant Future: Why it Matters and What it Means", *The University of Chicago Law Review* 74(1), 5-40.

Creedy, John (2007) "Policy Evaluation, Welfare Weights and Value Judgements: A Reminder", *Australian Journal of Labour Economics* 10(1), 1-15.

Dixit, Avinash & Robert Pindyck (1994) *Investment Under Uncertainty*, Princeton University Press, Princeton NJ.

Easterlin, R. (1974) "Does Economic Growth Improve the Human Lot? Some Empirical Evidence", in: P. David & M. Reder (eds.), *Nations and Households in Economic Growth: Essays in Honour of Moses Abramovitz*, Academic Press: New York.

Glaeser, Edward & Joshua Gottlieb (2009) "The Wealth of Cities: Agglomeration Economies and Spatial Equilibrium in the United States", *Journal of Economic Literature* 47(4), 983-1028.

Grimes, Arthur (1996) "Monetary Policy", in: B. Silverstone, A. Bollard & R. Lattimore (eds), *A Study of Economic Reform: The Case of New Zealand*, 247-278, Contributions to Economic Analysis No. 236, North Holland, Elsevier, Amsterdam.

Grimes, Arthur (2009a) The Role of Infrastructure in Developing New Zealand's Economy, Motu Note #1, Motu Economic and Public Policy Research, Wellington.

Grimes, Arthur (2009b) "Capital Intensity and Welfare: Traded and Non-Traded Sector Determinants", New Zealand Economic Papers 43(1), 21-39.

Grimes, Arthur & Yun Liang (2010) "Bridge to Somewhere: Valuing Auckland's Northern Motorway Extensions", Journal of Transport Economics and Policy 44(3), in press.

Harrison, Mark (2010) Valuing the Future: The Social Discount Rate in Cost-Benefit Analysis, Visiting Researcher Paper, Productivity Commission, Australian Government.

Haughwout, Andrew (2002) "Public Infrastructure Investments, Productivity and Welfare in Fixed Geographic Areas", Journal of Public Economics 83(3), 405-428.

Henry, Ken (2010) To Build, or Not to Build: Infrastructure Challenges in the Years Ahead and the Role of Governments, Address to the conference on the Economics of Infrastructure in a Globalised World: Issues, Lessons and Future Challenges

Hirschman, A. (1958) The Strategy of Economic Development, Yale University Press, New Haven.

HM Treasury (accessed 2010) The Green Book: Appraisal and Evaluation in Central Government, London: TSO; http://www.hm-treasury.gov.uk/d/green_book_complete.pdf

Hummels, D. & Klenow, P. (2005). The variety and quality of a nation's exports. American Economic Review 95(3), 704-723.

Infrastructure Australia (2009) Better Infrastructure Decision-Making, Australian Government.

Lakshmanan, T.R. (2010) "The Broader Economic Consequences of Transport Infrastructure Investments", Journal of Transport Geography, in press.

Laird, James, Karst Geurs & Chris Nash (2009) "Option and Non-Use Values and Rail Project Appraisal", Transport Policy 16(4), 173-182

Lintner, John (1965) "The Valuation of Risk Assets and the Selection of Risky Investments in Stock Portfolios and Capital Budgets", Review of Economics and Statistics 47, 13-37.

Lowe, Joseph (2008) Intergenerational Wealth Transfers and Social Discounting: Supplementary Green Book Guidance, HM Treasury, London.

Miller, Roger & Donald Lessard (2008) "Evolving Strategy: Risk Management and the Shaping of Mega-Projects", in: Priemus, H., B. Flyvbjerg & B. van Wee, Decision-Making on Mega-Projects: Cost–Benefit Analysis, Planning and Innovation, Chapter 8, 145-172, Edward Elgar, Cheltenham, UK

New Zealand Government (2010) National Infrastructure Plan, http://purl.oclc.org/nzt/i-1266, Wellington.

New Zealand Transport Agency (2010) Economic Evaluation Manual, Volume 1, Wellington.

New Zealand Treasury (2005) Cost Benefit Analysis Primer, The Treasury, Wellington, www.treasury.govt.nz/publications/guidance/costbenefitanalysis/primer (page updated 27 October 2009).

New Zealand Treasury (2008) Public Sector Discount Rate, Treasury Circular 2008/13, Wellington.

