Scoping approach and measuring the impact of indexing unit cost parameters in cost-benefit analysis

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C Parker
NZ Institute of Economic Research (NZIER)
Wellington

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NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

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An important note for the reader

The NZ Transport Agency is a Crown entity established under the Land Transport Management Act 2003. The objective of the Agency is to undertake its functions in a way that contributes to an affordable, integrated, safe, responsive and sustainable land transport system. Each year, the NZ Transport Agency funds innovative and relevant research that contributes to this objective.

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Abbreviations and acronyms

BCR	benefit-cost ratio
CBA	cost-benefit analysis
CPI	Consumers Price Index
GDP	gross domestic product
GHG	greenhouse gas
MED	Ministry of Economic Development
MoT	Ministry of Transport
NPV	net present value
NZTA	NZ Transport Agency
RLTS	Regional Land Transport Strategy
TBC	travel behaviour change
VFEM	Vehicle Fleet Emissions Model
VOC	vehicle operating costs
VoSL	value of a statistical life
VTTS	value of travel time savings

Contents

Executive summary

This study's purpose

This study was undertaken between 2009 and 2011 to consider the materiality and feasibility of allowing for real-price changes (ie changes in prices after stripping out general price inflation) in cost–benefit analysis (CBA). At the time of this research, the NZ Transport Agency's (NZTA) policy was that real-price changes to unit costs used to estimate benefits over a project's lifetime were not required because the discounting of future costs and benefits reduced the significance of the impact. However, this meant that the values applied to, for example, vehicle operating cost savings, were not subject to changes in expected oil prices.

It was thought that allowing for real-price changes could materially improve the accuracy of benefit and cost estimates over a project's appraisal period. A change in benefit–cost ratios (BCRs) of different projects could result in a change in project rankings, which in turn could lead to a change in investment decisions.

Research findings: time indexing will materially affect BCRs and relative priorities

This study found that BCRs increase materially for the majority of project categories, but not for all of them.

For example, the BCRs for motorway projects were expected to increase by 22% on average, with a 90% confidence interval of 14–30%. Thus, if a motorway project had a BCR of 1.8, this could increase to 2.2, enough to change the NZTA's economic efficiency rating from 'low' to 'medium'. A motorway with a net present value of $1.73 billion would be expected to increase by $358 million (a 21% increase).

Other findings were as follows:

- Projects with high forecast benefit growth rates over appraisal periods benefited most from the compounding effects of real-price changes – ie public transport infrastructure projects (27% mean BCR increase), bridge renewals (22%), motorways (22%), rural realignments (18%), walking networks (15%) and cycling networks (14%). (Data for public transport operations was not available.) Such projects had a substantial proportion of benefits occurring later in the appraisal period, and these were proportionally more favoured by time indexing.
- The BCRs for congestion improvement and safety improvement projects increased, but relatively modestly (13% for each). This was attributed to the relatively low rates of benefit growth for the sample projects, which limited the extent that they 'capitalised' on the cumulative effects of time indexing. Travel behaviour change (TBC) projects were not materially affected by time indexing (a mean increase of 5%), as they had relatively short economic lives of 10 years (compared with 30 years for most other project categories).
- Maintenance and road-quality projects (preventative maintenance, pavement smoothing and seal extensions) were generally not affected by time indexing (0%, 4% and 9% respectively). This was because: (a) maintenance cost savings were assumed to already provide for 'cost escalation', and (b) the unit cost of improving vehicle wear and tear was held constant in this study by assumption. Considering uncertainty around these assumptions could be an extension to the research.
- Future vehicle operating costs (VOC) were particularly uncertain (oil prices and fuel efficiency improvements) and could significantly affect a project's CBAs. However, we found that that accounting for real VOC unit cost changes over time did not greatly affect project BCRs for given travel

behaviours. This means that concerns about oil prices etc should centre on how people’s travel behaviours are affected, rather than just the value applied to given VOC savings. Other related issues were as follows:

- This study found that only the CBAs of bridge renewal projects were materially affected by time indexing VOC unit cost parameters. This was because the CBAs of bridge renewal projects assumed vehicles would otherwise need to divert considerable distances, whereas the remaining project categories generally did not accrue significant energy savings.
- It is important that the assumptions about increasing unit costs to value VOC savings are consistent with the assumptions used by analysts to model transport demand and are consistent across projects.

Research findings: time indexing is feasible

The research found that time indexing unit cost parameters in transport CBA is feasible, with the following specific points:

- There is a strong theoretical basis for including updating unit cost parameters each year in appraisals.
- Real changes in income are the most important factor to consider when adjusting unit cost parameters over time. Real GDP per capita is an appropriate measure of income, and long-term forecasts are readily available.
- The willingness to pay for many categories of benefits increases at a rate less than income growth, and these relationships are governed by the relevant income elasticities. Tailored values for the income elasticities for each benefit category are required. These can be developed at the time that new willingness-to-pay surveys are undertaken. Values drawn from the literature can be used in the meantime.
- Even if time indexing is not undertaken, income elasticities should still be developed and applied to the NZTA’s practice of updating unit cost parameters each year. Otherwise some of the values for benefits will, all else being equal, become more inaccurate over time, and costly surveys will be required more frequently.
- Time indexing unit cost parameters is done overseas. Some overseas jurisdictions require that it is done in their transport CBAs, most notably in the UK. The NZ Treasury, in its CBA Primer, advises that if real-price changes are expected they should be incorporated into the analysis.

Recommendations

It is recommended that the NZTA:

- requires time indexing of unit cost parameters to occur in transport CBAs and provides guidance on the assumptions to use
- applies reasonably conservative values for income elasticities, perhaps at the lower end of the range of plausible values informed by overseas studies, until each can be updated by the results from willingness-to-pay surveys as they occur over time
- time indexes VOC benefits, with the focus on guiding and complementing the assumptions used in transport demand analyses and modelling
- applies the income elasticities developed to annually update the benefit values (ie the update factors issued in section A12 of the NZTA’s *Economic evaluation manual* volume 1 (2010)).

Abstract

This study assessed the feasibility and materiality of allowing for real-price changes in economic appraisals over the course of a transport project's appraisal period. The research found that time indexing unit cost parameters in transport CBA is feasible, and that benefit–cost ratios (BCRs) increase materially for the majority of project categories, but not for all. The report considers some of the issues involved, identifies the relative effects of various assumptions, and provides recommendations.

1 Introduction

Good-quality cost–benefit analysis (CBA) helps decision makers to make informed investment decisions, demonstrate value for money, and lead to better-quality decisions, including those made regarding transport projects.

A key ingredient of a good CBA is a well-grounded judgement of how people value benefits over the life of a project. Different assumptions can affect the relative rankings of projects and thus the value for money from a transport investment.

At present, the approach taken in the NZ Transport Agency's (NZTA) CBAs is to hold today's values for costs and benefits fixed over a project's appraisal period. In effect this is holding real, or constant, prices fixed for the period. This is unrealistic, because real prices actually change over time, and are expected to change over time. For example, it is generally expected that in future there will be increases in real prices for oil and wages. This will increase the benefits of reducing vehicle operating costs (VOC) and travel time savings.

The NZTA commissioned this study to investigate whether the unit prices of costs and benefits over the life of a project could be reliably and proactively estimated; whether the impact is material; and whether transport CBAs should therefore allow for changes in prices (relative to general price inflation) over time – what we refer to as 'time indexing' of unit cost parameters. The research was carried out between 2009 and 2011.

The report:

- explains the concept of adjusting for real-price changes in the CBA of a project over a project's life, and the various ways that appraisals may be affected by such adjustments
- summarises how it is approached in New Zealand and by overseas jurisdictions
- reviews the factors that govern price changes, such as the elasticities of willingness to pay with respect to income ('income elasticities'), and forecasts of income
- identifies a plausible range of indexes that could be applied to a wide-ranging database of CBAs to assess the materiality 'time indexing' has on benefit–cost ratios (BCRs)
- makes recommendations on how to improve the quality of CBAs as they relate to valuing future impacts.

This report focuses on the theory, and the materiality, of time indexing unit cost parameters in transport CBAs for given input data (eg from transport models). The following related issues were outside the scope of this report:

- how transport modelling results may change as a result of time indexing unit cost parameters (eg a higher cost of oil may suppress economic activity and thus travel demand, all else being equal)
- the effects of changes over time to other factors or assumptions relating to appraisals and modelling (such as pricing policies and demographic change)
- advice to the NZTA on specific unit cost indexes to apply in practice
- specific methods to operationalise unit cost indexing in the NZTA's 2010 *Economic evaluation manual* (EEM)
- forecasting overall financial costs to the NZTA for its budgeting processes.

2 Definitions and concepts

2.1 Some definitions

This section introduces and clarifies the terminology used in this report. (HEATCO (2006) is a good reference if a reader requires more background to these concepts.)

The *general price level*[1] and the *relative prices*[2] of individual goods and services in the economy change with time[3]. For economic CBAs it is usually most convenient to express the values of costs and benefits in constant dollar terms; ie to net out the effects of price *inflation*[4]. This denotes costs and benefits in *real* prices. In order to express costs and benefits in constant dollar terms, a common *base date* is required.

When the real price of a cost or benefit is anticipated to increase or decrease over the course of a project's life, then we can make adjustments to the *unit costs*. These real-price adjustments can be expressed in the form of a time index.

2.2 Measures of general price inflation

To estimate real-price changes, price forecasts are often done in nominal terms and then converted into constant dollar terms, using forecasts of general price inflation over the period. How general price inflation is measured is thus a relevant issue for time indexing unit cost parameters.

There are two measures of general price inflation:

- the Consumers Price Index (CPI), which is a price index of a representative 'basket' of goods and services *consumed* domestically
- the gross domestic product (GDP) [price] deflator, which measures the prices of goods and services *produced* by a country.

The two are usually very similar, but may differ when overseas prices change substantially (eg imported oil prices).

The UK DfT (2009b, paragraph 1.3.10a) describes the case for using the GDP deflator rather than the CPI:

> *The GDP deflator is a much broader price index than the CPI [Consumers Price Index], RPI [Retail Prices Index] or RPIX [Retail Prices Index minus mortgage interest payments] (which only measure consumer prices) as it reflects the prices of* ***all*** *domestically produced goods and services in the economy. Hence, the GDP deflator also includes the prices of investment goods, government services and exports, and subtracts the price of UK imports. The wider*

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[1] The *general price level* is a measure of overall prices within the economy. Which measure to use is considered further in section 2.2.

[2] This defines the price of a particular good or service relative to other goods and services in general. If any good or service is expected to change relative to the *general price level*, then it is said to have changed in *real* terms.

[3] This report is about changes in the prices of undiscounted costs and benefits, and not to the effects of discounting.

[4] *Inflation* is the term economists use to refer to increases in the *general price level* over time, such as that measured by the CPI. The inflation rate defines the rate at which the general price increases over a specified time period – eg monthly or yearly.

coverage of the GDP deflator makes it more appropriate for deflating public expenditure series.

Transport Canada (1994) also advises that the GDP deflator should be used to convert nominal into real values.

In practice, the most commonly available forecasts of general price inflation will be expressed in terms of consumer prices, ie the CPI. Also conceptually the CPI, which measures the general price level in terms of consumption, aligns with the measurement of benefits, which are expressed in units of consumption.

Our recommendation is that the CPI should be used to convert nominal benefits into real benefits, and not the GDP deflator.

2.3 Real-price changes for construction, maintenance and operating costs

Increases in relative costs, say, to construct a transport project will reduce the amount of resources available to invest in other areas of the economy.[5] This should be taken into account in project appraisals in the years when such changes are expected. Examples of the inputs for constructing, maintaining and operating transport facilities are labour, bitumen, aggregates and capital equipment.

In order to identify the relative price movement, the expected trend in the unit price over the future period of interest for the project appraisal should be identified and compared with the expected trend in the general price level. The resulting annual percentage change in unit prices relative to the general price level should then be applied to the unit price over the appraisal period.

For example, if the cost of road resealing was expected to increase at 4% per year over the appraisal period (in nominal terms) when the annual rate of general inflation over the same period is expected to be 2.5%, then the annual change in the real price of road resealing is given by $(1+0.04)/(1+0.025)-1=0.014$. Therefore, the cost of road resealing in the appraisal, expressed in constant prices, should be increased by 1.4% per year, reflecting this relative price change over the period for which it will continue.

2.4 Real-price changes for benefits

Economic appraisals can be considered as the following three broad steps (see figure 1):

1. Define the scenarios (the initiatives and the base case).
2. Determine the consequences of the scenarios by considering how people's behaviours are affected.
3. Appraise the economic welfare impacts by comparing and valuing the consequences of the scenarios.

The focus of this study was the impact of adjusting for real-price changes to the valuation step only (the third step, where net benefits are measured).

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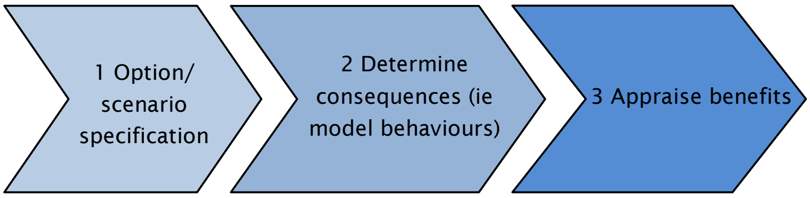
[5] This holds for given changes in the costs of inputs for projects. However some projects may be so substantial that they induce changes in the prices of their inputs. In that case they still use the same amount of inputs and they do not reduce the amount available for other areas of the economy. The opportunity costs of those inputs that experience price changes are greater, however.

A complication is that real-price changes assumptions can and do also relate to the modelling of people's travel behaviour, which indirectly affects benefits. There are currently some consistency problems within transport appraisals – this issue is touched on in section 3.1.2.

Figure 2.1 Three-step process for economic appraisals



2.4.1 Distinguishing between market and non-market benefits

Benefits are valued by 'willingness to pay', which is driven predominantly by people's incomes. As incomes rise in real terms over time it is reasonable to expect that the real value of benefits will also increase.

Sometimes we can observe willingness to pay directly from markets, whereas other times there are no explicit markets, and analysts need to determine this from surveys and/or other means.

2.4.1.1 Market-based transport benefits

Market-based transport benefits include:

- work-time travel savings benefits (ie from wages)
- VOC (eg the price of petrol)
- a small component of crash savings for labour costs associated for health, legal and vehicle repair services
- agglomeration benefits and perhaps some one-off classes of benefits for particular appraisals (neither of which is considered further in this report).

Unit costs based on observed market prices move one-to-one with those market prices.

2.4.1.2 Non-market-based transport benefits

Non-market transport benefits include:

- leisure and commuting time savings
- the value of a statistical life and injury.

Others classes such as the cost of carbon, noise, pollution, walking and cycling, etc can be inferred from market-based approaches or from non-market valuation techniques (such as surveys). As described in section 5.3.4, the unit cost parameter for greenhouse gas (GHG) emissions is based on estimates of damage value.

The unit cost of benefits valued using non-market techniques usually increase with incomes, but generally at a rate less than a one-to-one basis. This is a common finding of willingness-to-pay studies that are repeated over time. The relationship between income growth and the willingness to pay for a unit of benefit is regarded as the income elasticity. It is usually established to be between 0.5 and 1, which means that the unit valuation of an impact increases at a rate 50–100% of income growth. This may vary depending on the type of benefit. These issues are considered in detail in appendix A.

Project appraisals ideally estimate the consequences to those with standing (ie those whose well-being ‘counts’) in each period of a project’s appraisal period, and values the impacts as they are expected to be in each respective period (and are then discounted). Any future real changes to the values of each unit of impact (based on non-market valuation methods) are principally derived from income growth forecasts. If there is a systematic difference between how incomes and unit valuations relate, then not accounting for this will bias the estimates of future-periods’ benefits (prior to discounting). Growing unit valuations at too great (or too low) a rate relative to the rate of income growth makes the value of future-period impacts less accurate, which undermines the results of appraisals overall and thus increases the risk of misallocating resources.

For example, consider if real incomes were expected to increase at 2% per year over the appraisal period, and the income elasticity for the value of travel time savings (VTTS) for work and leisure trips was 1 and 0.5 respectively. Then the annual change in each of work and leisure VTTS in the appraisal should be increased by 2% and 1% per year respectively.

3 Approaches to time indexing

3.1 The NZ Transport Agency

3.1.1 Policy on time indexing unit cost parameters

The NZTA's EEM currently seems to advise against allowing for real-price changes in any benefits or costs (pp2-12 of volume 1 of the EEM (2010)):

> *Price inflation is a different concept from discounting. In general, all benefits and costs should be calculated in present-day (constant) dollars. The discounting of future values reduces the significance of any future inflation that might be expected to occur between various categories of benefits and costs, and therefore no adjustment for inflation is required in the evaluation.*

This statement has a degree of ambiguity. Whether it absolutely rules out time indexing unit cost parameters over a project's appraisal period is unclear.

This statement appears to be using the word 'inflation' to refer to different changes in real values between different categories of benefits and costs. Even if all categories of benefits and costs change by the same proportion in real terms, the important question is how this proportionate change compares with the general price level.

Our interpretation of the EEM is that real-price changes occurring in the future will be insignificant in present-value terms.[6]

3.1.2 Time indexing perceived costs in transport modelling

People's behaviours are affected by their perceptions of prices and these are a major determinant of travel demand. These prices can differ from the 'shadow prices' used to value the welfare impacts of projects. Some New Zealand transport-modelling appraisals take account of changes to real perceived prices (summarised in appendix C), and the results can be very sensitive to these assumptions.

Although the focus of this study was on appraising given transport outcomes rather than behavioural modelling, the NZTA may wish to consider how improvements could be made to help ensure assumptions relating to making real-price adjustments are appropriate and consistent across the various steps of economic appraisals. The following issues could be considered:

- *Consistency* of assumptions (economic forecasts, efficiency improvements, income elasticities):
  - *Internal consistency (for a given appraisal)* – the unit cost parameter values used in a CBA are perhaps more prescriptive (normative) than those used for transport modelling, where the unit cost parameter values are more descriptive (positive).[7] For example, average national wage rates are used for work-based travel time savings for reasons of equality across different regions, rather than for reasons of actual willingness to pay for transport improvements within a region. It may be appropriate for transport modellers to use reasonable judgement, evidence and regional

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[6] The EEM guidance was issued before the discount rate was reduced from 10% (real) to 8%. The materiality of real-price changes in present-value terms will be greater now than when the view was established.

[7] However, modelling is perhaps not entirely descriptive because analysts may face the tension of conforming to the relevant planning authorities' views of how the region ought to develop over time.

  circumstances to time index unit cost parameters for descriptive modelling and analysis. However, it is preferable that differences in the values in the transport models used to estimate project benefits for the CBAs and benefits in the CBAs themselves are not too large.
  - *External consistency (across different appraisals)* – some coordination of assumptions would assist with making projects more comparable. This is important when projects compete for the same scarce funding and/or when they are interrelated (ie have a degree of complementarity or substitutability, such as projects within a common transport corridor). Having a body such as the NZTA determine the indexation rates would avoid having project proponents choosing their own with the aim of inflating project benefits.
- *Appropriateness* of assumptions (economic forecasts, efficiency improvements, income elasticities):
  - Analysts use their own reasonable judgement and available evidence to try to make appropriate assumptions (eg relating to economic forecasts, vehicle efficiency improvements, and income elasticities). However, some centralised work may need to be done, such as large-scale survey analysis to identify reasonable income elasticities for the New Zealand context that cannot be done for individual projects. In some cases it may be effective and efficient for the NZTA to research these values and advise analysts, via the EEM, to use them.

