Appraising transport strategies that induce land use changes

Estimating benefits of long-term land use change from standard transport model outputs

NZIER public discussion document
Working paper 2013-04

June 2013

About NZIER

NZIER is a specialist consulting firm that uses applied economic research and analysis to provide a wide range of strategic advice to clients in the public and private sectors, throughout New Zealand and Australia, and further afield.

NZIER is also known for its long-established Quarterly Survey of Business Opinion and Quarterly Predictions.

Our aim is to be the premier centre of applied economic research in New Zealand. We pride ourselves on our reputation for independence and delivering quality analysis in the right form, and at the right time, for our clients. We ensure quality through teamwork on individual projects, critical review at internal seminars, and by peer review at various stages through a project by a senior staff member otherwise not involved in the project.

NZIER was established in 1958.

Authorship

Each year NZIER devotes resources to undertake and make freely available economic research and thinking aimed at promoting a better understanding of New Zealand's important economic challenges. This paper was funded as part of this public good research programme.

This paper was prepared at NZIER by Chris Parker. It was quality approved by Dr John Yeabsley.

NZIER thanks Dr John Bates for his comments on an earlier draft. We also thank Dr David Simmonds for helping us to understand the issues in the early stages of our work.

The assistance of Auckland Council (and the work they commissioned NZIER to undertake for the draft City Centre Masterplan) and NZ Transport Agency (for Auckland-based major transport strategy appraisals) is gratefully acknowledged.

Any errors, omissions, opinions or judgements are our own.

NZIER
NEW ZEALAND INSTITUTE OF ECONOMIC RESEARCH

L13 Grant Thornton House, 215 Lambton Quay | PO Box 3479, Wellington 6140
Tel +64 4 472 1880 | econ@nzier.org.nz

Key points

This paper develops formulations for estimating the economic welfare impacts of transport strategies that change land use. The formulations seek to use outputs of transport modelling typically used for transport appraisal.

At present conventional cost-benefit appraisal (CBA) techniques focus only on the short-run impacts of transport schemes — changes in the generalised cost of travel — taking it as given how people live, work and play. Recent work to estimate 'wider economic benefits' of transport strategies augment the benefit estimates of conventional CBAs, but they still do not resolve the remarkably narrow extent of transport CBAs. By ignoring how transport strategies may alter regional populations, economic activity and employment, and land use patterns (which is all called 'land use' for brevity), it is possible that some major projects may be much better, and others much worse, than the currently estimated benefit-cost ratios would indicate.

Economic theory, and *ex post* evaluations of transport schemes, suggest that it is common for major transport schemes to have relatively major changes in land use. This means the long-run impacts of transport schemes is not reduced costs of travel *per se*, but changed location and activity patterns of households and firms. All else equal the longer term direct benefits of such schemes must be greater than the direct benefits estimated as most people must be better off following the lifestyle and/or work change — else they would not have changed. Against this, however, are negative congestion externalities from the additional induced travel (because of the absence of efficient pricing) that in some instances could not only negate the land use change benefits, but could make the project detrimental overall to society.

This paper develops new appraisal formulations to apply to the typical sorts of outputs of transport models to estimate the total net-benefits of transport schemes that induce land use change. The paper provides a microeconomic intuition to the approach, demonstrating that the additional benefits relate to changes in the context with which people express their preferences. The paper concludes with some insights learned from an application of one of the formulations to an Auckland transport scheme that land use modelling was undertaken for.

Contents

Figures

Tables

1. Introduction

This paper develops a cost-benefit appraisal (CBA) methodology to apply to infrastructure strategies that are expected to induce long-run change to land use, population and economic activity (‘land use’ for short).

Transport investment is a major area of public spending, at over $3 billion annually in New Zealand (of a population of some four million). Similar per capita levels of spend occur overseas. In the long-run transport can change the shape and nature of cities and economic prosperity overall; for instance, motorways are generally shown to induce urban sprawl. With so much at stake, the careful appraisal of transport strategy matters a great deal.