Nijkamp, Peter & Jacques Poot (2004) "Meta-Analysis of the Effect of Fiscal Policies on Long-Run Growth", European Journal of Political Economy 20, 91-124.

OECD (2006) Infrastructure to 2030: Telecom, Land Transport, Water and Electricity, Organisation for Economic Cooperation and Development, Paris.

OECD (2007), Infrastructure to 2030, Volume 2: Mapping Policy for Electricity, Water and Transport, Organisation for Economic Cooperation and Development, Paris.

OECD (2008), Infrastructure to 2030, Policy Brief (January), Organisation for Economic Cooperation and Development, Paris.

Parker, Chris (2009) The Implications of Discount Rate Reductions on Transport Investments and Sustainable Transport Futures, Research Report 392, NZ Transport Agency, Wellington.

Roback, Janet (1982): "Wages, Rents and the Quality of Life", Journal of Political Economy 90, 1257-1278.

Rosenstein-Rodan, P. (1943) "Programs of Industrialization in Eastern and Southeastern Europe", Economic Journal 53, 202-211.

Samuelson, Paul (1958) "An Exact Consumption-Loan Model of Interest with or without the Social Contrivance of Money", Journal of Political Economy 66, 467-482.

Sen, Amartya (2009) The Idea of Justice, Belknap Press of Harvard University Press, Cambridge MA.

Sharpe, William (1964) "Capital Asset Prices: A Theory of Market Equilibrium under Conditions of Risk", Journal of Finance 19, 425-442.

Stern, Nicholas (2007) The Economics of Climate Change: The Stern Review, Cambridge University Press, Cambridge.

Weitzman, Martin (1998) "Why the Far-Distant Future Should be Discounted at its Lowest Possible Rate", Journal of Environmental Economics and Management 36(3), 201-208.

Weitzman, Martin (2001) "Gamma Discounting" American Economic Review 91(1), 260-271.

Young, Louise (2002) Determining the Discount Rate for Government Projects, New Zealand Treasury Working Paper 02/21.

APPENDIX 1: Intertemporal Optimisation Issues

A1.1 Simple Two-Period Consumption Model

The term 'discount rate' has been used to refer to multiple concepts, causing confusion when undertaking intertemporal analysis. In this Appendix we outline a simple two-period model of consumption faced by an individual in order to clarify the concepts.

The individual has nominal (i.e. dollar) income, y, in period 1 which she can use either to consume in period 1 or she can save some or all of it. The number of physical units of the good that are consumed in period 1 is denoted c_1, with each unit purchased at price p_1. Her nominal consumption in period 1 is therefore p_1c_1 and consequently her savings balance at the end of period 1 is $y - p_1c_1$.

The individual positively values consumption in both periods, but earns no further income in the second period other than what she earns on her savings. The nominal interest rate between periods 1 and 2 is denoted i. In period 2, she can therefore spend her savings plus interest (leaving no bequest) and consume c_2 units of the good, each purchased at price p_2. Her budget constraint is therefore given by equation (A1):

$$p_2c_2 = (y - p_1c_1) * (1+i) \qquad \text{(A1)}$$

We assume that the consumer has the same single period utility function in each period of life, $u(c)$, but that in making her decisions at the outset, she displays some impatience, exhibited through her rate of time preference, ρ. The resulting lifetime utility function is given by (A2):

$$U = u(c_1) + (1+\rho)^{-1}u(c_2) \qquad \text{(A2)}$$

Note that ρ is a characteristic of the individual's utility function. It remains the same no matter what happens to the market rate of return (i) or any other variable.

The individual maximises U subject to the budget constraint through her choices of c_1 and c_2. This gives the standard result for the dynamics of her consumption path in (A3), where $u'(c)$ is the marginal utility of consumption, and r is the real rate of return[28]:

$$\frac{u'(c_1)}{u'(c_2)} = \frac{1+r}{1+\rho} \qquad \text{(A3)}$$

[28] Note that $(1+r) = (1+i)/(1+\pi)$ where π is the rate of inflation given by $(p_2-p_1)/p_1$.