3.1.3 Annual updating of unit cost values

The NZTA uses the concept of a ‘base year’, which is the financial year in which the evaluation is prepared. The NZTA provides ‘update factors’ to adjust unit cost parameters established in earlier years to the common base year. These update factors are based on a range of price indices published by Statistics NZ.

There is, however, a potential shortcoming in the current practice for developing these update factors.

As the table in appendix B shows, the unit costs are not indexed by a single inflation index, such as the CPI, but instead by combinations of price indices tailored to closely match the class of benefit or cost (eg VOC are based primarily on Statistics NZ’s Fuel and Oil index, and work-based travel time savings are based on the ‘all sectors’ Salary and Wage Rates index). Given that wages and energy prices have generally increased more than inflation, real-price changes are being incorporated. The intention is for projects to be evaluated using the unit costs current at the time of the evaluation.

However, some of these values are non-market based and so the appropriate income elasticities need to be applied. Currently an income elasticity of +1.0 is implied, as the price indices are translated directly into increases in the unit cost parameters. This means that actual non-market benefits may be increasing at a slower rate than assumed. The longer the lapse in time since the relevant survey was undertaken, the greater the problem.

3.2 The NZ Treasury

The Treasury (2005, section 2.4.1) states that:

> *... the only time that we make real adjustments to prices over time is if the price of a particular good or service is expected to increase or decrease relative to all other goods and services. In such cases the relative change should be quantified and built into the analysis.*

3.3 Overseas approaches to time indexing

Table 3.1 Summary of overseas approaches to time indexing

Country and jurisdiction	Time indexing advised?	Guidance provided?	Description
UK Department for Transport (DfT) Source: UK Department for Transport (2009a, s2.3, and 2009b)	✓	Yes	The DfT issues guidance on time indexing unit cost parameters, including forecasts for income, income elasticities for VTTS, and forecasts of energy prices, energy efficiencies and changing fleet make-up over project appraisal periods. Non-fuel VOC are assumed to remain constant in real terms over the forecast period because 'the main elements that make up non-fuel VOC are subject to less volatility than fuel VOC'. Income elasticities for non-work VTTS and safety benefits are 0.8 and 1.0 respectively.
Australian Transport Council National Guidelines Source: ATC (2006, pp50–51)	✓	Some	Cautiously supports time indexing. Notes potential for project proponents to use their own assumptions to manipulate CBA results. 'Forced to choose' a value for the income elasticities without Australia- specific research, ATC advises a conservative factor of 0.5.
Australia Federal Department of Finance and Administration Source: Commonwealth of Australia (2006, p60)	✓	No	'If there are good reasons for thinking that particular cost or benefit streams will not follow general price movements, those changes in relative prices should be built into the analysis'.
Australian Civil Aviation Safety Authority Source: Australian Civil Aviation Safety Authority (CASA) (2007, pp3–17)	✓	Some	Same as the Australia Federal Department of Finance and Administration above.
US Department of Transport Source: US Department of Transport (2003, p11)	✓	No	'The analyst should work with experts to determine how much the real price of the resource will change over time and include this adjusted price in the economic analysis'.
California Department of Transport Source: California Department of Transport (2007)	✓	No	Cautiously supports, but notes uncertainties in forecasting prices and views time indexing as being ultimately immaterial to decisions.
Transport Canada Source: Transport Canada (1994)	✓	No	'Ideally, costs, benefits and other effects should be forecast in nominal dollars (ie current or budget year dollars), taking account of the particular way in which their values are expected to change over time. The effects of general inflation would then be removed by converting these nominal dollars to constant dollars.'

4 Forecasting market-based unit costs

The two main factors to forecast for market-based benefits are incomes and VOC, the latter of which are determined by energy prices and fuel efficiency. Non-market benefits are considered differently, by applying specific income elasticities to forecasted income; appendix A contains a literature review on developing these income elasticities.

This chapter considers the issues around forecasting incomes and VOC and the feasibility of forming robust assumptions about each. This provides the basis for specifying plausible values for each variable to model the sensitivity of appraisal results to time indexing.

4.1 Forecasting income increases – GDP per capita or real wages?

There are different ways of measuring income, such as GDP per capita and real wages. These do not necessarily move at the same rate; for instance, in New Zealand since late 1993, the average real increases for labour wages and GDP per capita have been 2.20% and 1.68% p.a. respectively.[8]

The Australian Transport Council (ATC 2006, p51) argues that expected growth in real GDP per capita should represent real incomes as it relates to non-market benefits, and that expected growth in real wages should relate to market-based benefits. This is because for non-market benefits, a sizeable proportion of the relevant population whose willingness to pay is estimated are not workers (eg retirees and students).

The UK Department for Transport uses GDP per capita as their measure of income for time indexing all unit cost parameters (DfT 2009b) without mention of the above issue raised by ATC.

For New Zealand, the average real annual GDP per capita growth rate between 1948 and 2006 was approximately 1.4%, calculated using the GDP series from Hall and McDermott (2007) and historical population data from Statistics NZ. The Treasury's *Long-term fiscal statement* (2009a) assumes an economy-wide labour productivity growth rate of 1.5% per annum (real GDP growth per capita).

4.2 Forecasting vehicle operating costs

Factors influencing VOC over time are energy prices, energy efficiency improvements and the evolution of vehicle fleet technology. For example, the following factors should be considered:

- The difficulties of estimating future oil prices is well known, and the usual approach is to consider high-, medium- and low-price scenarios and to reserve judgement about which scenario is more likely.
- Technological progress in energy efficiency of vehicles is also uncertain. There are a variety of significant advances in development, including electric vehicles, camless engine technologies, and light-weighting of vehicles (Hyder Consulting 2009).
- Transport CBAs include assumptions made about the energy efficiency characteristics of the overall vehicle fleet, which is influenced by many factors such as: the proportion of new versus second-hand vehicles entering the fleet; the scrappage rate of old vehicles; and the preferences for fuel-efficient vehicles versus larger and/or more powerful vehicles.

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[8] Statistics NZ codes SNCQ.S6RB01SNZ (real GDP per capita) and LCIQ.SG51Z9 (all sectors Salary and Wage Rates index) respectively.

These features will be interrelated: higher oil prices will cause more people to buy fuel-efficient vehicles; and sustained high prices will encourage more research and development into energy-efficient vehicles, which will affect the fleet make-up in the long term.

The greater the cost to operate vehicles, the greater the benefits from projects that save on such costs, all else being equal. (Recall that behavioural responses, such as whether higher costs lead to people travelling less, is outside the scope of this report.)

Below are estimates of these factors made by the Ministry of Economic Development (MED). These patterns of energy-cost and fuel-efficiency improvements across the vehicle fleet inform the assumptions used in the sensitivity analysis outlined in section 5.3.4.

4.2.1 Energy prices

MED annually publishes its *Energy outlook*, which is a range of forecasts of New Zealand's future energy supply, demand, prices and GHG emissions.

Some of the relevant points of MED's 2010 Energy Outlook are as follows:[9]

- Exchange rates (which are important to transform international oil prices into domestic prices) to 2013 are also based on Treasury's updated forecast. For the period 2014–2020, exchange rates trend towards the long-run rate of 0.60$US/$NZ and remain at this rate indefinitely.
- Oil prices:
  - The core forecast assumes prices will follow the New York Mercantile Exchange (NYMEX) future prices in the near term, trending towards the international energy agency's World Energy Outlook mid-case projection of US$97/bbl and US$115/bbl by 2020 and 2030 respectively. For 2030 this corresponds to a petrol pump price of $2.70 per litre (in 2010 New Zealand dollars).
  - A high oil price scenario is US$172/bbl by 2030, equating to around $3.50 and $3.00 per litre for petrol and diesel respectively.
  - A low oil price scenario of US$70/bbl is held constant in real terms.
- A shift towards more efficient light vehicles and migration to light diesel vehicles is expected, and by 2030 there will be no further growth in petrol demand.

4.2.2 Vehicle operating costs

MED and the Ministry of Transport (MoT) own and operate the New Zealand Vehicle Fleet Emissions Model (VFEM). Projections for the light-vehicle fleet fuel economy based on the VFEM follow in figure 4.1. Note that these projections assume no wholesale move to alternative fuel or vehicle technologies. These projections show a modest improvement from just over 10 litres per 100km in 2009 to just over 8 litres in 2030.[10]

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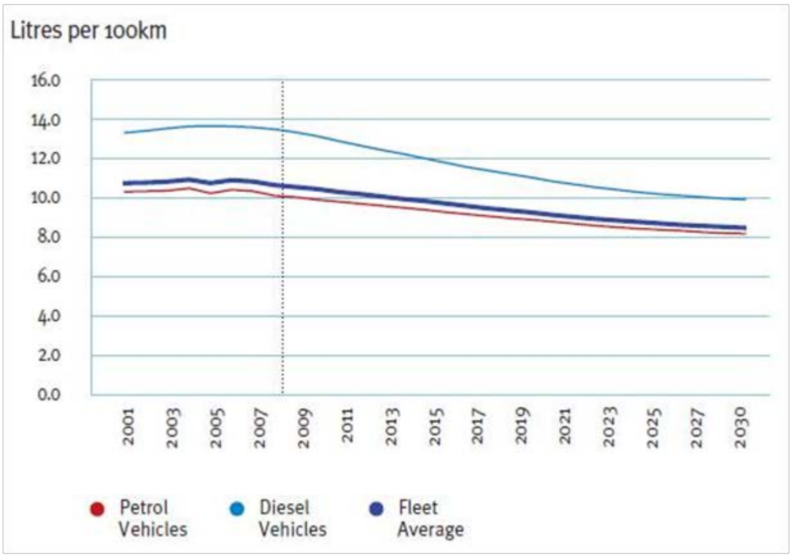
[9] Dollar figures are expressed in 2010 dollars.

[10] As described in appendix C, transport modelling for the Additional Waitemata Harbour Crossing used forecasts for vehicle efficiency improvements from the VFEM that are more recent than MED (2009), which were improvements over 2006 of 13% by year 2026 and 31% by year 2041.

Figure 4.1 New Zealand light-vehicle fleet fuel economy (MED 2010)



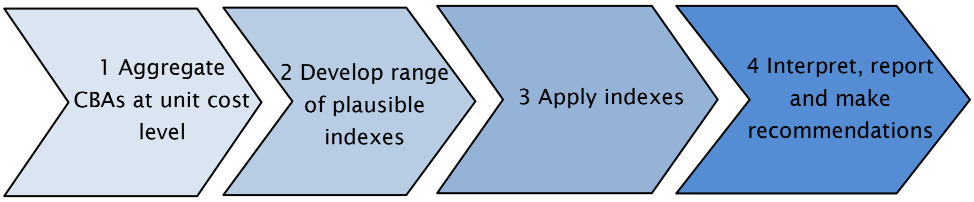
5 Methodology and assumptions for modelling

5.1 Outline of methodology

The approach we took to assess the impact of time indexing unit cost parameters in transport CBAs is summarised in figure 5.1 and involved the following four steps:

1. Obtain data on CBAs from multiple types of transport projects and combine them in a single dataset that all reference a single set of unit cost parameters.
2. Develop a range of time indexes for each unit cost parameter that is supported by the literature and can reasonably be estimated.
3. Apply the indexes on the set of unit cost parameters and determine which assumptions and parameters most influence CBA results for each class of project. We used 'Monte Carlo' simulation to simultaneously assess the combined effect of multiple assumptions.
4. Interpret and report the findings, and form recommendations.

Figure 5.1 Methodology outline



5.2 Aggregation of CBAs

The dataset of projects developed by Parker (2009) was used for this study. The model was further adapted for this study by allowing for Monte Carlo simulation and by including a public transport infrastructure project.

The model combined the CBAs of 151 initiatives across the domain of land transport. The key assumptions and methods for those initiatives were consistent with those prescribed in the EEM. The key inputs for each CBA were the unit cost parameters in the EEM plus the key data variables unique to each appraisal.

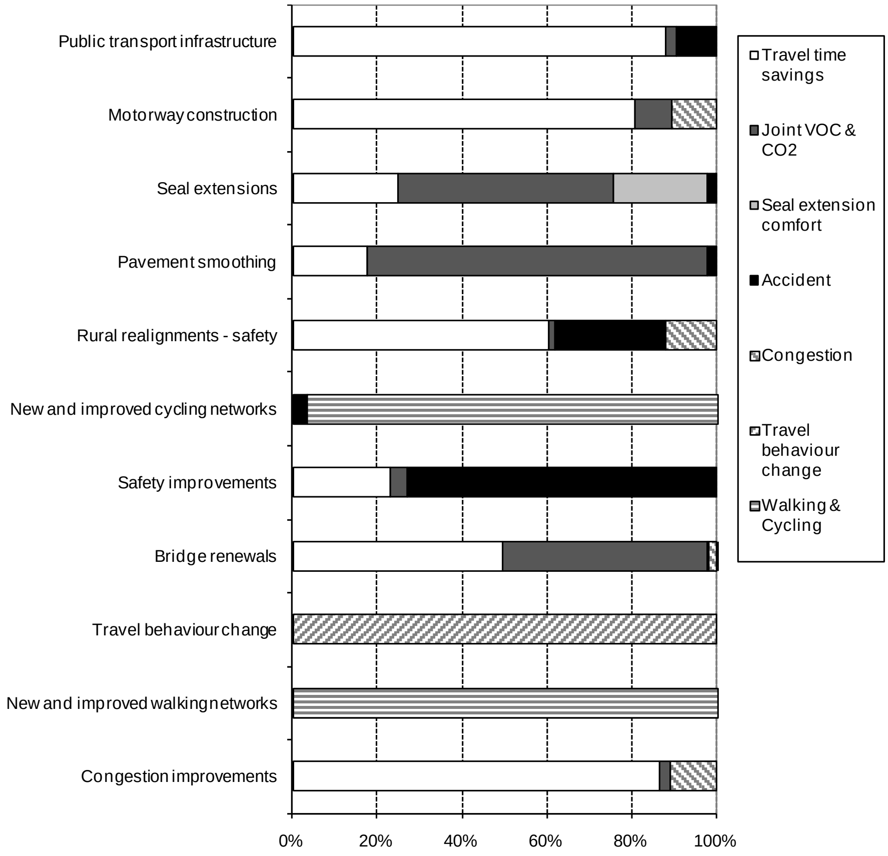
The basis for most of the CBA data was from 'LTP Online', the NZTA's internet portal system for 'approved organisations' to submit their land transport programmes. This was augmented by occasional project evaluations supplied directly to the author by the NZTA, for research purposes. Most approved organisations kindly provided read-only access to their secure portals. Table 5.1 contains an overview of the project categories included in the model. The projects were representative not of the National Land Transport Programme, but of the projects that were included in LTP Online.

Table 5.1 Summary of project category and count of projects

Project category	Number of projects
Public transport (PT) infrastructure projects	1
Motorway construction	2
Seal extensions	50
Pavement smoothing	37
Rural realignments – safety	2
New and improved cycling networks	10
Safety improvements	9
Bridge renewals	4
Travel behaviour change (TBC)	8
Preventive maintenance	21
New and improved walking networks	5
Congestion improvements	2

Figure 5.2 shows the sources of benefits and their relative shares for each project type from the 151 projects (excluding the 21 preventive maintenance projects, which focused on cost savings only).

Figure 5.2 Types of benefits for the projects within the dataset[11]



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[11] Present-value benefits discounted at 8% and not time indexed. Congestion benefits are as defined in the EEM.

5.3 Developing a range of plausible unit cost indexes

This section clarifies how Monte Carlo analysis was used and how the assumptions were determined using the findings from the literature reviews in chapter 4 and appendix A.

5.3.1 Use of Monte Carlo analysis

The software package @RISK was used to assess the materiality of time indexing unit cost parameters to CBA results, and the impact on the ranking of initiatives. The benefit of this approach was that the sensitivity of a wide number of parameters could be assessed in a single integrated process.

Probability distributions were assigned to key values relating to real-price changes and formed the basis of the analysis. Probability distributions were not used here because of any presumption that the variables were inherently random; rather, at this point in time it was not certain what value each parameter would take if decision makers did indeed decide to time index. The challenge with specifying the probability distributions was to identify the most plausible range of values decision makers could actually specify for transport CBAs if time indexing were to occur. This was informed by the results of the literature review and professional judgement.

Key decisions at this part of the analysis were to determine what kind of probability distribution was the most appropriate and the relevant parameter values for each distribution. Table 5.2 summarises the main probability distributions considered in this study.

Table 5.2 Summary of how @RISK probability distributions can be judged for each parameter

Type of distribution	What to specify	Need not specify	Circumstances when it is useful
Normal (‘bell curve’)	Mean and standard deviation	Minimum and maximum values	Useful when upper and lower limits cannot be specified, but mean and standard deviation can be. Likelihood of values further from the mean are considered to diminish.
Uniform	Minimum and maximum values	Mean or standard deviation	Useful when one can specify the limits to the upper and lower boundaries but there is no reason to presume that any one value is more likely than another within that range.
Triangular	Minimum, maximum and most likely values	Mean or standard deviation	Useful when one can specify the limits to the upper and lower boundaries and one value is more likely than the rest (and the distribution need not be symmetric about the mean).
Discrete	Specific values that may occur and the likelihood of each		Useful for a discrete (rather than continuous) domain of outcomes where the probability of each event can be specified.

The key outputs are box plots of the proportional increase in BCRs relative to no-indexing. This indicates the general extent that BCRs are expected to change, and how that may differ across project types. ‘Tornado plots’ rank the materiality of input assumptions to BCR changes.

The @RISK results are the product of randomly picking combinations of values for each unit price parameter (given the specified distribution of possible values for each unit price), and doing this many times over. This means that results will differ slightly in each simulation, although this variation should be random and not affect the results in a statistically significant way. The @RISK results will also differ slightly from the manual deterministic calculations used to report certain impacts. This explains why there are sometimes small deviations between figures reported in tables and the corresponding graphs.

5.3.2 Forecasting income increases

Real GDP per capita was used as the measure of income.[12] The approach taken in this study was relatively simple: in any given scenario, a single annual growth rate of GDP per capita was used for the full appraisal period for the CBA of each project modelled. That is, the possibility of the annual growth rate changing over a project's life in a single given scenario was not considered (eg 1.4% for years 1–10 and 1.5% for years 11–30). For each single simulation, the same GDP per capital growth rate was used for all unit cost parameters. More sophisticated assumptions were not warranted for this study, which focused on the general materiality of an income growth rate assumption on CBA results.

The central estimate for the long-term growth rate was 1.5%. For the illustrative purposes of this study, we judged that rates higher or lower than this were less probable, indicating that a uniform or triangular distribution was suitable. No specific upper or lower limits were apparent.

A normal distribution with a mean of 1.5% and standard deviation of 0.25% was used here. This implied that the probability of the real GDP per capita growth rate being outside the range of 1–2% p.a. was less than 0.046.