Although transport investment and polices can affect how households and organisations live, work and play over longer-periods of time, current methods (theory and practice) for transport strategy appraisal assume such effects away. Instead cost-benefit appraisals consider only short-run impacts over projects’ economic lives. This is the case worldwide; New Zealand is not the odd one out.

It is of concern that infrastructure cost-benefit analysis progressed on such a counterfactual basis. The economic trade literature has shown that ‘dynamic efficiency’ gains from trade liberalisation can yield net benefits an order of magnitude greater than what was expected before the fact using static ‘Harberger triangle’ analyses (Romer 1994, and Nordås, Miroudot and Kowalski 2006). These additional long-run gains relate to new markets, products and processes that would not have arisen had the earlier intervention not occurred.

Modelling technologies to forecast the long-run effects of transport strategies are continuing to develop, such as ‘Land Use/Transport Interaction’ (LUTI) modelling.[1] However current conventional wisdom is that LUTI models should have no role in cost-benefit analysis; their role is restricted to positive (descriptive), rather than normative (prescriptive) economic welfare analysis.

This research considered whether it was possible to appraise transport strategies that induce land use changes over the longer-term using only the typical outputs of transport models (supposing one knows sufficiently well what the induced land use changes would or could be).

This paper starts by reviewing literature that establishes links between transport and land use (chapter 2); the finding is that transport usually has considerable long-run impacts on land use.

Chapter 3 then reviews the state of transport CBA literature: it describes the ‘rule of a half’ as the workhorse of transport CBA, and its wide applicability (which is complemented by ‘wider economic benefits’ estimation where needs be). It then reviews reasons why induced land use changes are ignored, and methods proposed to date to include these effects in CBAs.

Chapter 4 starts by considering the more general issue of differing long-run and short-run demand schedules and what the CBA literature says on the matter. The chapter then develops estimates of the change in total social surplus under multiple demand

[1] Auckland Council owns one such model.

schedules using outputs from typical transport model outputs. The chapter concludes by discussing complications that might arise from applying the approaches to network modelling.

Chapter 5 describes what was learned in an initial application of the technique to an Auckland transport project that used the Auckland LUTI model, and chapter 6 concludes.

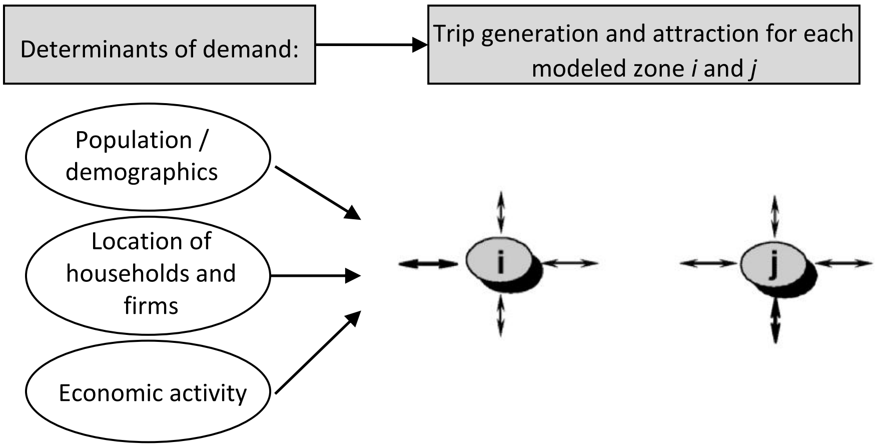
The scope of this paper has been kept narrow. The proposed appraisal method relates to induced land use changes caused by altered accessibility. It omits other effects such as returns to agglomeration and wider economic benefits relating to imperfect pricing in related markets (imperfect competition, labour taxation etc). Similarly, this paper does not focus on capital, operating, and maintenance costs to road and public transport infrastructure providers, which are relatively straightforward to estimate. Thus the term 'appraisal' relates to the 'calculation of user net-benefits' (i.e. the top line of a benefit-cost ratio, or BCR).