To make (A3) easier to interpret, assume that *u(c)* takes the constant relative risk aversion (CRRA), or iso-elastic, form in (A4):

$$u(c) = \frac{c^{1-\gamma}}{1-\gamma} \tag{A4}$$

The dynamic consumption path then becomes:

$$\frac{c_2}{c_1} = \left(\frac{1+r}{1+\rho}\right)^{1/\gamma} \tag{A5}$$

From (A5), future consumption will be raised relative to current consumption: (a) the higher is the real rate of return, and (b) the lower is the rate of time preference. Importantly in terms of understanding CBA methodology, both the rate of return and the rate of time preference are important in determining whether current consumption should be high relative to the future or not. The two rates are entirely separate concepts and both are important in determining the allocation of resources across time.

We note here that there is no logical reason, at least in a small open economy, for there to be any relationship between ρ and *r*. The former is a property solely of the individual's utility function; the latter is determined by the world capital market. Even at the global level, Samuelson (1958) showed that there is no relationship between the two variables.

A1.2 Social Rate of Time Preference

The simple framework used above may also be used, with care, to analyse the case of two separate generations (*1* and *2*). The utility function is now interpreted as a social welfare function. In that case, the social planner will wish to allocate resources between current consumption and consumption for the next generation according to (A3) or, with CRRA utility, using (A5). Thus, at the inter-generational level, both ρ (now interpreted as the social rate of time preference) and *r* are again important.

Importantly, however, Cowen (2001) notes that the social rate of time preference (i.e. the trade-off across generations) cannot be interpreted as having the same value as an individual's rate of time preference (i.e. the trade-off by an individual within her own lifetime). The latter involves an individual making a sacrifice today (i.e. to save instead of consume) so as to receive a greater consumption benefit tomorrow. By contrast, the future generation makes no sacrifice today in order to consume when they are alive, for the simple reason that they are not alive today.

To give a feeling for the importance of this argument, consider the counter view that the social rate of time preference should be considered as being equal to an individual's rate of time preference, and further assume that the latter is taken to be equivalent to the real cost of capital, taken to be 8% p.a. Now imagine that in 1066, William the Conqueror had the choice of adding one extra glass of wine to his victory banquet (at a cost of a farthing)[29] or saving it for the benefit of his new realm (and its colonies). If someone[30] were now given the choice of having NZ$70,000,000,000,000,000,000,000,000,000 (if King William had foregone the extra wine) or preferring that the king had imbibed the extra glass of wine, he would logically conclude that the extra glass was optimal.

As a less extreme (non-monetary) example, consider a choice between conducting one hip operation today or six identical hip operations (at the same per unit cost) in 25 years time. Using an 8% social rate of time preference, the same decision-maker would favour the one hip operation today.[31]

This comparison fully incorporates issues surrounding the funding of the operations (i.e. by debt and/or taxes). To see this, imagine that the government could choose between: (a) investing in equipment that produces one hip operation today, and (b) investment in an infrastructure project that yields a compound 7.9% p.a. real return over 25 years (that is reinvested at the same rate over time). Both choices cost the identical amount and are funded in exactly the same manner (i.e. the identical choices for both taxes and debt). In 25 years time, the infrastructure project is worth 6.2 times the amount of the initial investment; i.e. 6.2 times the cost of the hip operation today. Given that the two choices have the identical tax flow and debt structure as each other, the choice is between one hip operation today and six operations in 25 years time; the 8% discount rate favours the former.

---

[29] I.e. formerly one quarter of a penny, or approximately one-fifth of a New Zealand cent.
[30] I.e. someone who adheres to an 8% p.a. social rate of time preference.
[31] In related vein, Ken Caldeira of the Carnegie Institute is quoted in the *Economist* Magazine (5 December 2009) in relation to climate change: "If we already had energy and transportation systems that met our needs without using the atmosphere as a waste dump for our carbon-dioxide pollution, and I told you that you could be 2% richer, but all you had to do was acidify the oceans and risk killing off coral reefs and other marine ecosystems, risk melting the ice caps with rapid sea-level rise, shifting weather patterns so that food-growing regions might not be able to produce adequate amounts of food, and so on, would you take all the environmental risk, just to be 2% richer?" He has yet to find an affirmative answer! This example raises behavioural economics issues relating to lock-in and framing effects that are also important in decision-making but are beyond the scope of this paper.