5.3.3 Income elasticities for non-market benefits

5.3.3.1 Value of travel time savings

- *Non-work value of travel time savings*: Based on theoretical considerations, the statistical distribution for sensitivity testing the income elasticity of non-work VTTS should have a maximum value of no more than +1.0, and a minimum value of +0.5 (supported by Mackie et al 2003 and ATC 2006). Because we had no basis from experience or reason to give higher weight (probability) to any value within this range, we used a uniform distribution, which implied a mean value of +0.75.
- *Distinguishing between work and non-work travel time savings in existing CBAs*: The data on travel time savings for the transport CBAs used in this study did not explicitly differentiate between work and non-work travel time savings. This distinction was approximated, based on the 'road categories' assigned to each project, being 'urban arterial', 'urban other', 'rural strategic' and 'rural other', as described in 'Table A2.2: Road categories' in section A2 of the EEM (volume 1) (NZTA 2010). The traffic composition and the travel purpose by traffic type and road category in the EEM (tables A2.3 and A2.4) were then used to proportion the two income elasticities, depending on the nature of each project.

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[12] As discussed in section 4.1. Although it is common for real GDP per capita to be used to index unit costs estimated on WTP basis, such as crash costs and non-work time, arguably real wages should be used for unit costs based on average earnings (such as work-based travel). If real GDP per capita growth was deemed a constant share of the growth in real wages then one could perhaps scale up the growth of average earnings to suit. This possibility was considered after the results of the simulations were documented in this report, and so the materiality of this possible assumption has not been empirically assessed.

Table 5.3 Proportioning VTTS benefits to work and non-work

Road category	Work	Non-work
Urban arterial	22.7%	77.3%
Urban other	22.3%	77.7%
Rural strategic	39.5%	60.5%
Rural other	38.2%	61.8%

5.3.3.2 Value of a statistical life (VoSL)

Based on theoretical considerations, the statistical distribution for sensitivity testing the income elasticity of the VoSL should have a maximum value of no more than +1.0, and a minimum value of +0.4. The majority of meta-analyses indicate that the most likely value is between +0.5 and +0.6, and this was applied by the US Department of Transport (2005). While Miller (2000) calculated values closer to 1, they were across countries, and Miller noted that within a country the value was closer to the 0.5–0.6 range. Miller noted a US study that estimated a value of unity, but one of the authors of that study (Viscusi) subsequently estimated a value within the 0.5–0.6 range also.

These studies indicate that the most likely value of the income elasticity of the VoSL is +0.55. A triangular distribution of the income elasticity with a peak of +0.55, a minimum of +0.4 and a maximum of +1.0 was applied in the assessment, which implied a mean value of +0.65.

5.3.3.3 Other benefit types

The other benefit types included in the model used for this study were:

- walking and cycling benefits
- TBC
- congestion-reduction benefits
- seal extension comfort values.

Not all benefit types outlined in the EEM were included in the projects contained in the model used in this study; examples included agglomeration economy benefits, driver frustration benefits, passing-lane crash savings, and public transport operations benefits. This was because no such projects were obtained at the time data was collected and the CBA model was built.

The unit cost parameters for walking and cycling benefits were assumed, for simplicity, to all be estimated using non-market methods. This assumption was supported by the EEM (NZTA 2010, vol 2, p8-3). The EEM notes that although walking and cycling time savings can be based on values of time for work, commuting and non-work travel, the values ‘applicable to most pedestrians and cyclists are those for non-work travel purposes (including commuting to and from work). These standard values are derived willingness to pay (WTP) values, ie they are based on consumer surplus methodology.’

The EEM (ibid, vol 2, sections 3.2, 3.3 and 3.8) describes a wide range of benefit areas for TBC projects. Section 3.2 implies that the methods to establish the unit cost parameters for benefits are primarily willingness to pay. Some components of the unit cost parameters are market-based, such as hospital cost savings from improved health (p3-16). It is not clear in the EEM what proportions of non-market and market-based values are used to determine TBC projects’ default unit cost parameters (such as those listed on page SP12-7).

For the purpose of this study, which was to quantify the potential materiality of time indexing unit cost parameters, it was assumed it was 100% comprised of non-market values. If time indexing were to become NZTA policy, then the make-up of the unit cost parameters assumed should be clarified, and income elasticities only applied to the components derived using non-market valuation methods.

The NZTA applies 'congestion-reduction benefits' over and above normal travel time and VOC savings. This is because 'Road users value relief from congested traffic conditions over and above their value of travel time saving' (2010, EEM vol 1, pA4-4). There is no clarification made or references to literature on how the unit cost parameters for this type of benefit were established.

It was assumed in this research that the values related to frustration and inconvenience to travellers (as distinct from reliability benefits) and were established using non-market methods. However, some component could relate to marginally higher VOC, and thus the unit cost parameters would have a market-derived component. Like TBC projects, if further work was done to apply time indexation in practice, then the exact make-up of the congestion-reduction unit cost parameters would need to be clarified and treated accordingly.

The unit cost parameters for seal extension comfort benefits were assumed to have been established using non-market valuation methods.

For the purpose of the empirical analysis, a uniform distribution between +0.5 and +1.0 for each individual income elasticity for walking, cycling, congestion reduction, seal extension comfort, and TBC unit cost parameters were applied (ie the same sample distribution as assumed for the non-work VTTS income elasticity).

5.3.4 Greenhouse gas emissions

5.3.4.1 Greenhouse gas (GHG) emissions

The \$40 per tonne of CO_2 value used in the EEM is based on a value of \$30 in 1996 dollars, recommended by the *Land transport pricing study – environmental externalities* (LTPS-EE, Ministry of Transport 1996), which was derived from the lower end of a range (US\$9–197 per tonne in 2000 dollars) of values stated in studies reviewed in the IPCC's 1995 Second Assessment Report (Clarkson and Deyes 2002, Ministry of Transport 2009). The LTPS-EE document clarifies that the social cost estimates are derived from damage cost estimates.

The Ministry of Transport (2009, p24) cautions against using the market price of emission units (as they are traded on international markets) to estimate the social cost of GHG emissions because it is only a market-based means to achieving an obligation under international agreements such as the Kyoto Protocol. The Ministry argues that using the market price of emission units may result in underestimates of the total cost of GHG emissions.

As the unit cost parameter is not derived from non-market methods, income elasticities are not relevant. However, short of reviewing each of the studies reviewed by the IPCC, it is not clear how the real changes in future damage costs can be forecasted robustly. The approach taken in this study was to assume the unit cost parameter per tonne of CO_2 equivalent increases, and the rate of increase is correlated with per capita GDP. A normal distribution with a mean of 0.8 and standard deviation of 0.1 was used to sample the proportions that the CO_2 unit cost parameter moves with per capita GDP. If in one of our time-indexing simulations the per capita GDP growth rate was 1.5% and the CO_2 parameter was 0.8, then it was assumed that the unit cost parameter for CO_2 grew at 1.2% per annum. The normal distribution assumptions (for both per capita GDP and CO_2) implied there was about a 0.12 probability that CO_2 unit costs increased at greater than 1.5% per annum and a 0.05 probability they increased at less than 0.82% per annum.

5.3.5 Forecast unit cost parameters for vehicle operating costs (VOC)

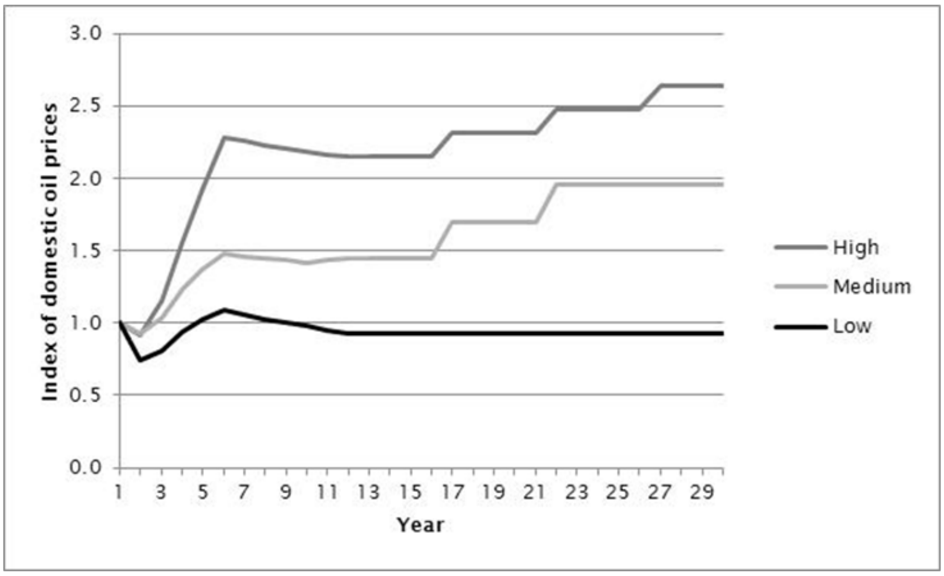
The follow subsections describe how future values of VOC were forecast for the purpose of this study. The method necessarily approximated the effects, and the various components of VOC could vary between projects.

Separate forecasts were made for oil prices and for fuel-efficiency improvements, as follows.

5.3.5.1 Energy price forecasts

The oil price scenarios were based on a CBA of electric vehicle uptake by Hyder (2009), which was informed by forecasts for oil prices and the exchange rate from MED (2009) and from MED input into the Hyder study.

Figure 5.3 Possible oil price scenarios (NZD real) (Hyder 2009)



The low-price scenario was based on current international oil prices remaining steady in real terms, and the high-price scenario was based on the highest price in US dollars occurring within five years, and subsequently growing at US$2 per annum.[13] The short-term fluctuation was driven by the exchange rate forecasts. Table 5.4 describes the corresponding indices.

Although the forecasts were slightly dated relative to the relative volatility of oil prices since, the scenarios were still useful indications of plausible oil price scenarios for the purposes of this study.

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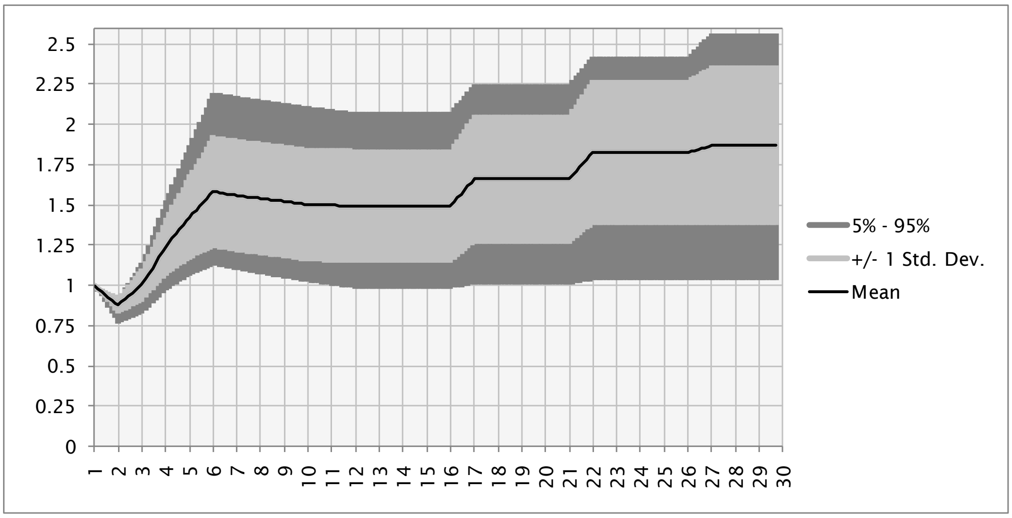
[13] The original five-year period referred to related to 2010–2014, and the integrated CBA model used for this study was developed in 2010. Although some time had elapsed since, the analysis was still useful in quantifying the absolute and relative effects on project BCRs from various scenarios of oil prices.

Table 5.4 Projected index of domestic oil prices (Hyder 2009)

Year	Low oil price scenario	Medium oil price scenario	High oil price scenario
2009	1.000	1.000	1.000
2010	0.748	0.922	0.913
2015	1.057	1.462	2.256
2020	0.930	1.452	2.149
2025	0.930	1.702	2.312
2030	0.930	1.953	2.474
2035	0.930	1.953	2.637
2040	0.930	1.953	2.800

The low, medium and high scenarios were assigned labels of -1, 0, and +1 respectively. A uniform distribution across this range (-1 to +1) was applied across these three scenarios to reflect that no single scenario was judged more likely than another. Random variables less than zero were used to weight the index between the low and medium values, and variables greater than zero were used to weight the index between the medium and high values. For example, a value of -0.5 from the uniform probability distribution led to an index of oil prices that were a 50/50 average of the low and medium oil price scenario indices from table 5.4. Figure 5.4 shows the spread of expected values these assumptions imply in the @RISK simulation.

Figure 5.4 Variability of index of domestic oil price assumptions[a]

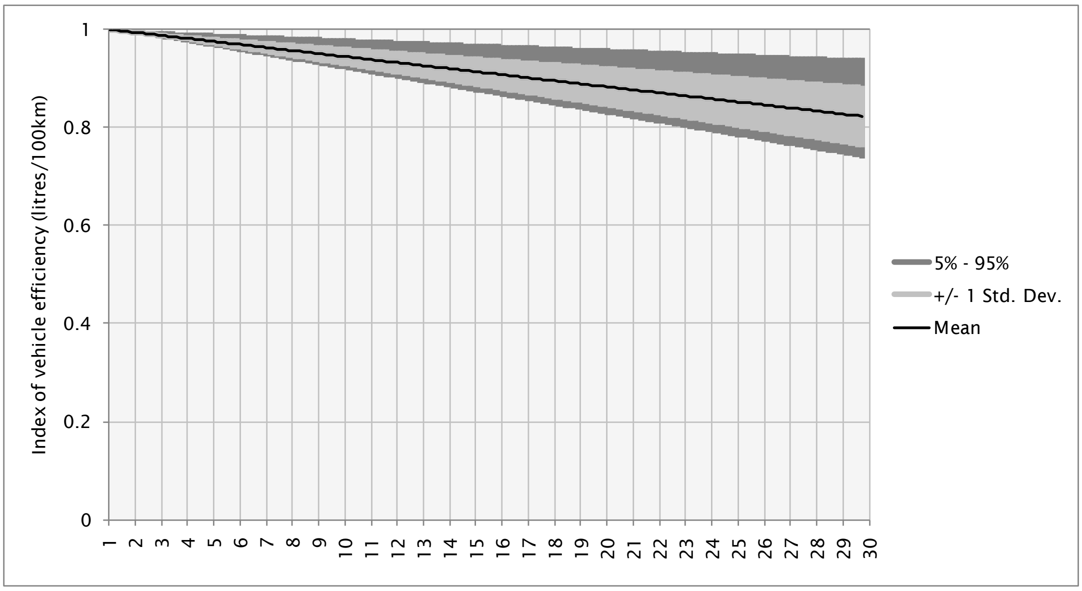


a) The vertical axis is an index, and the horizontal axis is the years in the appraisal period.

5.3.5.2 Vehicle fuel-efficiency improvements

The analysis assumed a linear rate of improvement in vehicle efficiency, as this captured the broad issues without overcomplicating the analysis. The minimum rate of improvement assumed was 0% over the appraisal period, and the maximum assumed was 1%. The most likely value assumed was 0.85%, which was slightly more conservative than that used by SKM (2010) based on the VFEM (refer to appendix C). A triangular distribution for the rate of efficiency improvement with these values was used, which implies a mean rate of improvement of 0.62%. The given rate was applied uniformly across the entire appraisal period; figure 5.5 describes the direct results of these assumptions. The mean value is broadly in line with figure 5.2 earlier.

Figure 5.5 Variability of vehicle fuel-efficiency improvements



- *Combining fuel prices and fuel-efficiency improvements*: The indices of figures 5.4 and 5.5 were multiplied together to determine the adjustment made to VOC benefits.

  One complication that arose in the analysis was that seal extension and pavement-smoothing projects benefited to a very large extent from this approach. However a large proportion of the VOC benefits for these projects accrued not from fuel savings, but from reduced road roughness, which would lead to less vehicle damage, for which no real price escalation was assumed. To assume that all VOC costs increase at the rate of fuel price increases (net of fuel-efficiency improvements) would thus overestimate the present-value VOC benefits. To correct for this, the proportion of each project's VOC benefits that came about by reduced road roughness was netted out from the VOC time index.[14] This markedly reduced the variability and the average increase of the benefits for these two project categories.

- *Other components of vehicle operating costs:* The remaining contributors to the unit cost parameters for VOC, such as vehicle maintenance and repairs, depreciation and tyre wear and tear, were not specifically addressed. The time indexation schedule developed for fuel and oil unit cost parameters was assumed to apply to remaining VOC unit cost parameters. Whilst not ideal, there was insufficient information in the underlying project CBAs to distinguish between the different subclasses of VOC.

5.3.6 Clarification of the approach taken regarding maintenance and operating costs for infrastructure facilities

The focus of this study was on user-benefit calculations, rather than the upfront capital and ongoing maintenance/operating costs to 'approved authorities'. This was because it was expected that best practice for cost estimators would be to include real-price changes and productivity improvements as and where they saw appropriate. The practice of cost estimation for transport projects is to estimate nominal

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[14] For example, refer to Worksheet 5 of the 'Seal extension simplified procedures (SP4)' in the EEM vol 1 (2010). VOC benefits are caused by improvements to roughness (CR) and base operating costs (CB). The percentage of VOC benefits relating to CB was used to weight against the VOC unit cost time index for each respective project.

price escalation for various categories of inputs, such as labour, concrete, aggregate, etc, and then convert these into real prices using estimates of general price inflation.

This was the assumption used for the modelling undertaken in this study: only benefit categories were time indexed for sensitivity testing. Although it could have been useful to consider the effects of increasing maintenance and operating costs caused by the rising cost of, say, oil, it would potentially be misleading to apply this to all projects generally as it would risk double counting the effect of expected oil price increases.

5.3.7 Summary of assumptions for Monte Carlo analysis

Table 5.5 Assumptions for Monte Carlo analysis

Input	Assumptions for transforming forecast variables to time-indexation schedules
Non-work VTTS income elasticity	Uniform distribution for income elasticity between +0.5 and +1.0. This implies a mean value of +0.75.
Work VTTS income elasticity	Income elasticity fixed at +1.0.
VoSL income elasticity	Triangular distribution for income elasticity with peak of +0.55, minimum of +0.4 and maximum of +1.0. This implies a mean value of +0.65.
GHG emissions	Grows as a proportion of per capita GDP with a normal distribution of mean +0.8 and a standard deviation of 0.1.
Other income elasticities	Uniform distribution for income elasticity between +0.5 and +1.0. This implies a mean value of +0.75.
Incomes	Real GDP per capita, normally distributed with mean of 1.5% and standard deviation of 0.25%.
Fuel prices	Low, medium and high oil price scenarios considered, based on MED forecasts with a (continuous) uniform probability distribution assigned across the three scenarios.
Fuel efficiency	Vehicle fuel-efficiency improvements were assumed at a linear rate. A triangular distribution for this rate of improvement with a minimum of 0, maximum of +0.01, and most likely value of +0.0085. This implies a mean linear rate of improvement of 0.62%.
Costs	Not indexed, on the assumption that cost estimates already factor in real-price changes.