A1.3 Income Changes and Catastrophic Change

Equation (A3) can be used to consider how one should handle the potential for income change over time (both absolute and relative to another country). It can also address potential catastrophic changes. For any of these cases, consider $u'(c_2)$ as the marginal utility of consumption in the (potentially distant) future, and calibrate *r* and ρ accordingly (in terms of return period). Then we can solve (A3) for *r*, treating this variable as the required return on the marginal investment project so as to give the optimal inter-generational consumption path for a given ρ (and given other exogenous parameters determining income).

Ceteris paribus, if income and consumption are growing over time, then $c_2 > c_1$ and hence, with risk aversion, $u'(c_1) > u'(c_2)$; thus the left-hand-side of (A3) is "high" and we will require a "high" *r* (where "high" is interpreted relative to ρ). In other words, the marginal investment will need to have a "high" rate of return. The higher is the expected exogenous growth rate in the economy, the more that the optimal policy will curtail current investment relative to current consumption, by setting a high *r* for a given ρ.

Consider the implications for potential catastrophic changes associated, for instance, with long-term effects of climate change or the risk of a major pandemic. These events may cause a substantial loss in future income and hence reduce c_2 to very low levels; accordingly $u'(c_2)$ will be large and the left-hand-side of (A3) small. Recognising that there will now be a probability distribution over future outcomes, we can, to a first approximation, still solve (A3), in an expected value sense, for the optimal *r*. In addition, we would favour investment in projects that have returns which are negatively correlated with consumption outcomes as discussed in the irrigation example of section 6.

Using the same framework (but for a nearer term time horizon), consider the implications for policy if the utility function is such that New Zealanders' utility is dependent on the level of domestic consumption *relative* to the level in Australia, c^A. The comparison to determine whether *r* should be "high" or "low" now comes down to whether $c_2 / c_2^A > c_1 / c_1^A$ and hence whether $u'(c_1 / c_1^A) > u'(c_2 / c_2^A)$. If Australian income and consumption is growing fast, then the same logic as before demonstrates that the optimal *r* to adopt in New Zealand is low; i.e. the marginal investment will have a "low" rate of return. In this case, public policy will optimally set a low discount rate in order to boost the level of current investment.

APPENDIX 2: Extension of Two-Sector Model to Include Infrastructure

The long run equilibrium model in Grimes (2009b) is designed to mimic key features of a small open economy such as New Zealand that imports much of its capital stock. It has two sectors, traded (T) and non-traded (N), each with a constant returns to scale Cobb-Douglas production function using capital (K) and labour (L) as inputs, and with multi-factor productivity being determined by an exogenous constant (A). All capital in the economy is imported at world prices, while the economy's total labour supply is given. The capital stock in each sector is chosen endogenously by profit-maximising firms; the same process allocates labour across the two sectors (with wages equated across sectors). Depreciation rates on capital are determined exogenously by technical conditions, and the real return on capital is set exogenously by world capital markets. Consumer demand for the two finished goods is determined via a constant elasticity of substitution utility function defined over traded and non-traded goods. Wage rates and non-traded goods prices are both determined endogenously so that non-traded consumption equals non-traded production while labour is fully employed. Imports of capital to satisfy depreciation requirements results in domestic production exceeding domestic consumption, with the current account of the balance of payments being zero.

The baseline model had no role for government. In the current application, we introduce a government sector that invests in infrastructure (G) across each of the two sectors; the capital costs and depreciation associated with the infrastructure are financed through lump sum taxation. All government infrastructural capital is sourced from abroad. It is assumed to bear the same depreciation rate and cost of capital as private sector capital.

To keep the model as similar as possible to the baseline model, we make only three modifications to that model. First, we model the productivity parameter in each production function (A_N and A_T for non-traded and traded sectors respectively) as a function of government infrastructure servicing each sector (G_N and G_T respectively). The production functions (A6 and A7 for non-traded and traded goods respectively) are identical to those in the baseline model; (A8) and (A9) provide the specifications for A_N and A_T where, for symmetry, we choose identical parameters across the two sectors.

$$Y_N = A_N K_N^{\alpha} L_N^{1-\alpha} \quad \text{(A6)}$$

$$Y_T = A_T K_T^{\beta} L_T^{1-\beta} \quad \text{(A7)}$$

$$A_N = \exp(\upsilon + \omega G_N + \psi G_N^2) \quad \text{(A8)}$$

$$A_T = \exp(\upsilon + \omega G_T + \psi G_T^2) \quad \text{(A9)}$$

As in the original model, we assume that $\alpha=\beta=0.33$. We set $\upsilon = -0.6$, $\omega = 1$ and $\psi = -0.4$ with $G_N = G_T = 1$ initially, so that initial $A_N = A_T = 1$. With these parameters, for a given K and L, a 1% increase in G for a sector increases that sector's production by 0.2%.[32] Larger increases bring smaller relative returns owing to the negative term in the quadratic in (A8) and (A9).

All other equations are as in the original study, except that income available to consumers is reduced by $(r+d)*(G_N+G_T)$ corresponding to the lump sum tax required to service the infrastructure stock, where r is the cost of capital and d is the depreciation rate.

The original model was simulated with consumption symmetry imposed; i.e. consumption of non-traded goods equalled consumption of traded goods. This assumption required production of traded goods to exceed production of non-traded goods; the extra traded goods production was required to meet the import of capital goods used in both sectors (with the imported amount equal to the capital depreciated in each period). Thus while consumption symmetry was imposed, the model did not include production symmetry. With consumption symmetry, the asymmetry in production in the current model is magnified since extra traded goods production is required to meet the import of (depreciated) infrastructure capital.

We test the sensitivity of our results by adopting two different share parameters in the consumption function.[33] In the first set of simulations, we set the consumption shares as equal ($\gamma = 0.5$) when $G_N = G_T = 1$; in the second set we set the share parameter so that production volumes in the non-traded and traded goods sectors are identical in the baseline simulation (γ=0.7317) when $G_N = G_T = 1$.

Under each version of the model, reported in section 7, we analyse the impacts of varying G_N and G_T individually by 1% (i.e. from 1.00 to 1.01) on the following variables:

- Y_N non-traded sector production;
- Y_T traded sector production;
- Y total production ($=Y_N + Y_T$) ;
- C total consumption ($=C_N + C_T$, where $C_N = Y_N$); and
- U utility defined by the agents' Cobb-Douglas utility function.

---

[32] Note that with these parameters, the overall production function for each sector (i.e. incorporating G, K and L) has increasing returns across the three factors. The parameters in (A8) and (A9) can be varied to produce increasing, constant or decreasing returns across the three factors, but constant returns across all three factors can only be achieved where additional infrastructure, at the margin, has a negative impact on overall output.

[33] We assume that the consumption function is Cobb-Douglas; Grimes (2009b) also provides simulations with other CES specifications but finds similar results across different specifications. The CES parameter that varies across our simulations is the share parameter, γ.

Motu Working Paper Series

All papers are available online at www.motu.org.nz or by contacting Motu Economic and Public Policy Research.

10-04 van Benthem, Arthur and Kerr, Suzi. 2010. "Optimizing Voluntary Deforestation Policy in the Face of Adverse Selection and Costly Transfers".

10-03 Roskruge, Matthew; Grimes, Arthur; McCann, Philip and Poot, Jaques.. 2010. "Social Capital and Regional Social Infrastructure Investment: Evidence from New Zealand".

10-02 Coleman, Andrew. 2010. "Uncovering uncovered interest parity during the classical gold standard era, 1888-1905".

10-01 Coleman, Andrew. 2010. "Squeezed in and squeezed out: the effects of population ageing on the demand for housing".

09-17 Todd, Maribeth and Suzi Kerr. 2009. "How Does Changing Land Cover and Land Use in New Zealand relate to Land Use Capability and Slope?"

09-16 Kerr, Suzi and Wei Zhang. 2009. "Allocation of New Zealand Units within Agriculture in the New Zealand Emissions Trading System".

09-15 Grimes, Arthur; Cleo Ren and Philip Stevens. 2009. "The Need for Speed: Impacts of Internet Connectivity on Firm Productivity".

09-14 Coleman, Andrew and Arthur Grimes. 2009. "Fiscal, Distributional and Efficiency Impacts of Land and Property Taxes".

09-13 Coleman, Andrew. 2009. "The Long Term Effects of Capital Gains Taxes in New Zealand".

09-12 Grimes, Arthur and Chris Young. 2009. "Spatial Effects of 'Mill' Closure: Does Distance Matter?"

09-11 Maré, David C and Steven Stillman. 2009. "The Impact of Immigration on the Labour Market Outcomes of New Zealanders".

09-10 Stillman, Steven and David C Maré. 2009. "The Labour Market Adjustment of Immigrants in New Zealand".