6 Modelling results

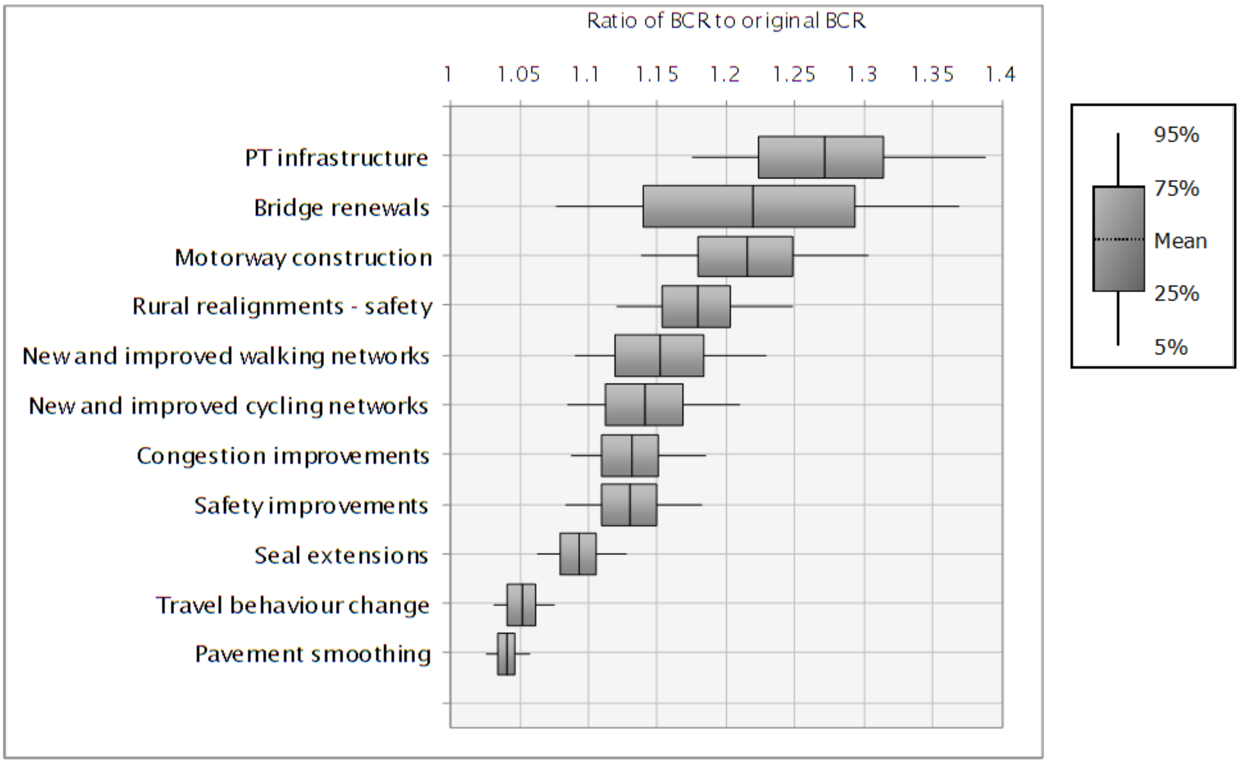
The results of the sensitivity analysis showed that time indexing materially affected the BCRs of most projects, and would materially affect project rankings and thus would contribute to more economically efficient investment decisions.

The key results are outlined in section 6.1, with detailed analysis for each project category and each class of benefit in appendix D and appendix E respectively. Section 6.2 outlines how the results changed under different scenarios for the discount rate and for VOC. The actual data values that underpin each boxplot in this chapter are provided in appendix F.

6.1 Effect on BCRs by category of project

Figure 6.1 shows the range of BCR increases expected for each project category using a 'box and whisker plot'. The 'whisker' at the upper end represents the 95th percentile, where 'percentile' means the value of a variable below which a certain percent of observations fall; the width of each box presents the 25th and 50th percentiles (from left to right respectively), and the vertical line in each box represents the mean increase; and the bottom whisker represents the 5th percentile.

Figure 6.1 Proportional increase in BCRs



The input variables driving these changes to BCRs are documented in appendix D. Generally we found the major drivers behind the increase in BCRs were the rates of income growth and the income elasticities for non-work travel time savings and the VoSL. The income elasticities for walking and cycling benefits were also relatively significant for those projects. Oil price assumptions are particularly influential for some project types, but because transport behavioural responses to high oil prices were not considered in this study, the results represented only a partial story about oil price effects on BCRs.

Our findings were as follows:

- The public transport infrastructure project category had the greatest proportional impact from time indexing, and this was primarily attributed to the very high levels of growth in conventional benefits for the sample project available. (Only one project was obtained for this project type, and it may not have been representative. Unfortunately no public transport operations CBAs were available to include in the model.)
- Bridge renewals increased significantly with high variability, and this was driven by the range of higher oil price scenarios applied. This category of project significantly saved on VOC.
- The BCRs of motorway projects increased more than other project categories because the underlying rate of benefit growth was more sustained over the appraisal periods than for other project categories.
- Rural realignments also increased relatively significantly, for a range of reasons:
  - being rural, they had a higher proportion of work-based travel, and so travel time savings were indexed one-to-one with income growth rates
  - the substantial proportion of benefits occurred later in the appraisal period, which was proportionally more favoured by time indexing (note that only two projects in this category were obtained, and so the data may not have been very representative).
- Walking and cycling projects had material increases, but relatively less than other project types. This was driven by the non-market basis of the benefits, and thus income elasticities less than +1.0 (whereas other project categories had a proportion of travel time savings that were work-based that increased at the same rate of income growth).
- The BCRs for congestion improvement and safety improvement projects increased, but relatively modestly. This was attributed to the time profile of benefits assumed for these projects, where benefits were lower or did not grow as much as other project categories, and therefore they did not ‘capitalise’ on the cumulative effects of time indexing.
- The BCRs for seal extension and pavement-smoothing projects were not materially affected by time indexing. Such projects are motivated by maintenance cost savings and reduced wear and tear on vehicles, neither of which were assumed in this study to have real changes in their unit valuation. It was assumed that the road maintenance cost savings already account for expected real-price changes net of productivity improvements, and ongoing productivity improvements could potentially even reduce the real cost of maintaining a vehicle from wear and tear.[15]
- TBC projects were not materially affected by time indexing because such projects are relatively short-term in nature. Benefits were not expected to continue after 10 years and thus the compounding effects of growing values of benefits did not accrue.
- Preventative maintenance projects, for which the model had much data, did not have any effects from time indexing because it was assumed that all maintenance and operating cost estimates already included provisions for real-price changes and productivity improvements.

Table 6.1 lists the absolute and proportional increases in net present value (NPV) arising from time indexing, by project category.

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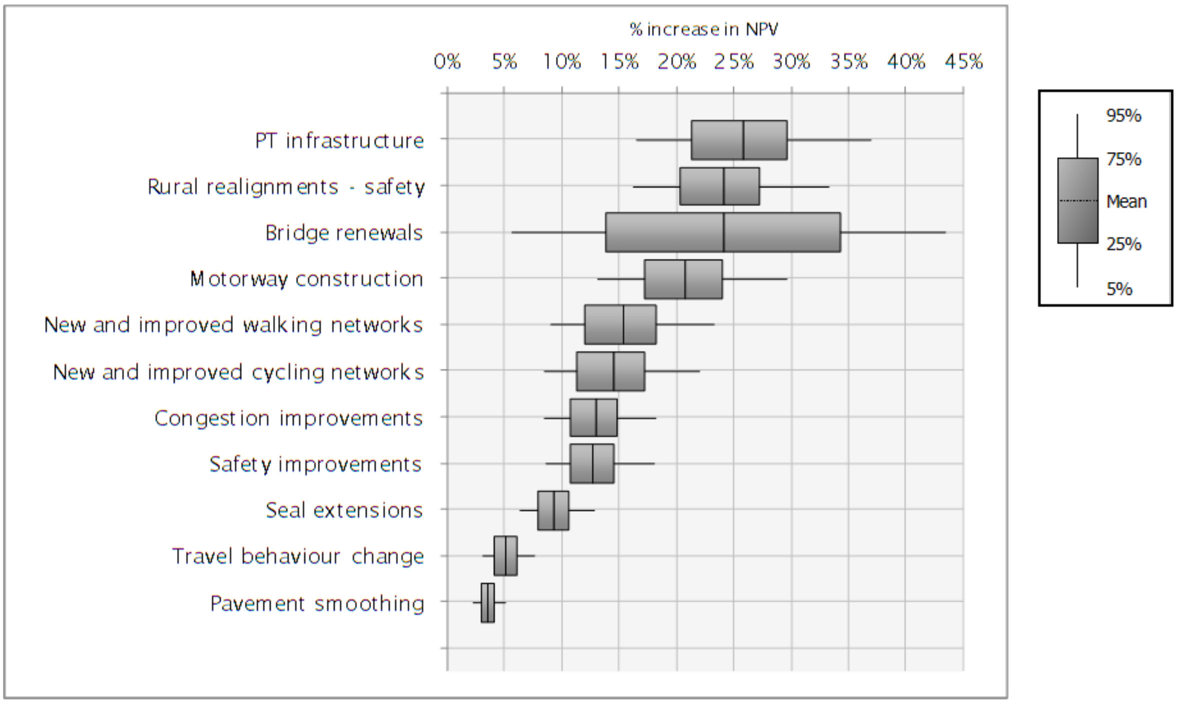
15 If these assumptions are deemed to be unrealistic, then further analysis could be undertaken in future.

Table 6.1 NPV increase for all project categories

Project category	NPV (original)	NPV increase	% increase
PT infrastructure	$16,490,000	$4,226,000	25.6%
Rural realignments – safety	$36,035,000	$8,633,000	24.0%
Bridge renewals	$23,965,000	$5,675,000	23.7%
Motorway construction	$1,732,136,000	$357,582,000	20.6%
New and improved walking networks	$4,333,000	$665,000	15.3%
New and improved cycling networks	$7,515,000	$1,090,000	14.5%
Congestion improvements	$3,973,000	$509,000	12.8%
Safety improvements	$3,757,000	$477,000	12.7%
Seal extensions	$948,000	$89,000	9.4%
TBC	$2,090,000	$109,000	5.2%
Pavement smoothing	$1,628,000	$60,000	3.7%

Figure 6.2 demonstrates the spread of potential proportional increases in NPV, by project category. Although similar to the corresponding figures for BCR increases, there were some subtle differences, such as rural realignment safety projects increasing in NPV by 24% on average, but the BCRs increased by 18%.

Figure 6.2 Percentage increase in NPV



6.2 Materiality of time indexing in other scenarios

Would combining time indexation with a lower social discount lead to blow-outs in the BCRs for projects? If BCRs were to increase massively from the combined effect, then policy makers would be apprehensive about having a requirement for time indexation.

Sections 6.2.1 and 6.2.2 consider the effects of combining time indexation with different discount rates (4% and 10%) to account for the range of discount rates that have been used in practice. Section 6.2.3 demonstrates the low influence that VOC have on BCRs for most projects (for given transport behaviours).

6.2.1 Effects of time indexing if a 4% discount rate was used

The NZTA currently uses an 8% (real) discount rate and allows projects to be sensitivity tested using values of 4% and 6% (real) for 'evaluations of activities that have long-term future benefits that cannot be adequately captured with the standard discount rate'. The effect of low discount rates combined with time indexing could make some analysts apprehensive about whether this could lead to BCRs that seem implausibly high (or at least increase outside their frame of reference).

Figure 6.3 shows the proportional increase in BCRs from time indexing when a 4% discount rate is used in the time-index and no-time-index scenarios (and if the appraisal periods are unchanged). Contrary to expectations, combining time indexation with low discount rates did not lead to a step-change in proportional increases to BCRs. Of course, the standard BCRs would all be higher at a 4% discount rate, and so the absolute increase in net benefits would be substantially increased, as is shown in tables 6.2 and 6.3.

Figure 6.3 Proportional increase in BCRs at a 4% real discount rate (max 30-year appraisal period)

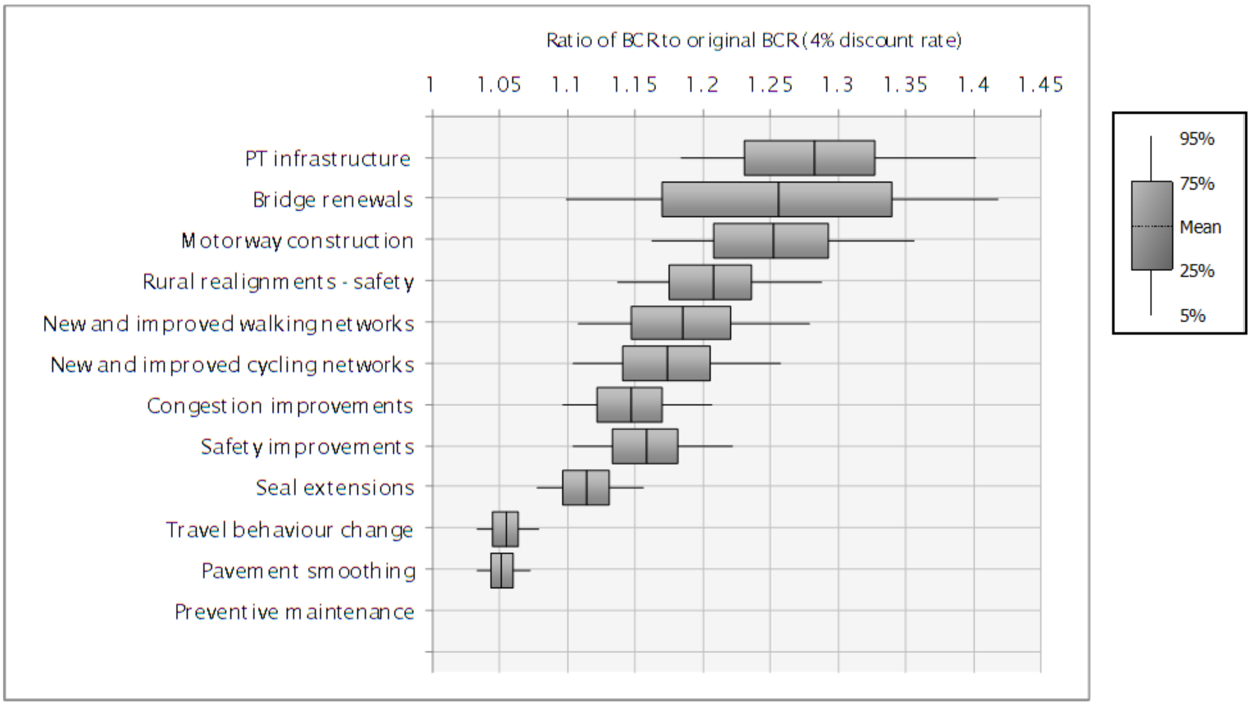


Table 6.2 lists the absolute and proportional increases in NPV arising from time indexing when a 4% discount rate is used, by project category.

Table 6.2 NPV increase for all project categories at a 4% real discount rate (max 30-year appraisal period)

Project category	NPV (original)	NPV increase	% increase
PT infrastructure	$35,011,000	$9,832,000	28.1%
Rural realignments – safety	$72,791,000	$19,617,000	26.9%
Bridge renewals	$38,856,000	$10,797,000	27.8%
Motorway construction	$3,142,158,000	$770,302,000	24.5%
New and improved walking networks	$7,386,000	$1,376,000	18.6%
New and improved cycling networks	$12,499,000	$2,219,000	17.8%
Congestion improvements	$5,963,000	$930,000	15.6%
Safety improvements	$5,933,000	$924,000	15.6%
Seal extensions	$1,558,000	$179,000	11.5%
TBC	$2,534,000	$139,000	5.5%
Pavement smoothing	$2,650,000	$120,000	4.5%

The sizes of the NPV increases by project category at a 4% discount rate were substantially greater than those that could occur at the current 8%. For motorway projects the increase in NPV from time indexing at a 4% discount rate was 115% greater than that at an 8% discount rate ($770 million versus $358 million); table 6.3 lists these for each project category.

Table 6.3 NPV increase for all project categories at a 4% real discount rate (max 30-year appraisal period)

Project category	% larger increase in NPV: 4% discount rate compared with 8% discount rate
PT infrastructure	133%
Rural realignments – safety	90%
Bridge renewals	127%
Motorway construction	115%
New and improved walking networks	107%
New and improved cycling networks	104%
Congestion improvements	83%
Safety improvements	94%
Seal extensions	101%
TBC	28%
Pavement smoothing	101%

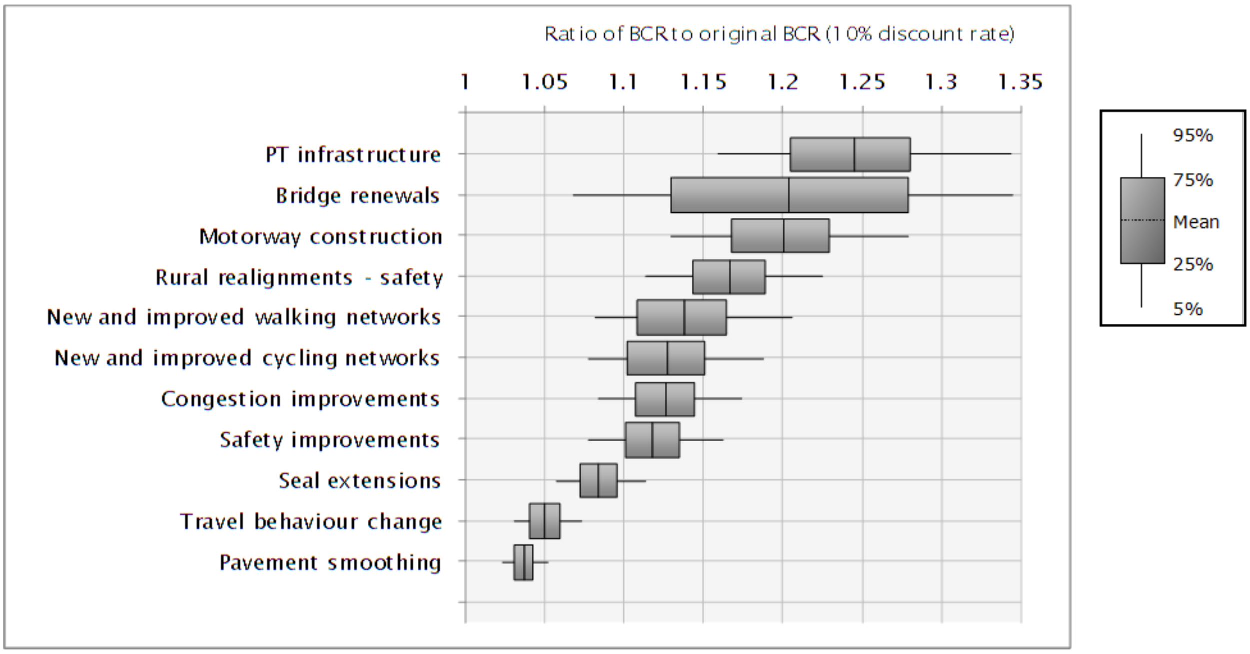
These results showed that although the effect of time indexing on BCRs was not substantially affected by the discount rate used, the effect time indexing had on NPVs was affected by the discount rate used.

6.2.2 Effects of time indexing if a 10% discount rate was used

Section 3.1.1 described that the effects of time indexing was judged to be immaterial due to the effects of discounting. This view was established when the discount rate was 10% p.a. (real).

A 10% discount rate was applied to the model to test this proposition. (The 30-year appraisal period was retained, rather than the previously standard 25-year appraisal period). Figure 6.4 shows the results, whereby the mean increases in BCRs were slightly less than the baseline 8% discount rate scenario. The ranking of project categories was unchanged from the 8% discount rate scenario (based on mean increases).

Figure 6.4 Proportional increase in BCRs at a 10% real discount rate (max 30-year appraisal period)

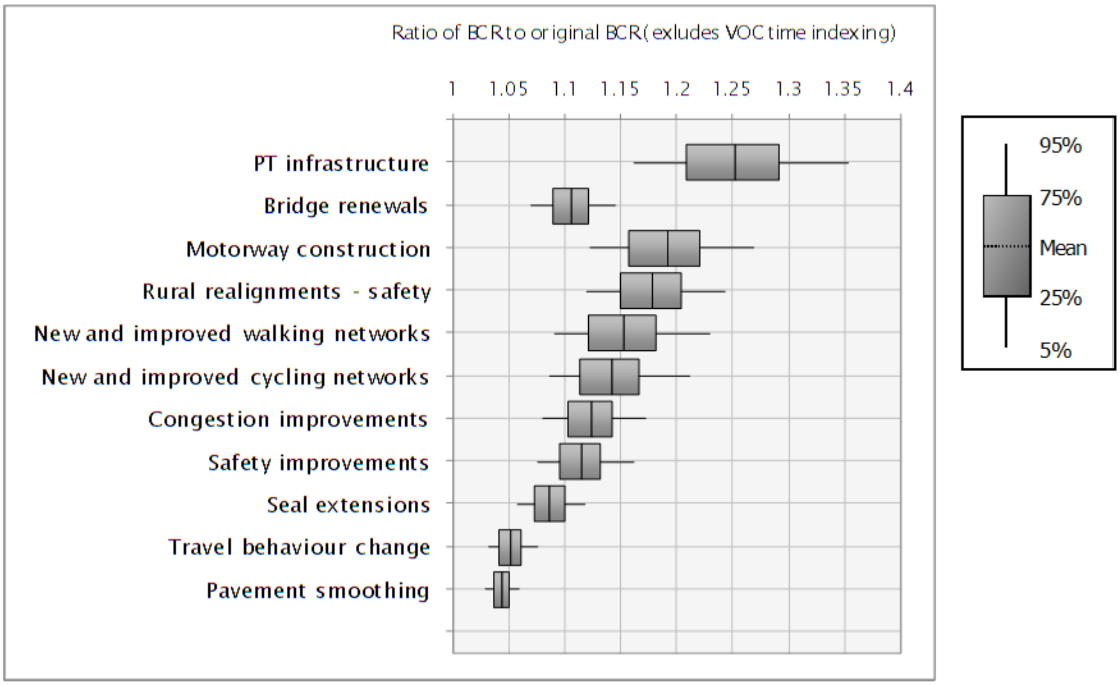


Just as a substantially lower discount rate did not lead to markedly higher BCR increases from time indexing, a higher (10%) discount rate did not affect the materiality of time indexing unit cost parameters.

6.2.3 Overall role of oil prices and vehicle efficiency changes

The tornado plots in appendix D indicate that, based on current forecasts, including real changes in oil prices and vehicle efficiency improvements does not materially affect BCRs, except for bridge renewal projects. Figure 6.5 describes the effect on BCRs if VOC are not time indexed. The result was that with the exception of bridge renewals, all project categories were broadly unchanged from section 6.1.

Figure 6.5 Proportional increase in BCRs when VOC was not time-indexed (sensitivity assessment)



The CBAs of bridge renewal projects were particularly affected by the time indexing of VOC because it was assumed in the appraisals that vehicles would otherwise need to divert for considerable distances. The other project categories were not materially affected because they generally did not provide energy-savings benefits.

These results did not indicate that CBAs on the whole were insensitive to changing VOC over a project's life. Rather, it indicated that the focus should be on guiding and complementing the assumptions used in transport demand analyses and modelling, from changing energy prices and energy efficiency improvements. This should focus on ensuring that appraisals are *internally consistent* (ensuring the assumptions relating to the modelling of behaviour are consistent with those relating to valuing benefits) and *externally consistent* (so that CBAs of different projects are comparable).

7 Conclusions

- *Time indexing unit cost parameters is material*: This study found that time indexing materially increases the BCRs of the majority of project categories, but not all. Thus time indexing unit cost parameters can materially affect investment decisions and thus the value for money from transport investment.

  The growth rate of benefits over project appraisal periods was a key determinant of how much BCRs increased by project category. The BCRs of public transport infrastructure, bridge renewals, motorways, rural realignments and walking and cycling projects increased significantly. Maintenance and road-quality projects were the least affected by time indexing unit cost parameters because they are motivated by maintenance cost savings and reduced wear and tear on vehicles – neither of which was assumed in this study to have real changes in their unit valuation.

  The discount rate used did not have a large effect on these findings for BCR increases (holding appraisal periods fixed at 30 years and with no allowance for ‘residual values’). This was contrary to our interpretation of the explanation offered in the NZTA’s EEM (2010, section 3.1.1), that the effect of discounting makes time indexing immaterial.

- *Time indexing unit cost parameters is feasible*: The study also found that time indexing unit cost parameters in transport CBA is feasible. The most influential assumption was the growth rate in incomes, most likely to be real GDP per capita, and long-term forecasts are readily available. The income elasticities for each benefit category can be developed at the time that new willingness-to-pay surveys are undertaken, and the literature can assist in the meantime.

  Although changes to the cost of fuel and other factors affecting VOC were thought likely to significantly affect CBAs, this study found that this should be centred on the modelled transport behaviour, and not on the valuation of benefits from given transport behaviours. It is important, however, that the assumptions about increasing unit costs to VOC savings are consistent with the assumptions used by analysts to model transport demand, and are consistent across projects.

- *Income elasticities should be developed and applied even if time indexing is not adopted*: The study also identified that income elasticities have a role in the annual updating of non-market unit cost parameters, such as the value of a statistical life and non-work travel time savings. Currently, income elasticities of +1.0 are implicitly applied, as the price indices are translated directly into increases in the unit cost parameters, but it is most likely that a value less than one is appropriate for non-market benefits. This means that the actual willingness to pay for some classes of benefits may, in actuality, be increasing at a slower rate than assumed.

8 Recommendations

It is recommended that the NZTA:

- requires time indexing of unit cost parameters to occur in transport CBAs and provides guidance on the assumptions to use
- applies reasonably conservative values for income elasticities, perhaps at the lower end of the range of plausible values informed by overseas studies, until each can be updated by the results from willingness-to-pay surveys as they occur over time
- time indexes VOC benefits, with the focus on guiding and complementing the assumptions used in transport demand analyses and modelling
- applies income elasticities when annually updating the benefit values (ie when developing the update factors issued in section A12 of the NZTA's *Economic evaluation manual*, volume 1 (2010)).

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Appendix A Literature review of income elasticities

Economic theory and empirical evidence suggests that one should not necessarily assume that the willingness to pay for non-market benefits increases at the same rate of real income growth. Non-market valuation studies that compare the willingness to pay with the levels of participants' incomes tend to show that there is not a one-to-one relationship. These issues can be empirically estimated by repeating studies over time, from cross-sectional analysis within a study, and from comparing different studies of similar effects (meta-analysis) (for instance Mackie et al 2001b).

It is important to account for systematic deviations between the rate of change in unit cost parameters and in income growth for the following two reasons:

1. Future real changes to unit valuations are usually determined via assumptions relating to real income growth.
2. Inaccuracies in the rate of growth of unit cost parameters will compound over time, and may materially bias the results of project appraisals, which risks lowering the quality of investment decisions.

This section considers the concept of income elasticities of willingness to pay, and the empirical estimations of income elasticities for a variety of non-market measures.

A.1 Income elasticities of willingness to pay

Income elasticities of willingness to pay are a different concept from income elasticities of demand. The former relates to the degree to which the inverse demand schedule shifts when income is increased (the increase in willingness to pay for good *i* from a $1 increase in income). The latter relates to how the quantity demanded adjusts to income changes (Flores and Carson 1997, p289). Algebraically the income elasticity of willingness to pay of good *i* can be expressed as

$$\frac{\partial WTP_i}{\partial y}\frac{y}{WTP_i}. \qquad \text{(Equation A.1)}$$

The concept of income elasticities of demand can be used to define luxury, normal/necessity and inferior goods by whether the income elasticities are respectively greater than one, between zero and one, or are less than zero.[16] Flores and Carson (ibid) use theoretical modelling in a world of multiple public (non-market) goods to clarify that although the two concepts of income elasticities of willingness to pay and of demand are related, they can be very different depending on other factors that are generally unobservable. For instance, they provide examples of demand luxury goods that have income elasticities of willingness to pay that are less than one (ie are necessities), and demand necessity goods can have income elasticities of willingness to pay that are actually negative. These strong results come about when there are two or more public goods that are sufficiently complementary or substitutable for each other.

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[16] www.economist.com/economics-a-to-z

The generally unobservable ‘other factors’ that Flores and Carson (ibid) describe that can drive a non-trivial wedge between the income elasticities of demands and ‘virtual prices’ may come from any one or combination of:

- the compensated cross-price substitution elasticities of demand between public goods
- the demand income elasticities of all other public goods
- the budget share of market goods relative to total virtual expenditure (which includes the ‘virtual prices’ of public goods times the quantity consumed)
- possible expenditure adjustment factors needed to account for ‘income effects’ when the marginal effect of income on utility is not constant over the policy scenarios.

What this means is that the willingness-to-pay income elasticities for each non-market unit cost parameter used in CBAs need to be estimated on a case-by-case basis.

A.2 Non-market value of travel time savings (non-work VTTS)

ATC (2006, p51) advises that income elasticities of unit cost parameters less than one be applied to non-market benefits because as incomes rise (all else being equal), people are likely to substitute additional leisure for some of the additional income. Mackie et al (2001a) describes this as the income effect being stronger, on average, than the substitution effect. With people taking more leisure time, the marginal utility, and therefore value, is lower than otherwise.

Mackie et al (2001b) note that the value of travel time is the ratio of the marginal utility of time, which is composed of effects attributable to the opportunity cost and to the disutility of time spent travelling, and the marginal utility of money. Variations in either of these can lead to variations in the value of time over time. Mackie et al (ibid) note that there is no reason, from a theoretical standpoint, for the value of time to grow directly in line with income with no consideration given to possible changes in the value of time for other reasons ‘since it is a matter of personal preference how an individual allocates additional income to time savings’. Mackie et al argue that the case for a close link between the value of time and income can hardly be questioned for business travel.

Empirical research indicates that the income elasticity of non-work VTTS is in the range of 0.5–1.

Hensher and Goodwin (2003) note that the empirical studies suggest that the willingness to pay has increased over time, but less than proportionately – somewhere between one-quarter and three-quarters of the rate of income increase.

Mackie et al (2003) investigate the income elasticities of VTTS for non-working time using a variety of sources (eg Wardman 2001). The estimated GDP per head elasticities and 95% confidence intervals were +0.72 (+/- 43%) for all data and +0.82 (+/- 40%) for in-vehicle time data. They also note that average trip distances are increasing by 2.2 per cent per annum and this too affects the VTTS. The effect of increases in trip length over time adds a small amount (+0.03 to +0.08) to the above elasticities. However, the proportion of this journey-length effect that is due to GDP growth as opposed to other trends, such as the falling real cost of motoring, is not clear. Any chosen intertemporal elasticity is likely to be a mixture of a 'pure' income effect and other trends over time, which cannot easily be separated.

Mackie et al (ibid) conclude that the evidence as a whole tends to support an intertemporal elasticity for non-working time somewhere in the range 0.5–1. Based on their recommendation, the UK DfT uses a value of 0.8.

A.3 The value of a statistical life (VoSL)

Empirical research indicates a clear positive relationship between income and the VoSL; however, it is not a one-to-one relationship. Every 1% increase in wealth generally corresponds to about 0.5–0.6% increase in the VoSL.

The US Department of Transport (2005) adopts a value of income elasticity for the VoSL of 0.55, as supported by Viscusi and Aldy (2003), whose meta-analysis of over 60 studies of mortality indicated an income elasticity of VoSL from about 0.5–0.6.

Miller (2000) undertook a meta-analysis of international studies and found an income elasticity between 0.92 and 1.00. However, he notes the following:

> *Viscusi and Evans (1990) suggest that United States values vary roughly linearly with income. Persson et al (1995) estimate that Swedish values vary less sharply, with an income elasticity between 0.37 and 0.46. Jones-Lee et al (1987) estimate the income elasticity in the United Kingdom is between 0.3 and 0.6.*

From this Miller suggests that:

> *Perhaps the income elasticity between countries is larger than within countries. Essentially, rich countries might have higher expectations about the quality of life and its value. Those expectations would shape the VSLs of both the rich and the poor. Except for the wealth-elite, this hypothesis recognises that above-average income does not free individuals from constraints imposed by commonly shared infrastructure and services.*

Bellavance et al (2007) summarise several meta-analyses on the VoSL that are popular in the literature and are, to their knowledge, the only studies published in a scientific journal. Table 8.1 below summarises this, and highlights that there is a statistically significant positive relation between incomes and estimations of the VoSL. Bellavance et al (ibid) observe that the income elasticity obtained by these different meta-analyses is always equal to or lower than 1, except for the Bowland and Beghin study (2001).

Table A.1 Summary and results of meta-analyses (adaption of table 3 of Bellavance et al 2007)

Literature	Income elasticity	Statistically significant
Liu et al (1997)	+0.53	NO
Miller (2000)	+0.85 to +1.00	YES
Bowland and Beghin (2001)	+1.7 to +2.3	YES
Mrozek and Taylor (2002)	+0.46 to +0.49	YES
Viscusi and Aldy (2003)	+0.46 to +0.60	YES
de Blaeij et al (2003)	+0.5	YES

The VoSL used by the NZTA was established in 1991, based on the work of Miller and Guria (1991), and this has since been updated, effectively using an income elasticity of 1.0 (compounding for 20 years). This reinforces the need to update the VoSL using a fresh willingness-to-pay survey (eg refer to NZIER 2010). Such an exercise could provide a good opportunity to empirically estimate a New Zealand-specific income elasticity of the VoSL for base year updating, and for time indexing safety unit cost parameters over a project's appraisal period.

Appendix B The NZTA's method for update factors for common base year

The NZTA's unit cost parameters in the EEM are updated annually so that dollar values are expressed in today's dollars (described as 'the base date' in the EEM (2010), page 2-13 of volume 1). Table B.1 below describes the basis for the NZTA's annual cost and benefit update factors in appendix A12 of volume 1 of the EEM.

The update factors are based on Statistics NZ indices. Some update factors use various proportions of different indices, and these proportions are listed in the table below as 'weights'. Changes in these composite indices are passed one-to-one onto the unit cost parameters.

Table B.1 NZTA basis for updating unit cost parameters retrospectively (NZTA pers comm and MoT (2009)[17]

Variable	Indices/measures		Weights
Construction and maintenance	Producers price index: construction	PPIQ.SNE	100%
VTTS; comfort benefits; driver frustration; PT user benefits; walking and cycling benefits; passing-lane crash savings; TBC	Labour cost index: salary and wage rates (all sectors)	LCIQ.SE53	100%
VOC	Fuel & oil	FPIQ.SI9J	50%
	Transport & storage	PPIQ.SNI	12.5%
	Road transport	PPIQ.SNI01	12.5%
	Labour index	LCIQ.SE53Z9	12.5%
	Non-metallic mineral production	PPIQ.SNC12	12.5%
Accident cost savings[18] (based on the MoT's annual publication *Social cost of road crashes and injuries*)	Avg hourly earnings (ordinary time)	EESQ.SAAZ9A	~89%
	PPI: health and community services	PPIQ.SNO	~3%
	PPI: legal services	PPIQ.SC23	~1%
	CPI: vehicle servicing and repairs	CPIQ.SE907204	~7%

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[17] The weights do change over time, depending on what the benefits are composed of (as with the 2008 VOC rebase, which changed the weights significantly towards fuel and oil) and whether Statistics NZ cease producing some PPI indices that are used by the NZTA, requiring an adjustment.

[18] For fatal crashes, average hourly earnings make up 99% of the weight, but for minor crashes it is 71%. The NZTA weights fatal, serious, and minor crashes equally.

Appendix C Time indexing perceived costs in modelling

C.1 Guidelines for regional transport forecasting in Auckland

Beca (2010), on behalf of the NZTA, developed general guidance for preparing regional-level traffic and travel forecasts for larger-scale infrastructure or land use development projects in Auckland, focusing on use of the regional models on NZTA projects.

Beca (ibid, p4) note that forecasting needs differ between studies, and the appropriate approach should be developed based on the requirements of the particular study. The Auckland Regional Council (ARC) developed a series of forecasts and associated input assumptions for regional policy planning, such as the Regional Growth Strategy (RGS) and Regional Land Transport Strategy (RLTS). On the other hand, the NZTA's subsequent work on the Western Ring Route project involved developing a set of alternative inputs and assumptions for the regional strategic transport model (ART3) that were based on 'a more cautious and conservative approach' to estimating the effect and future of policies and economic influences.

Beca (ibid) recommends that while in future the inputs may converge to a single set as the effect of various policies or economic influences becomes more certain, current forecasts for NZTA projects should be based on both the NZTA and RLTS sets of input assumptions (see table C.1).

Table C.1 NZTA and RLTS 'policy/economic' input assumptions for Auckland transport modelling (Beca 2010)

Input	RLTS	NZTA
Private vehicle operating costs	Significant increases based on predicted fuel price (77% increase in real terms between 2006 and 2026)	Lower growth based on forecast fuel price and estimate of improved fuel efficiency (28% increase in real terms between 2006 and 2026)
Public transport fares	No increase over 2006 base model	Increased in line with private vehicle operating costs (28% increase in real terms between 2006 and 2026)
Integrated ticketing	Assumed faster bus boarding times than 2006 base	No change from 2006 bus boarding times on the basis of integrated ticketing off-setting the effect of increased number of boarders
Integrated fares	Assumed removal of second boarding fare for transferring passengers	Assumed removal of second boarding fare for transferring passengers but with 2c/km increase in all fares to retain same overall revenue and average fare
CBD parking costs	Increase of $1 and an increase of the proportion of people paying full parking cost	Increase of $1 but without any increase in the proportion of people paying full parking cost
Toll and road pricing	None in base case but as agreed for each scenario	None in base case but as agreed for each scenario

Assumptions may vary between the RLTS work and the NZTA's subsequent work in areas relating to land use, transport infrastructure and services, and travel demand management. The broad effects on regional travel from the two sets of input assumptions are summarised in table C.2 following. The two sets of inputs generate quite different growth forecasts, especially for public transport, with the NZTA assumptions projecting less than half the growth in public transport than the ARC does.