09-09 Kerr, Suzi and Kelly Lock. 2009. "Nutrient Trading in Lake Rotorua: Cost Sharing and Allowance Allocation".

09-08 Coleman, Andrew and Grant M Scobie. 2009. "A Simple Model of Housing Rental and Ownership with Policy Simulations".

09-07 Crawford, Ron. 2009. "Variations in Earnings Growth: Evidence from Earnings Transitions in the NZ Linked Income Survey".

09-06 Maré, David C. 2009. "Agglomeration Elasticities in New Zealand".

09-05 Poot, Jacques. 2009. "Trans-Tasman Migration, Transnationalism and Economic Development in Australasia".

09-04 Hengyun, Ma; Les Oxley and John Gibson. 2009. "China's Energy Situation and Its Implications in the New Millenium".

09-03 Hengyun, Ma; Les Oxley and John Gibson. 2009. "Testing for Energy Market Integration in China".

09-02 Hengyun, Ma; Les Oxley, John Gibson and Bongguen Kim. 2009. “China's Energy Economy: Technical Change, Factor Demand and Interfactor/Interfuel Substitution”.

09-01 Cumming, Jackie; Steven Stillman and Michelle Poland. 2009. “Who Pays What for Primary Health Care? Patterns and Determinants of the Fees Paid by Patients in a Mixed Public-Private Financing Model”.

08-14 Coleman, Andrew. 2008. “Tax, Credit Constraints, and the Big Costs of Small Inflation”.

08-13 Coleman, Andrew. 2008. “Storage Under Backwardation: A Direct Test of the Wright-Williams Conjecture”.

08-12 Maré, David C. 2008. “Labour Productivity in Auckland Firms”.

08-11 Stillman, Steven; Malathi Velamuri and Andrew Aitken. 2008. “The Long-Run Impact of New Zealand's Structural Reform on Local Communities”.

08-10 Grimes, Arthur and Andrew Aitken. 2008. “Water, Water Somewhere: The Value of Water in a Drought-Prone Farming Region”.

08-09 Coleman, Andrew. 2008. “Inflation and the Measurement of Saving and Housing Affordability”.

08-08 Coleman, Andrew and Özer Karagedikli. 2008. “The Relative Size of New Zealand Exchange Rate and Interest Rate Responses to News”.

08-07 Grimes, Arthur and Yun Liang. 2008. “Bridge to Somewhere: The Value of Auckland's Northern Motorway Extensions".

08-06 Stillman, Steven and David C Maré. 2008. “Housing Markets and Migration: Evidence from New Zealand”.

08-05 Lock, Kelly and Suzi Kerr. 2008. “Nutrient Trading in Lake Rotorua: Choosing the Scope of a Nutrient Trading System”.

08-04 Kerr, Suzi and Andrew Sweet. 2008. “Inclusion of Agriculture and Forestry in a Domestic Emissions Trading Scheme: New Zealand’s Experience to Date”.

08-03 Kerr, Suzi and Kit Rutherford. 2008. “Nutrient Trading in Lake Rotorua: Reporting and Modelling Net Nutrient Inputs”.

08-02 Lock, Kelly and Suzi Kerr. 2008. “Nutrient Trading in Lake Rotorua: Overview of a Prototype System”.

08-01 Stroombergen, Adolf. 2008. “ESSAM General Equilibrium Model: Estimation of 2005/06 Input-Output Tables”.

07-13 Hall, Viv and John McDermott. 2007. "A quarterly post-World War II real GDP series for New Zealand".

07-12 Gibson, John; Trinh Le and Steven Stillman. 2007. "What Explains the Wealth Gap Between Immigrants and the New Zealand Born?"

07-11 Maré, David C.; Melanie Morten and Steven Stillman, 2007. “Settlement Patterns and the Geographic Mobility of Recent Migrants to New Zealand”.

07-10 Grimes, Arthur; David C. Maré and Melanie Morten, 2007. “Adjustment in Local Labour and Housing Markets.”

07-09 Grimes, Arthur and Yun Liang, “Spatial Determinants of Land Prices in Auckland: Does the Metropolitan Urban Limit Have an Effect?”

07-08 Kerr, Suzi; Kit Rutherford and Kelly Lock, "Nutrient Trading in Lake Rotorua: Goals and Trading Caps".