Table C.2 Regional effect of alternative input assumptions (2-hour AM peak) (Beca 2010)

Item	2026		Growth 2006 to 2026	
	RLTS	NZTA	RLTS	NZTA
Total PT trips	107,947	73,678	129%	56%
Total private trips	540,978	603,816	18%	32%
Total PT travel (pax-km)	1,289,156	821,191	138%	52%
Total private travel (veh-km)	6,085,814	6,815,621	19%	34%

C.2 Additional Waitemata Harbour Crossing (AWHC)

For the AWHC appraisal, SKM (2010) undertook a similar approach to that of Beca (2010), but extended this further[19] to account for improvements in vehicle efficiency and increases in the VTTS using forecasts of GDP per capita (1.8% per annum[20]) and the income elasticities for work (+1.0) and non-work travel (+0.8) used in the UK. The improvements in vehicle efficiency improvements was based on updated advice SKM obtained from the Ministry of Transport (MoT), based on their Vehicle Fleet Emissions Model (VFEM), which for 2026 was an improvement over 2006 of 13%, and 31% by year 2041. The tables below show the effects of these assumptions on the VTTS and on VOC.

Table C.3 Values of time for modelling only ($/hr) (SKM 2010, p41)

	2006	2026	2041
Home-based work	10.40	13.84	17.14
Employer's business	33.10	47.29	61.80
Other	8.70	11.57	14.34

Table C.4 VOC for modelling only (SKM 2010, p41)

	2006	2026	2041
Fuel price ($/litre)	1.55	2.75	3.71
Vehicle efficiency (litres/100km)	10.0	8.7	6.9

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[19] SKM's 2010 work was peer reviewed and approved by the NZTA.

[20] This figure of 1.8% for real GDP per capita growth rate is materially higher than the figure used in this study, which was about 1.5% per annum compounding.

Appendix D Tornado plots for BCR increases, by project category

D.1 Interpreting the tornado plots

The following plots are outputs of @RISK called 'Regression – mapped values'. These show the proportional increase in BCRs from a one standard deviation change in each input value, all else being equal. The standard deviations for each input resulting from the probability distributions assumed are summarised in table D.1.

Table D.1 Standard deviations for each input variable

Input variable	Standard deviation
Annual growth real GDP per capita	0.0025
Non-work VTTS income elasticity	0.1443
VoSL income elasticity	0.1275
GHG unit cost growth as proportion of per capita GDP	0.1000
All other non-market income elasticities	0.1443
Rate of vehicle efficiency improvement (linear)	0.0022
Oil price scenarios	0.5774

For example, the BCRs for public transport infrastructure projects could be 1.9% greater if the annual GDP per capita growth rate was assumed to be 1.6% rather than 1.5%. This was because this increase in the rate of income growth would constitute 0.4 standard deviations (0.001/0.0025), and multiplied by 0.0482 (see figure D.1 following) equalled 0.01928, or 1.9%. (The tornado plots were directly produced by @RISK, and the percentages were expressed as factors that need to be multiplied by 100.)

Table D.1 represents the standard deviation from the medium oil price scenario; for one standard deviation above the mean this would constitute a 58:42 ratio of the high and medium scenarios respectively.

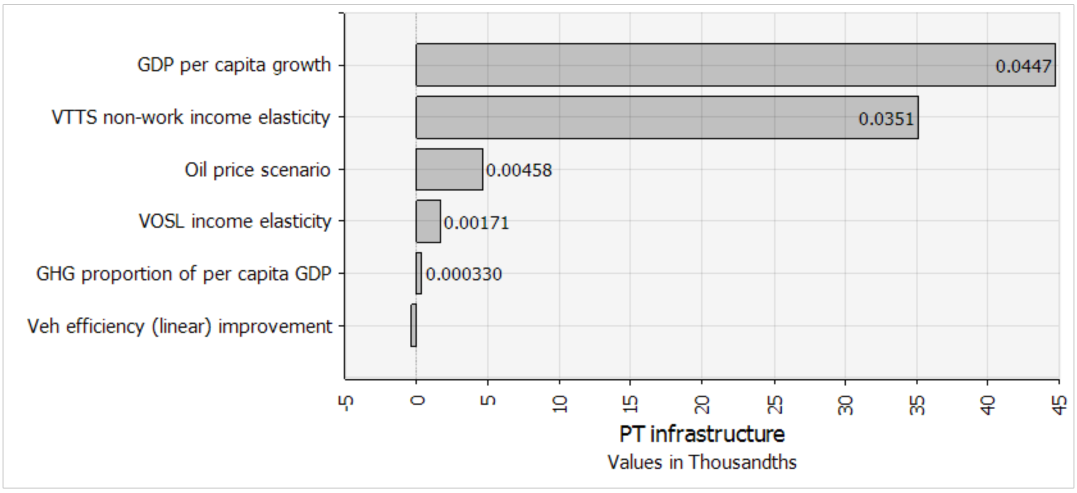
What the tornado plots did not represent well was the absolute importance of each input variable. Some variables may be particularly influential, but have a relatively small level of uncertainty about what value they would have if decision makers decided to implement time indexing. They thus have small standard deviations, and a one standard deviation change would have a relatively small effect on the increase in BCRs. To consider the absolute effect a given change to an input may have, the reader would need to calculate themselves how many standard deviations that change corresponds to and then multiply it by the regression coefficients labelled in the tornado plots.

@RISK also prescreens out input variables that it judges likely to be immaterial to each output (so that simulations are quicker). Thus the tornado plots may exclude some input variables that do contribute to a project's BCRs, and this may not appear consistent with some other results. For example, the bridge renewals tornado plot (see figure D.2) excludes the VOSL income elasticity – even though the breakdown for safety benefits in appendix E describes bridge renewal projects as having safety benefits (see table E.1).

D.2 Public transport infrastructure project

The single public transport infrastructure project for which data was available represented the project category with the greatest mean increase in the BCR as a result of time indexing the unit cost parameters. The primary drivers of the variability of increases to PT infrastructure projects were the assumed income growth rate and the income elasticity for non-work travel time savings; a one standard deviation increase in these inputs increased BCRs by about 4.5% and 3.5% respectively. Refining these two assumptions should be the research priority for decision makers if transport CBAs were to time index unit cost parameters.

Figure D.1 Tornado plot for one public transport infrastructure project

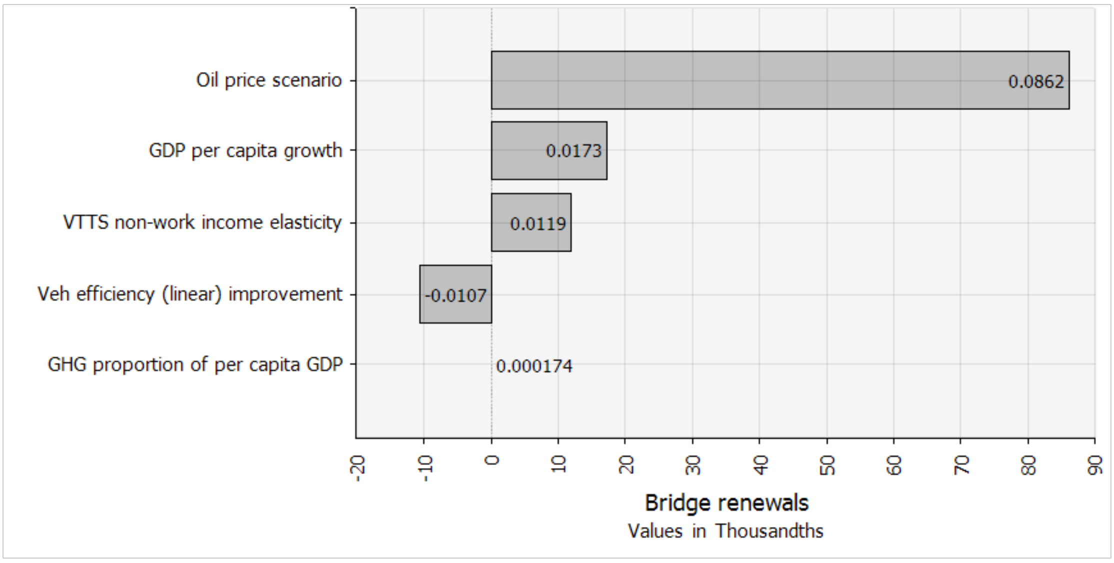


a) The ‘value in thousandths’ on the horizontal axis represents percentage changes to the BCR. They are expressed as factors that need to be multiplied by 100.

D.3 Bridge renewal projects

Oil prices were the key driver of changes to the BCRs of bridge renewal projects.

Figure D.2 Tornado plot for four bridge renewal projects

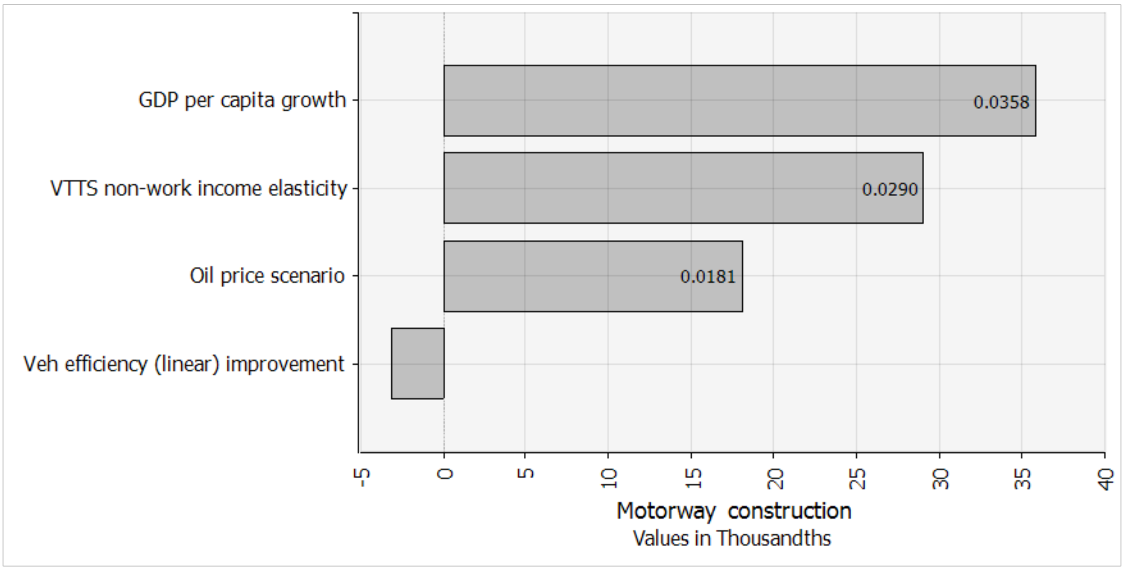


There is, however, a caveat with this analysis, as it relates to oil price assumptions (described in appendix section E.3). This study only partially considered the effects of different assumptions as to future oil prices on economic benefits. Because behavioural responses were not assessed in this study, the net effect of real oil price changes could be much different.

D.4 Motorway construction projects

The key assumptions that influenced motorway project BCRs were the income growth rate and the income elasticity for non-work travel time savings (see figure D.3). Oil prices increased BCRs, but relatively modestly: a one standard deviation increase, which was assumed to be quite a large movement, would only increase BCRs by 1.8%.

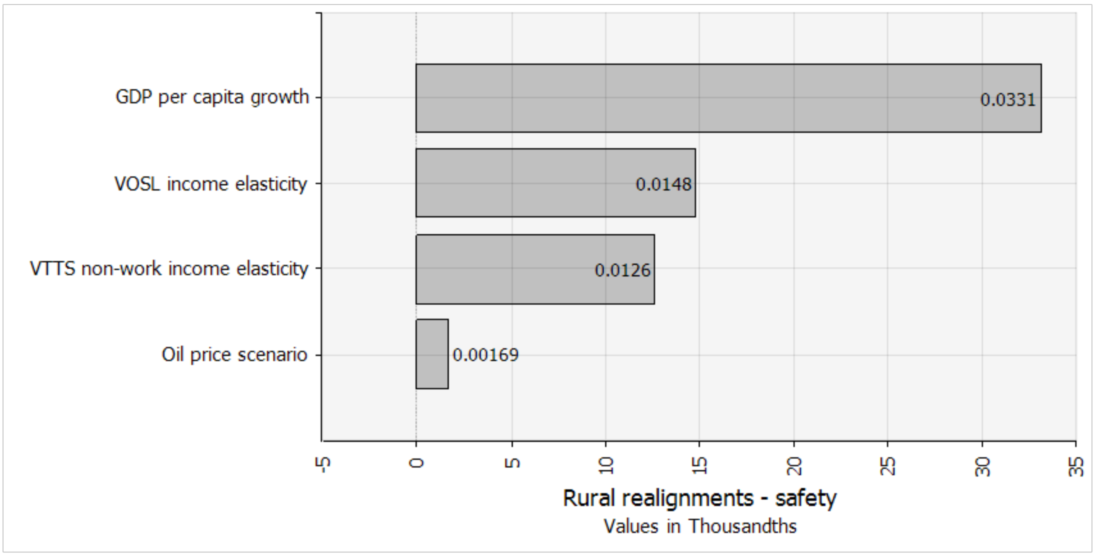
Figure D.3 Tornado plot for two motorway construction projects



D.5 Rural realignments – safety projects

The assumption that most influenced the BCRs of rural realignment safety project was the income growth rate. The assumptions on the income elasticities for the value of a statistical life and for non-work travel time savings were the next most influential, but they were not particularly material. Increasing them individually by 0.1 (eg from +0.7 to +0.8) would increase BCRs by about 1.2% and 0.9% respectively.[21]

Figure D.4 Tornado plot for two rural realignments – safety projects



D.6 New and improved walking networks

As shown earlier in figure 6.1 and in appendix table F.1, the BCRs for new and improved walking network projects would probably increase by between 9% and 23%, with an expected mean increase of 15% – these were material increases arising from time indexing. These potential increases were driven by the relevant income elasticity for walking benefits and for income growth rates. An increase of 0.1 to the income elasticity (0.69 of one standard deviation) would increase BCRs by 2.3% (0.69*0.0326; see figure D.5), which was relatively material given the large range of plausible values assumed for this income elasticity.

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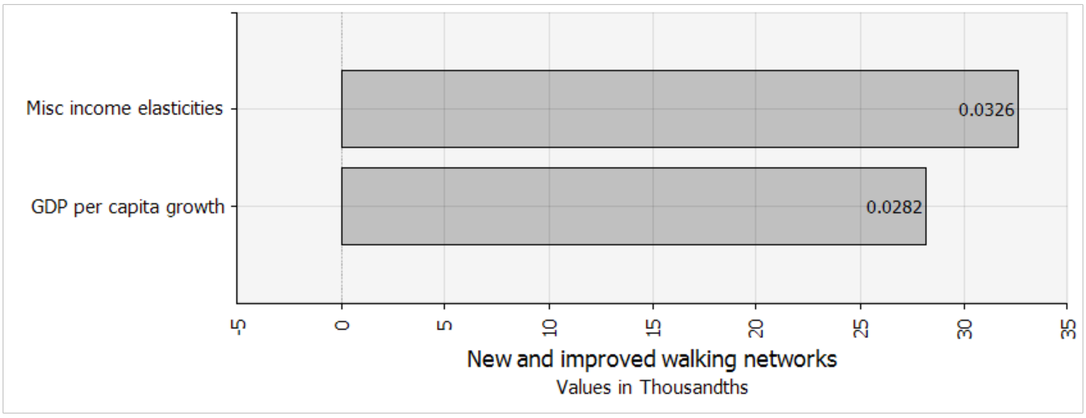
[21] For example, a 0.1 change in the VoSL income elasticity was a 0.7843 standard deviation change (0.1/0.1275). Multiplying by a regression coefficient of 1.48% (from the tornado plot) increased BCRs by approximately 1.2%. For the non-work travel time savings income elasticity, a 0.1 change was 0.7843 standard deviations. Multiplying by 1.26% (from the tornado plot) resulted in about a 0.9% increase in these projects' BCRs.

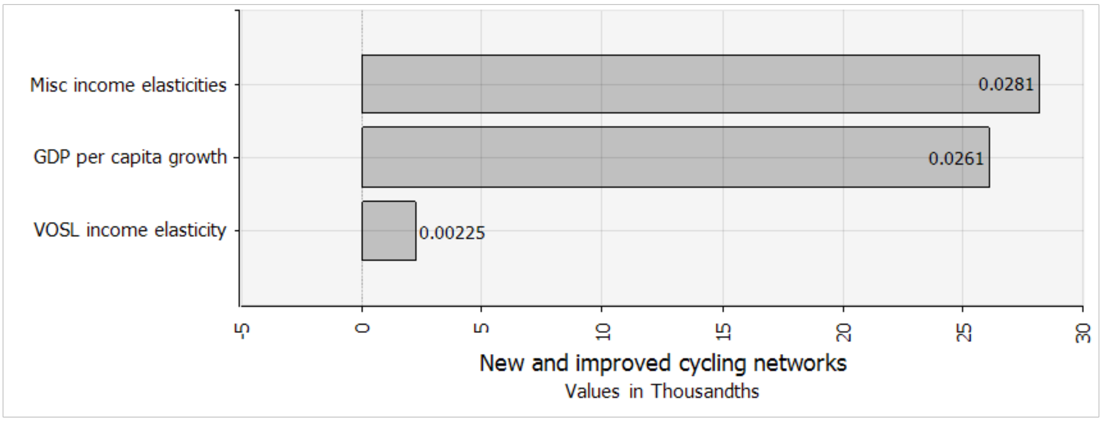
Figure D.5 Tornado plot for five new and improved walking network projects



D.7 New and improved cycling networks

BCRs for cycling projects would increase by nearly 2% for every 0.1 increase in the income elasticity considered (0.69 standard deviations times 0.0281 equals 1.9%) (see figure D.6).

Figure D.6 Tornado plot for 10 new and improved cycling network projects

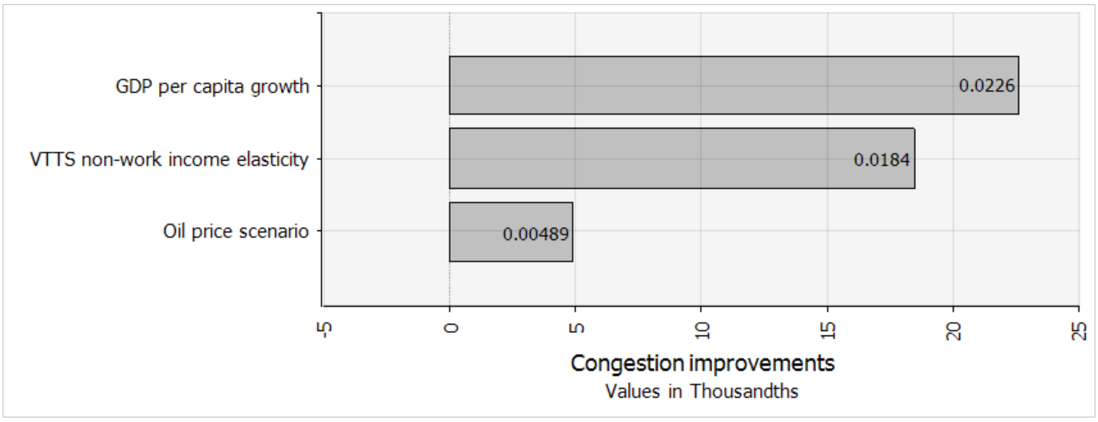


D.8 Congestion improvement projects

The BCRs for congestion improvement projects would probably increase by between 9% and 19%, with an expected mean increase of 13% (see figure 6.1 and appendix table F.1). Compared with some other project categories, these were modest increases arising from time indexing. This could be because the time profile of undiscounted benefits for the sample projects were more predominant in the short-to-medium term and were lower in the longer term (refer to section A12 in Parker (2009)), and so did not gain as much from the cumulative effects of time indexing.

These potential increases were driven by the income elasticity for travel time benefits and for income growth rates (see figure D.7). However relatively large absolute changes to these input variables did not change the proportional increase in BCRs from time indexing by very much. BCRs would increase by only 1.3% from each 0.1 absolute increase in the non-work travel time income elasticity (0.69 standard deviations x 0.0184 equals 1.3%).

Figure D.7 Tornado plot for two congestion-improvement projects

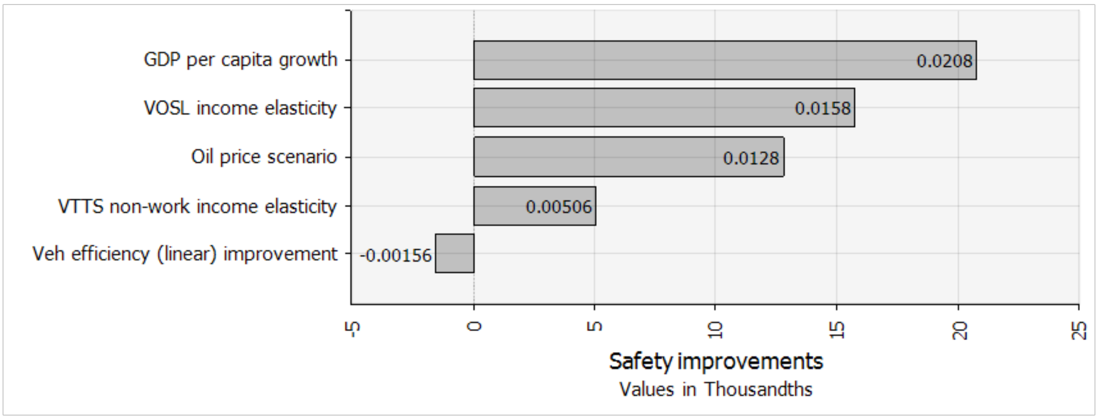


D.9 Safety improvement projects

Figure 6.1 and appendix table F.1 show that the BCRs for safety improvement projects would probably increase by between 9% and 18%, with an expected mean increase of 13%. As with congestion-improvement projects, this was somewhat modest, but was probably caused by the very modest rate of benefit growth over appraisal periods (refer to section A7 in Parker (2009)). Thus these projects would not capitalise on the cumulative effects of time indexing in the same way that other project categories might. Data for nine projects in this category were obtained, and so were probably representative.

Assumptions relating to income growth, VoSL income elasticity and oil prices were the main variables driving these modest increases (figure D.8).

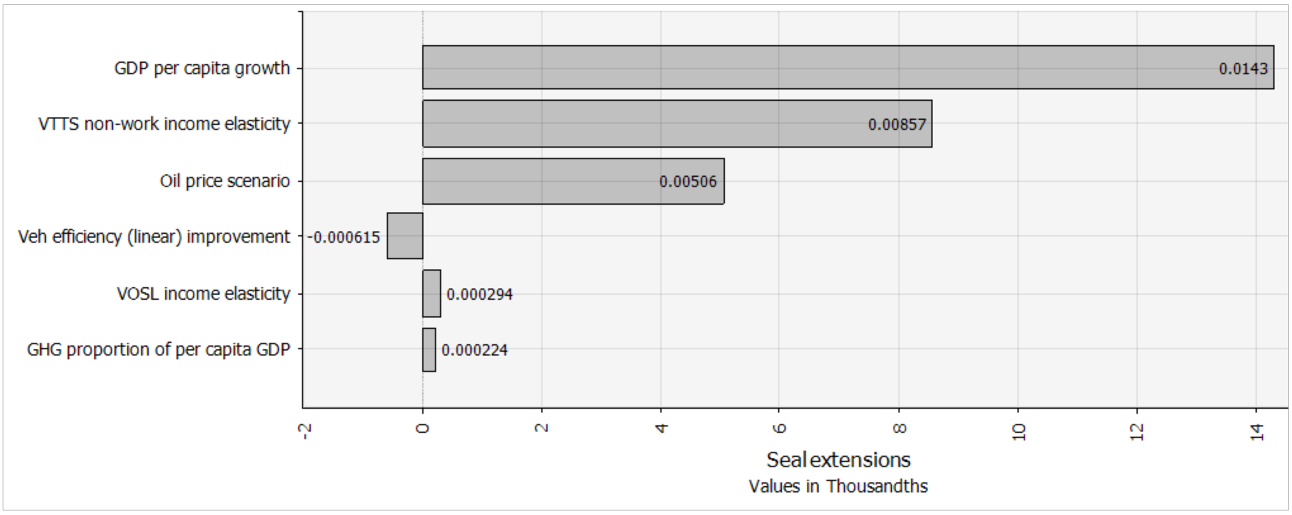
Figure D.8 Tornado plot for nine safety improvement projects



D.10 Seal extension projects

The BCRs for seal extension projects would probably increase by between 6% and 13% (see figure D.9), with an expected mean increase of 9% – relatively immaterial increases arising from time indexing (refer to figure 6.1 and appendix table F.1). The BCRs for these projects did not change much because these projects were motivated by maintenance cost savings and reduced wear and tear on vehicles – neither of which were assumed in this study to have real changes in their unit valuation.

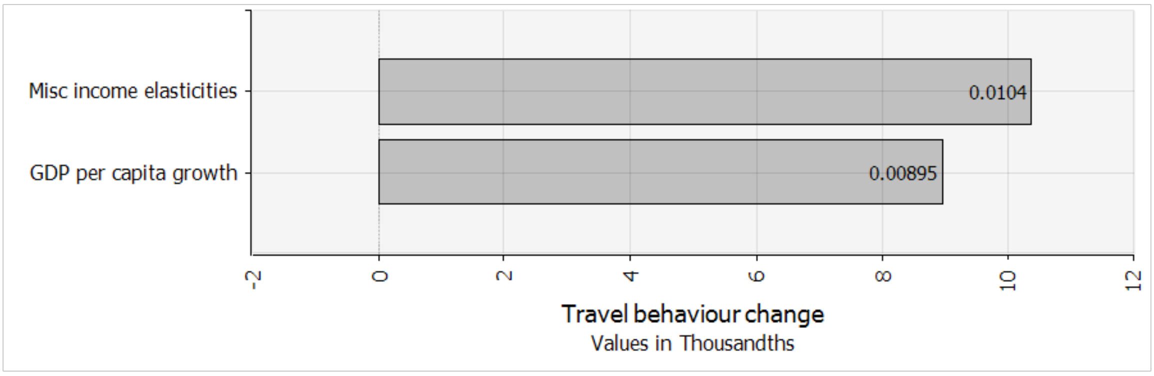
Figure D.9 Tornado plot for 50 seal extension projects



D.11 Travel behaviour change (TBC) projects

These projects were not materially affected by time indexing unit cost parameters. Figure D.10 shows that income and the relevant income elasticity both increased the measured PV benefit, but the effect was very small: a one standard deviation increase in either increased the BCR of these projects by only about 1%. This is because such projects are relatively short-term in nature, with benefits not expected to continue after 10 years. Thus the compounding effects of growing values of benefits over time were not material.

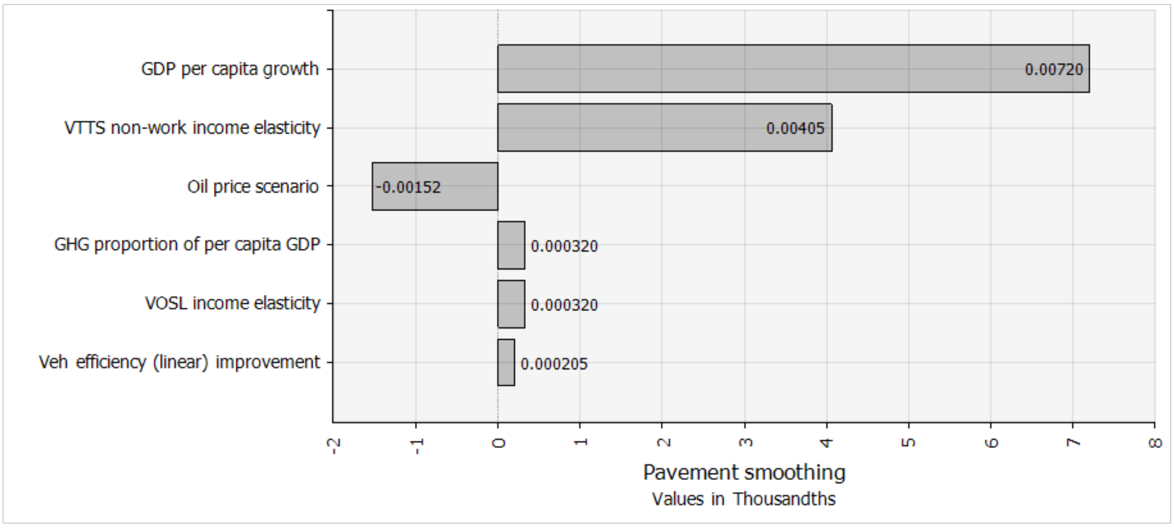
Figure D.10 Tornado plot for eight TBC projects



D.12 Pavement-smoothing projects

Time indexing was immaterial to pavement-smoothing projects: their BCRs would only increase by between 3% and 6%, with a mean increase of 4% (see figure D.11). As with seal extension projects, these projects were motivated by maintenance cost savings and reduced wear and tear on vehicles – neither of which were assumed in this study to have real changes in their unit valuation.

Figure D.11 Tornado plot for 37 pavement-smoothing projects



This was the only project category in the model used in this study where BCRs were negatively affected by higher oil prices. This was because higher vehicle speeds were expected when pavements were smoothed, which raised VOC when speeds were already at 50–60kph in the base case.

Appendix E Tornado plots, by benefit category

This appendix describes how the different classifications of benefits changed in absolute and relative terms, and what drove those changes.

E.1 Safety benefits

Safety benefits did not play a large role across all project categories, and the role that the income elasticity for the value of a statistical life has in the tornado plots in appendix D was immaterial for several project categories. However, for project categories that had a particular focus on improving safety, time indexing materially affected the value given to improved safety outcomes.

Table E.1 shows the absolute and relative increase in PV safety benefits for the relevant project categories. There was about an 11% mean increase in measured safety benefits from time indexing the benefits of safety improvements.

Table E.1 NPV increase of safety benefits

Project category with safety benefits	Safety benefit NPV (original)	Safety benefit NPV increase	% increase
Bridge renewals	$31,000	$3000	9.8%
Pavement smoothing	$35,000	$4000	11.8%
Rural realignments – safety	$8,568,000	$1,044,000	12.2%
Seal extensions	$19,000	$2000	11.6%
Safety improvements	$2,586,000	$279,000	10.8%
New and improved cycling networks	$73,000	$7000	9.8%
Public transport infrastructure	$1,327,000	$130,000	9.8%

Figure E.1 shows the distribution of these increases, with the 75th percentile being about a 13% increase in PV safety benefits.

Figure E.1 Percentage increase in PV of safety benefits

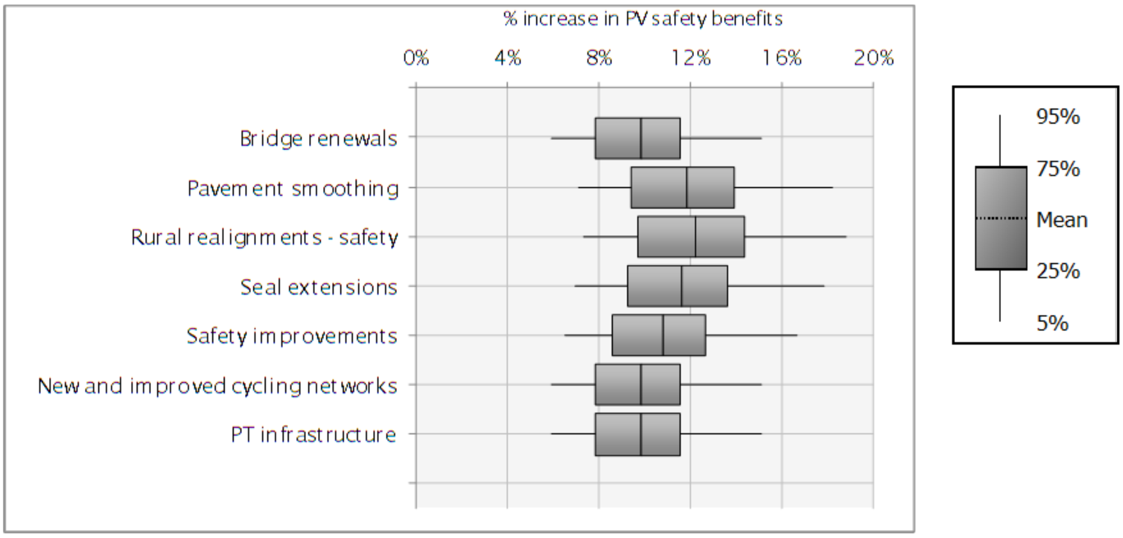
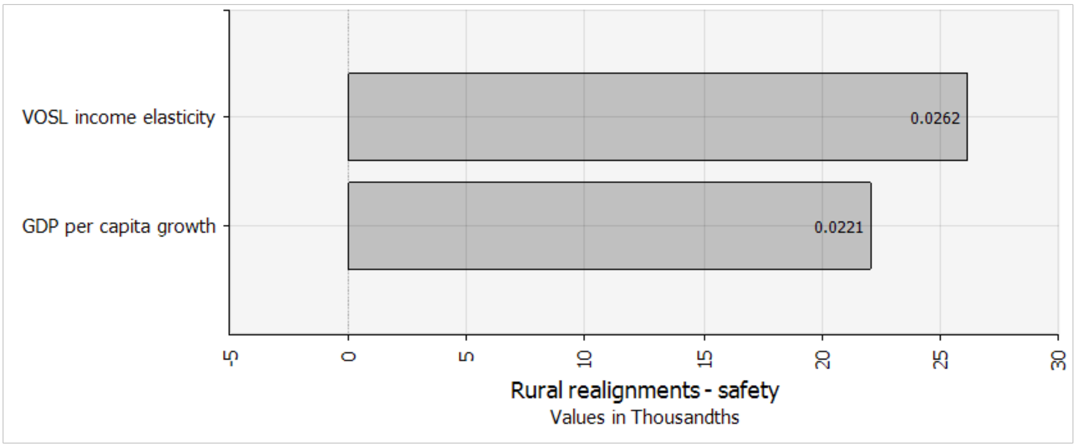


Figure E.2 shows that refining the value of the VoSL income elasticity within the range of plausible values assumed was relatively more important than refining the increase in income. The figure was for rural realignment projects in particular, but the result was similar for the other project categories.

As an example of how to interpret the tornado plot in figure E.2 following, consider that the average GDP per capita growth rate assumed was 1.5%, with a standard deviation of 0.25%. This mean growth rate was 6 standard deviations greater than assuming a zero growth rate, and multiplying by 0.0221 resulted in about a 13% increase in safety benefits, all else being equal. This was close to the 12.2% increase described above.

Figure E.2 Tornado plot for the percentage increase in safety benefits of rural realignment projects



E.2 Travel time benefits

For the modelling undertaken for this study, travel time benefits included seal extension comfort benefits and 'congestion' benefits.

Table E.2 NPV increase of travel time benefits

Project category with travel time benefits	Travel time benefit NPV (original)	Travel time benefit NPV increase	% increase
Rural realignments – safety	$27,074,000	$7,464,000	27.6%
Public transport infrastructure	$14,814,000	$3,986,000	26.9%
Motorway construction	$1,606,224,000	$303,048,000	18.9%
Seal extensions	$487,000	$79,000	16.1%
Pavement smoothing	$350,000	$55,000	15.6%
Bridge renewals	$13,739,000	$2,143,000	15.6%
Safety improvements	$1,003,000	$153,000	15.3%
Congestion improvements	$3,879,000	$481,000	12.4%

Figure E.3 Percentage increase in PV of travel time benefits

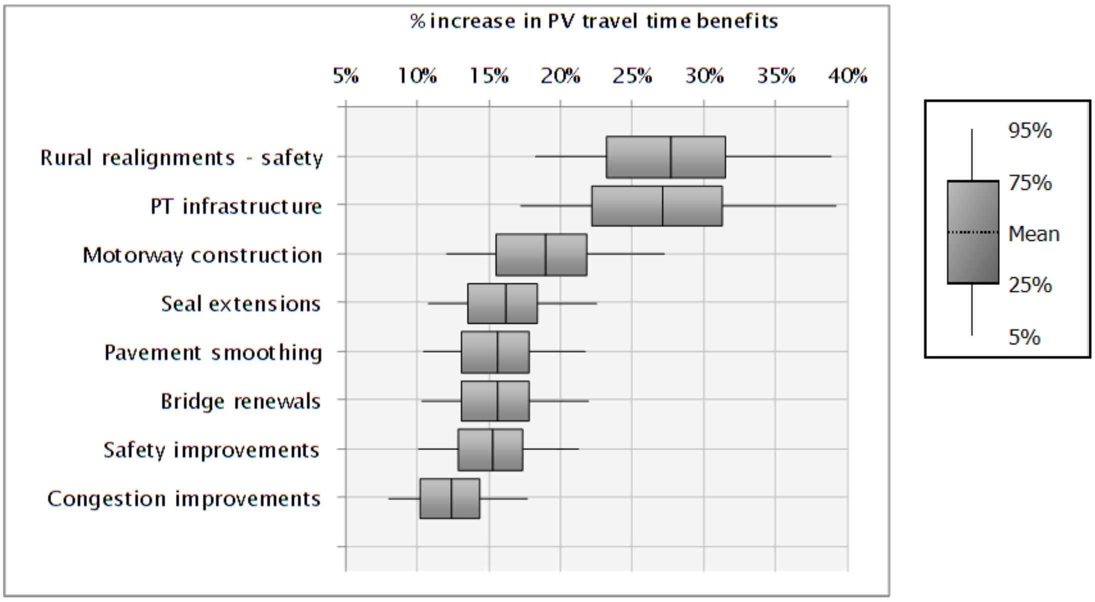
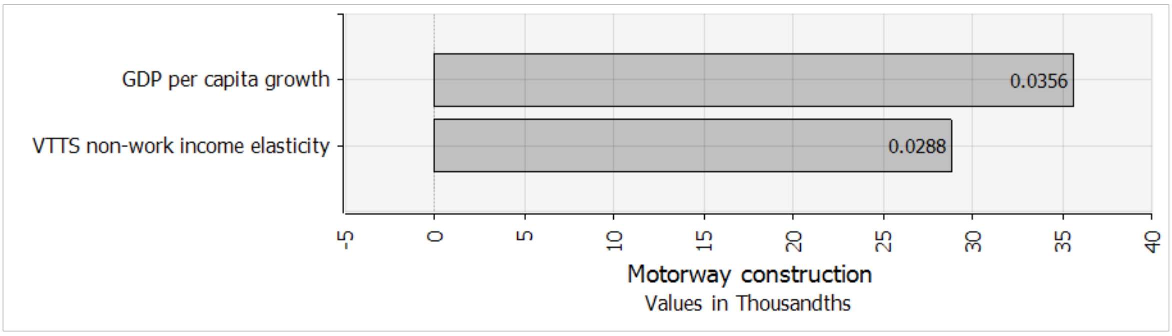


Figure E.4 following shows that refining the value of the income growth rate within the range of plausible values assumed was relatively more important than refining the non-work travel time income elasticity. The figure was for motorway projects in particular, but the qualitative results were the same for the other project categories.