07-07 Hendy, Joanna; Suzi Kerr and Troy Baisden, "The Land Use in Rural New Zealand Model Version 1 (LURNZ v1): Model Description".

07-06 Lock, Kelly and Suzi Kerr, "Nutrient Trading in Lake Rotorua: Where Are We Now?"

07-05 Stillman, Steven and David C Maré, "The Impact of Immigration on the Geographic Mobility of New Zealanders".

07-04 Grimes, Arthur and Yun Liang, "An Auckland Land Value Annual Database".

07-03 Kerr, Suzi; Glen Lauder and David Fairman, "Towards Design for a Nutrient Trading Programme to Improve Water Quality in Lake Rotorua".

07-02 Lock, Kelly and Stefan Leslie, "New Zealand's Quota Management System: A History of the First 20 Years".

07-01 Grimes, Arthur and Andrew Aitken. 2007. "House Prices and Rents: Socio-Economic Impacts and Prospects".

06-09 Maani, Sholeh A.; Rhema Vaithianathan and Barbara Wolf. 2006. "Inequality and Health: Is House Crowding the Link?"

06-08 Maré, David C and Jason Timmins. 2006. "Geographic Concentration and Firm Productivity".

06-07 Grimes, Arthur; David C Maré and Melanie Morten. 2006. "Defining Areas Linking Geographic Data in New Zealand".

06-06 Maré, David C and Yun Liang. 2006. "Labour Market Outcomes for Young Graduates".

06-05 Hendy, Joanna and Suzi Kerr. 2006. "Land-Use Intensity Module: Land Use in Rural New Zealand Version 1".

06-04 Hendy, Joanna; Suzi Kerr and Troy Baisden. 2006. "Greenhouse Gas Emissions Charges and Credits on Agricultural Land: What Can a Model Tell Us?"

06-03 Hall, Viv B; John McDermott and James Tremewan. 2006. "The Ups and Downs of New Zealand House Prices".

06-02 McKenzie, David; John Gibson and Steven Stillman. 2006. "How Important is Selection? Experimental vs Non-Experimental Measures of the Income Gains from Migration".

06-01 Grimes, Arthur and Andrew Aitken. 2006. "Housing Supply and Price Adjustment".

05-14 Timmins, Jason. 2005. "Is Infrastructure Productive? Evaluating the Effects of Specific Infrastructure Projects on Firm Productivity within New Zealand".

05-13 Coleman, Andrew; Sylvia Dixon and David C Maré, "Māori Economic Development—Glimpses from Statistical Sources".

05-12 Maré, David C 2005. "Concentration, Specialisation and Agglomeration of Firms in New Zealand".

05-11 Holmes, Mark J and Arthur Grimes. 2005. "Is There Long-Run Convergence of Regional House Prices in the UK?"

05-10 Hendy, Joanna and Suzi Kerr. 2005. "Greenhouse Gas Emission Factor Module: Land Use in Rural New Zealand—Climate Version 1".

05-09 Poland, Michelle and David C Maré. 2005. "Defining Geographic Communities".

05-08 Kerr, Suzi; Joanna Hendy, Emma Brunton and Isabelle Sin. 2005. "The Likely Regional Impacts of an Agricultural Emissions Policy in New Zealand: Preliminary Analysis".

05-07 Stillman, Steven. 2005. "Examining Changes in the Value of Rural Land in New Zealand between 1989 and 2003".

05-06 Dixon, Sylvia and David C Maré. 2005. "Changes in the Māori Income Distribution: Evidence from the Population Census".

05-05 Sin, Isabelle and Steven Stillman. 2005. “The Geographical Mobility of Māori in New Zealand”.

05-04 Grimes, Arthur. 2005. “Regional and Industry Cycles in Australasia: Implications for a Common Currency”.

05-03 Grimes, Arthur. 2005. “Intra and Inter-Regional Industry Shocks: A New Metric with an Application to Australasian Currency Union”.

05-02 Grimes, Arthur; Robert Sourell and Andrew Aitken. 2005. “Regional Variation in Rental Costs for Larger Households”.

05-01 Maré, David C. 2005. “Indirect Effects of Active Labour Market Policies”.

04-12 Dixon, Sylvia and David C Maré. 2004. “Understanding Changes in Māori Incomes and Income Inequality 1997–2003”.