Figure E.4 Tornado plot for the percentage increase in travel time benefits of motorway projects



E.3 Vehicle operating cost benefits

E.3.1 A caveat

We stress that the analysis of the economic effects on VOC benefits from real-price changes to oil and from fuel-efficiency improvements is only a partial assessment of these effects. The main issue with rising fuel prices is that they influence travel behaviour patterns and interact with other systems in society, such as the economy and land use development. This analysis takes the quantities of physical inputs (fuel, lubricating oil, tyres, parts, maintenance labour, capital costs for commercial vehicles) that are given—the result of transport modelling and other processes—and considers only the change in the value ascribed to savings in these inputs.

As projects are generally assumed to not materially affect the demand for transport (i.e. to not induce trip generation), projects generally show VOC improvements and higher values of unit benefits over time will lead to increased present-value benefits. In practice, demand may fall for certain aspects of private motor vehicle travel, and the when this behaviour is modelled this could in theory lead to a net reduction in benefits.

Thus any time indexing of vehicle operating costs in economic appraisals should be included in the assessment of transport demand and behaviours in the first instance; time indexing the value ascribed to benefits is arguably of secondary importance. Only considering the latter will not provide a complete picture of the net economic benefits of transport projects when oil prices are expected to increase in real terms.

E.3.2 Results

The caveats above should guide the interpretation of the following table and plots that show the results of the simulation.

Table E.3 NPV increase of VOC benefits

Project category with VOC benefits	VOC benefit NPV (original)	VOC benefit NPV increase	% increase
Motorway construction	$123,005,000	$53,965,000	43.9%
Congestion improvements	$63,000	$26,000	41.0%
Bridge renewals	$9,940,000	$3,492,000	35.1%
Public transport infrastructure	$236,000	$80,000	33.9%
Rural realignments - safety	$385,000	$124,000	32.2%
Safety improvements	$165,000	$45,000	27.1%
Seal extensions	$432,000	$7000	1.6%
Pavement smoothing	$1,214,000	-$3000	-0.3%

Figure E.5 shows a huge spread in potential VOC benefits arising from time indexing, and figure E.6 attributes most of this variability to assumed oil prices.

Figure E.5 Percentage increase in PV of VOC benefits

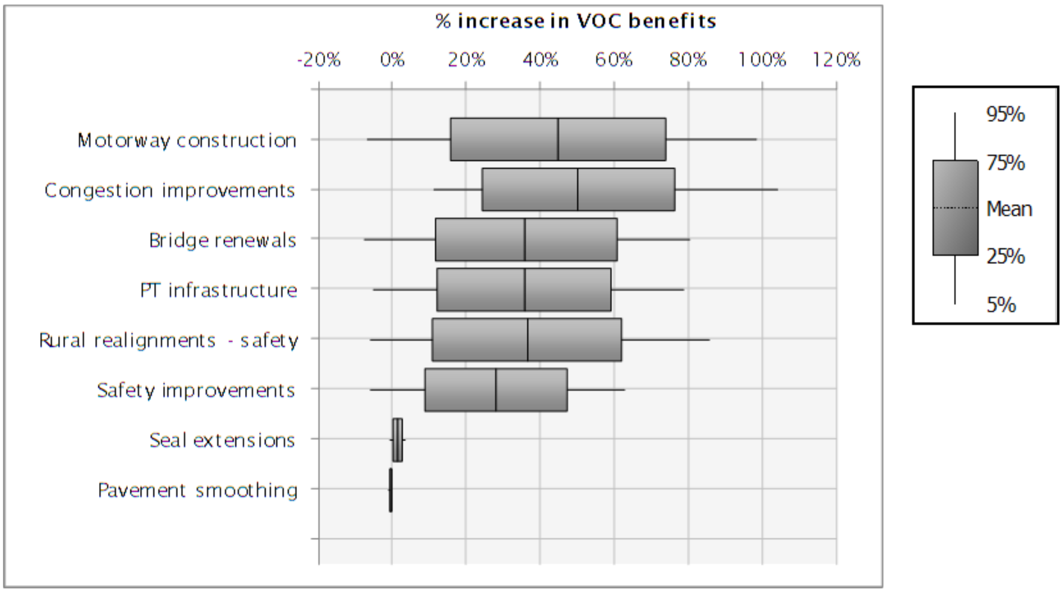
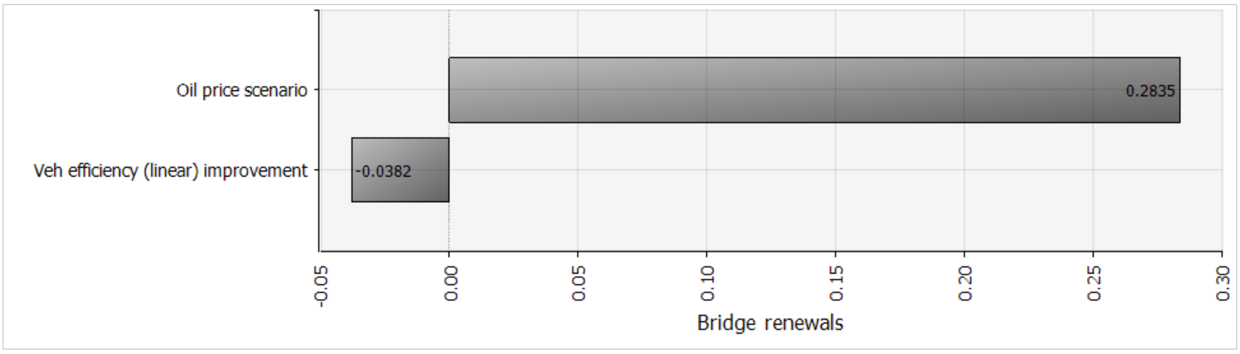


Figure E.6 also shows that improved vehicle efficiency reduces VOC benefits, all else being equal. This tornado plot is for bridge renewal projects, but the qualitative results were the same for the other project categories.

Figure E.6 Tornado plot for the percentage increase in VOC benefits of bridge renewal projects



E.4 CO_2 benefits

E.4.1 A caveat

It may seem paradoxical to some that increasing the social cost of CO_2 over time would increase the benefits of road projects. Increasing the value of CO_2 emissions increases the benefits of causing existing travellers to move more efficiently. If any additional traffic is generated then this reduces any positive benefits from CO_2 output, which should already be in the CBAs. For many project types, there is no generated traffic or the amount is so small that generated traffic can reasonably be assumed to be zero – eg seal extensions, pavement smoothing, safety improvements, bridge renewals, rural realignments.

Some critics argue that the way transport planning authorities worldwide appraise CO_2 leads to overstating of benefits.[22] There is some underlying truth in this criticism. The way transport CBAs are undertaken ignores the issue of transport inducing land use change, and it is land use that determines transport demand. Some projects may induce land use developments on the outskirts of urban areas and cause more travel overall compared with not having done the project. More travel causes more fuel consumption and more GHG emissions, which are not considered in prevailing transport CBAs. These issues are the subject of on-going debate and research. In the meantime this issue is perhaps best treated qualitatively, or with scenario testing in the transport modelling.

E.4.2 Results

The caveats above should guide the interpretation of the following table and plots that show the results of the simulation. The CO_2 benefits were either explicitly modelled or were included within VOC benefits; in the latter situations it was assumed that CO_2 comprised 4% of VOC benefits. One slight complication with CO_2 benefit values is that they are effectively decreasing in real terms retrospectively, as the NZTA maintains their nominal value at $40, and decreases the proportion of CO_2 benefits within VOC.

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[22] For example: Oram, R (2010) *Going down the wrong road*, Sunday Star Times, www.stuff.co.nz/sunday-star-times/business/4366408/Going-down-the-wrong-road

Table E.4 shows that the change to the net present value of CO_2 benefits was materially affected by time indexing, with increases between 7% and 26% on average; figure E.7 shows the 95% confidence intervals for these increases, with PT infrastructure projects incurring the largest and most variable changes.

Table E.4 NPV increase of CO_2 benefits

Project category with CO_2 benefits	CO_2 benefit NPV (original)	CO_2 benefit NPV increase	% increase
Public transport infrastructure	$113,000	$29,000	26%
Motorway construction	$2,906,000	$570,000	20%
Seal extensions	$10,000	$2000	15%
Pavement smoothing	$29,000	$4000	15%
Safety improvements	$2000	$315	15%
Bridge renewals	$235,000	$34,000	14%
Rural realignments – safety	$9000	$1000	11%
Congestion improvements	$30,000	$2000	7%

Figure E.7 Percentage increase in PV of CO_2 benefits

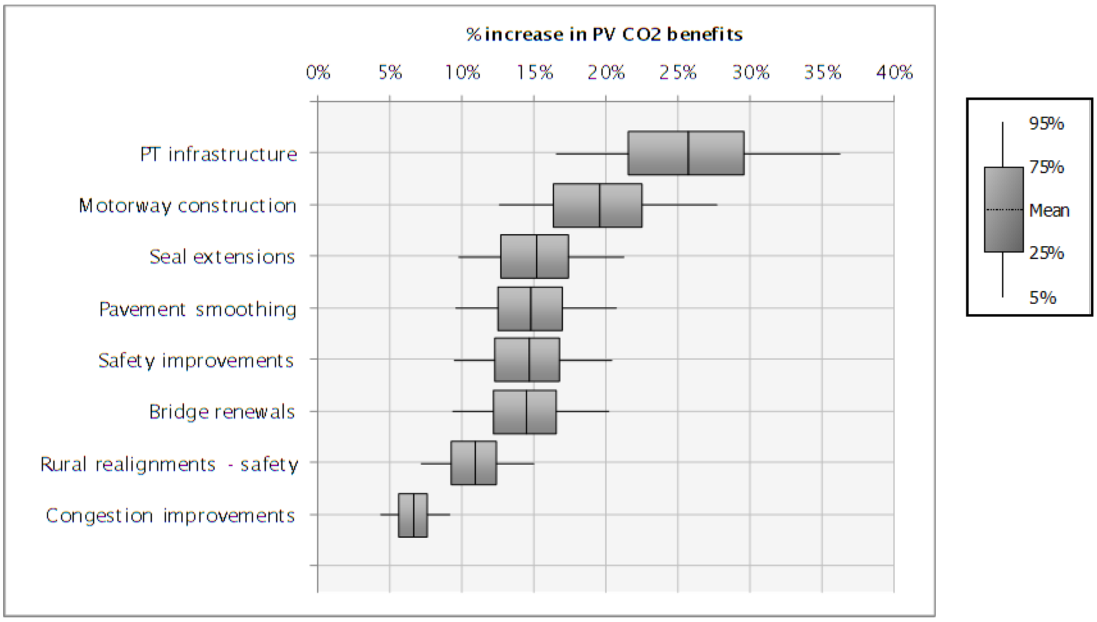
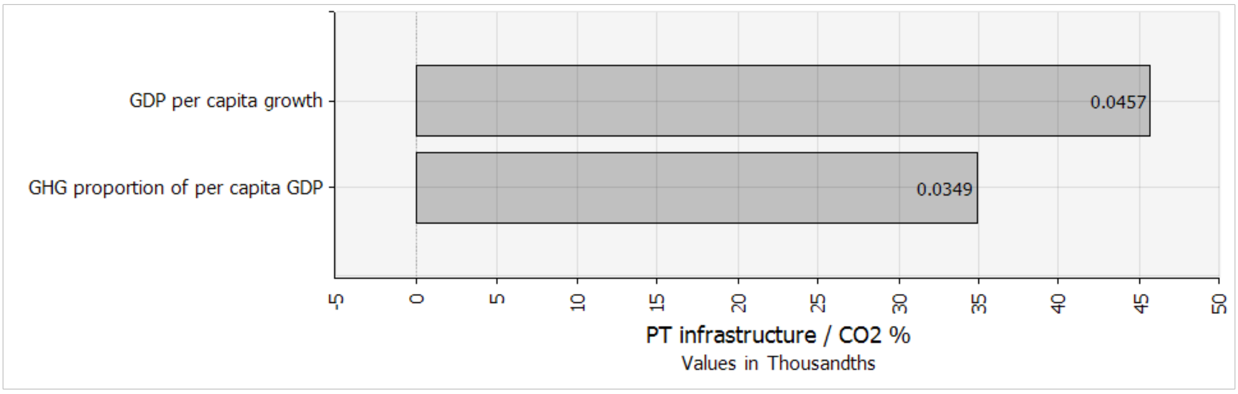


Figure E.8 shows that incomes, and the proportion that GHG increases with incomes, increased CO_2 benefits, with a standard deviation increase in each increasing PV CO_2 benefits by about 4.5% and 3.5% respectively. The figure is for the PT infrastructure project, but the qualitative results were the same for the other project categories, albeit slightly more subdued quantitatively.

Figure E.8 Tornado plot for the percentage increase in CO_2 benefits of PT infrastructure project



E.5 Travel behaviour change (TBC) benefits

This class of benefit relates only to TBC projects specifically, and the original NPV of $2,090,000 increased on average by $109,000 (5%). The tornado plot is essentially the same as figure D.10.

E.5.1 Walking and cycling benefits

Walking and cycling benefits generally, although not exclusively, accrued to walking and cycling projects, and as such the box plots and tornado plots do not need to be repeated here. NPVs increased 15% on average, with an increase of $665,000 for the average walking network project and almost $1.1 million for the average cycling network project.

Table E.5 NPV increase of walking and cycling benefits)

Project category with walking and cycling benefits	Walking and cycling benefit NPV (original)	Walking and cycling benefit NPV increase	% increase
New and improved walking networks	$4,333,000	$665,000	15%
New and improved cycling networks	$7,443,000	$1,082,000	15%
Bridge renewals	$21,000	$3000	13%

Appendix F Values for the boxplots

The tables below list the data values that the boxplots in chapter 6 were based upon.

Table F.1 Values for figure 6.1 – proportional increase in BCRs

Labels	Top whisker	Top box	Centre	Bottom box	Bottom whisker
PT infrastructure	1.389593	1.314614	1.272427	1.224628	1.176087
Bridge renewals	1.369254	1.294344	1.220426	1.140491	1.077488
Motorway construction	1.303696	1.24916	1.216396	1.18083	1.139764
Rural realignments – safety	1.24833	1.204006	1.180539	1.154782	1.121637
New and improved walking networks	1.229678	1.184191	1.153417	1.11999	1.090553
New and improved cycling networks	1.210855	1.168801	1.142398	1.112869	1.086133
Congestion improvements	1.185415	1.152072	1.132541	1.110989	1.087851
Safety improvements	1.183329	1.149848	1.131059	1.109765	1.084375
Seal extensions	1.127624	1.106667	1.093887	1.079885	1.063539
TBC	1.075947	1.062013	1.052066	1.041482	1.031702
Pavement smoothing	1.05798	1.047884	1.04188	1.035274	1.027042

Table F.2 Values for figure 6.2 – percentage increase in NPV

Labels	Top whisker	Top box	Centre	Bottom box	Bottom whisker
PT infrastructure	0.369749	0.296885	0.258599	0.213872	0.166464
Rural realignments – safety	0.333559	0.273663	0.241725	0.204102	0.163276
Bridge renewals	0.434933	0.343316	0.2417	0.139404	0.057799
Motorway construction	0.296677	0.241026	0.208646	0.172679	0.131663
New and improved walking networks	0.233851	0.183428	0.154555	0.121109	0.09106
New and improved cycling networks	0.220485	0.172817	0.145941	0.114507	0.086182
Congestion improvements	0.183203	0.149406	0.130362	0.108702	0.086292
Safety improvements	0.181045	0.145752	0.128109	0.107834	0.086462
Seal extensions	0.12915	0.10688	0.094529	0.080645	0.064464
TBC	0.076655	0.061335	0.052052	0.041548	0.031643
Pavement smoothing	0.051974	0.042164	0.03684	0.030817	0.023915

Table F.3 Values for figure 6.3 – proportional increase in BCRs at a 4% real discount rate (max 30-year appraisal period)

Labels	Top whisker	Top box	Centre	Bottom box	Bottom whisker
PT infrastructure	1.402781	1.327595	1.283133	1.231909	1.183828
Bridge renewals	1.419241	1.340657	1.256739	1.170851	1.099676
Motorway construction	1.356162	1.292821	1.252373	1.208295	1.162668
Rural realignments – safety	1.28803	1.23576	1.208554	1.175579	1.138177
New and improved walking networks	1.278867	1.22119	1.186122	1.14817	1.108497
New and improved cycling networks	1.25841	1.2054	1.174342	1.14082	1.104638
Congestion improvements	1.207501	1.17092	1.147979	1.122733	1.097431
Safety improvements	1.222031	1.181788	1.159642	1.134318	1.104206
Seal extensions	1.156803	1.130931	1.114834	1.096985	1.078275
TBC	1.079979	1.064796	1.054974	1.044644	1.033216
Pavement smoothing	1.072558	1.059753	1.052003	1.043664	1.034144
Preventive maintenance	0	0	0	0	0

Table F.4 Values for figure 6.4 – proportional increase in BCRs at a 10% real discount rate (max 30-year appraisal period)

Labels	Top whisker	Top box	Centre	Bottom box	Bottom whisker
PT infrastructure	1.344363	1.280835	1.245218	1.205188	1.159371
Bridge renewals	1.345688	1.279508	1.204086	1.129768	1.067993
Motorway construction	1.279478	1.229991	1.200749	1.168713	1.130003
Rural realignments – safety	1.226044	1.189537	1.1672	1.143479	1.114078
New and improved walking networks	1.206672	1.164928	1.138759	1.108838	1.08196
New and improved cycling networks	1.188792	1.151224	1.128364	1.101901	1.07788
Congestion improvements	1.174257	1.144698	1.126575	1.107283	1.084163
Safety improvements	1.162614	1.135812	1.118797	1.10085	1.078314
Seal extensions	1.11427	1.096018	1.084745	1.072581	1.057525
TBC	1.073692	1.05982	1.050666	1.040427	1.030804
Pavement smoothing	1.052061	1.042856	1.037516	1.031768	1.024364

Table F.4 Values for figure 6.5 – proportional increase in BCRs when VOC is not time-indexed (sensitivity assessment)

Labels	Top whisker	Top box	Centre	Bottom box	Bottom whisker
PT infrastructure	1.355141	1.292805	1.253183	1.208654	1.161759
Bridge renewals	1.146093	1.121624	1.106056	1.089029	1.069598
Motorway construction	1.269923	1.221563	1.192069	1.158384	1.123236
Rural realignments – safety	1.244058	1.203983	1.178526	1.150556	1.120268
New and improved walking networks	1.230195	1.181516	1.153424	1.121209	1.091064
New and improved cycling networks	1.212048	1.16684	1.142414	1.114039	1.087113
Congestion improvements	1.173268	1.143029	1.124269	1.103069	1.080511
Safety improvements	1.162944	1.131736	1.114815	1.094952	1.075319
Seal extensions	1.118705	1.09957	1.087157	1.073737	1.057989
TBC	1.076103	1.061178	1.052067	1.041882	1.031874
Pavement smoothing	1.059508	1.050145	1.043901	1.037298	1.029331

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