04-11 Grimes, Arthur. 2004. “New Zealand: A Typical Australasian Economy?”

04-10 Hall, Viv and John McDermott. 2004. “Regional Business Cycles in New Zealand: Do They Exist? What Might Drive Them?”

04-09 Grimes, Arthur; Suzi Kerr and Andrew Aitken. 2004. “Bi-Directional Impacts of Economic, Social and Environmental Changes and the New Zealand Housing Market”.

04-08 Grimes, Arthur and Andrew Aitken. 2004. “What’s the Beef with House Prices? Economic Shocks and Local Housing Markets”.

04-07 McMillan, John. 2004. “Quantifying Creative Destruction: Entrepreneurship and Productivity in New Zealand”.

04-06 Maré, David C and Isabelle Sin. 2004. “Māori Incomes: Investigating Differences Between Iwi”.

04-05 Kerr, Suzi; Emma Brunton and Ralph Chapman. 2004. “Policy to Encourage Carbon Sequestration in Plantation Forests”.

04-04 Maré, David C. 2004. “What do Endogenous Growth Models Contribute?”

04-03 Kerr, Suzi; Joanna Hendy, Shuguang Liu and Alexander S. P. Pfaff. 2004. “Uncertainty and Carbon Policy Integrity”.

04-02 Grimes, Arthur; Andrew Aitken and Suzi Kerr. 2004. “House Price Efficiency: Expectations, Sales, Symmetry”.

04-01 Kerr, Suzi; Andrew Aitken and Arthur Grimes. 2004. “Land Taxes and Revenue Needs as Communities Grow and Decline: Evidence from New Zealand”.

03-19 Maré, David C. 2003. “Ideas for Growth?”

03-18 Fabling, Richard and Arthur Grimes. 2003. “Insolvency and Economic Development: Regional Variation and Adjustment”.

03-17 Kerr, Suzi; Susana Cardenas and Joanna Hendy. 2003. “Migration and the Environment in the Galapagos: An Analysis of Economic and Policy Incentives Driving Migration, Potential Impacts from Migration Control, and Potential Policies to Reduce Migration Pressure”.

03-16 Hyslop, Dean R and David C Maré. 2003. “Understanding New Zealand’s Changing Income Distribution 1983–98: A Semiparametric Analysis”.

03-15 Kerr, Suzi. 2003. “Indigenous Forests and Forest Sink Policy in New Zealand”.

03-14 Hall, Viv and Angela Huang. 2003. “Would Adopting the US Dollar Have Led to Improved Inflation, Output and Trade Balances for New Zealand in the 1990s?”

03-13 Ballantyne, Suzie; Simon Chapple, David C Maré and Jason Timmins. 2003. “Movement into and out of Child Poverty in New Zealand: Results from the Linked Income Supplement”.

03-12 Kerr, Suzi. 2003. “Efficient Contracts for Carbon Credits from Reforestation Projects”.

03-11 Lattimore, Ralph. 2003. “Long Run Trends in New Zealand Industry Assistance”.

03-10 Grimes, Arthur. 2003. “Economic Growth and the Size & Structure of Government: Implications for New Zealand”.

03-09 Grimes, Arthur; Suzi Kerr and Andrew Aitken. 2003. “Housing and Economic Adjustment”.

03-07 Maré, David C and Jason Timmins, “Moving to Jobs”.

03-06 Kerr, Suzi; Shuguang Liu, Alexander S. P. Pfaff and R. Flint Hughes. 2003. “Carbon Dynamics and Land-Use Choices: Building a Regional-Scale Multidisciplinary Model”.

03-05 Kerr, Suzi. 2003. “Motu, Excellence in Economic Research and the Challenges of ‘Human Dimensions’ Research”.

03-04 Kerr, Suzi and Catherine Leining. 2003. “Joint Implementation in Climate Change Policy”.

03-03 Gibson, John. 2003. “Do Lower Expected Wage Benefits Explain Ethnic Gaps in Job-Related Training? Evidence from New Zealand”.

03-02 Kerr, Suzi; Richard G Newell and James N Sanchirico. 2003. “Evaluating the New Zealand Individual Transferable Quota Market for Fisheries Management”.

03-01 Kerr, Suzi. 2003. “Allocating Risks in a Domestic Greenhouse Gas Trading System”.