However the general nature of the approach means it can be extended to various other domains of public sector involvement where long-run and short-run demand schedules differ, such as energy and communications technologies and networks, and the built and natural environment.

2. Transport and land use

The demand for travel is primarily determined by population and demographics, economic activity, and the location of households and firms (plus other institutions such as schools and hospitals) (ATC 2006b p100). For brevity these determinants are described here as 'land use'. Figure 1 provides a stylised representation of this. Transport models typically partition the landscape into zones and assign trips across the network that are generated from one zone and attracted to another.

Figure 1 Determinants of trip generation and attraction



Source: NZIER, and ATC (2006b pp 99–100)

Major transport strategies have the potential to materially affect the determinants of transport demand in the long-term.

Coleman (2010) reviewed the evidence of how highway development influenced the evolution of American cities and Auckland. He finds that highway investment can reduce urban density and increase private transport use:

> *If private transport infrastructure – a highway – is built, people move out from high density central city locations to low density suburban locations, and population density declines: or to be more succinct, highways induce sprawl. (P24.)*
>
> *…United States evidence, and Auckland's own history suggest that new roads cause population dispersal and employment decentralisation, as firms and citizens flee the central city in search of desirable locations with easy city access located slightly further out of town. (P27.)*

Grimes (forthcoming) describes a conceptual framework that population and employment increase following material improvements to infrastructure networks. The work is underpinned by the theory of 'spatial equilibrium' in the urban economics literature; the idea is that people will keep adjusting in response to a new development until the net benefits of locating in each place is equal. Grimes shows that if net amenity benefits are positively related to region size, and if the economy exhibits returns to scale, then an infrastructure investment will cause a region to grow for a finite period of time.

Other evidence in the literature that transport schemes can cause long-term changes to land use, economic activity and regional population includes:

- Glaeser and Gottlieb (2009) show that a positive local shock (e.g. a major new transport investment) will impact on population, prices and wages of the affected area
- Baum-Snow (2007) and Duranton and Turner (2007) find that if a highway makes a region more productive, then we will see an increase in population and employment as long as housing supply is at least somewhat elastic
- In the United States, Blanchard and Katz (1992) find considerable regional geographic mobility of population and employment in response to local shocks (of all types)
- Mare, Grimes and Morten (2009) find evidence of migration responses within New Zealand that are similar to those found by Blanchard and Katz
- Cochrane et al (2010) explicitly model the endogenous interactions of New Zealand local authority investments with outcomes for population, employment and incomes. They find that an exogenously sourced infrastructure investment increases population of a local area and of neighbouring areas
- Grimes et al (2010) find that Australasian house prices tend to move together over the long run, implying that migration plays an equilibrating role across the regions of both countries.[2]

The effects of transport induced land use change and long-term traffic volumes

Wallis et al (2012) considers the impacts of road schemes on land use development and finds that:

- In theory major new road schemes would generally 'induce' different patterns of land use development (i.e. than would occur in the absence of the scheme)
- This induced land use will result in increased traffic volumes using the new road. There is very little 'hard' evidence of the extent to which this will happen, but:
  - in a study of traffic growth on UK motorways and trunk roads, Marcial Echenique & Partners concluded that land use effects made as important a contribution to traffic growth as transport effects (SACTRA 1994, p 238)
  - modelling work showed that "the long term land use development effects can be a large additional source of increased vehicle miles travelled associated with highway expansion." (Noland and Lem, 2001, p 18)

[2] Grimes argues that this implies that, in economic terms, New Zealand needs to be considered as a 'subnational' component of the broader Australasian economy, and that regional domestic population should not be exogenous in the economic appraisal of major infrastructure strategies.

- Induced traffic associated with land use development is primarily a medium/longer term phenomenon: however, it may start when the new road is at the planning stage and gradually increase prior to and subsequent to the scheme opening
- In the short-term, land use induced traffic is likely to represent a small component of all induced traffic effects (e.g. relative to mode switch, trip retiming etc). In the longer term, this land use induced traffic component may exceed the total of all other induced traffic components.

Duranton and Turner (2009) finds empirical evidence in the United States that roads can fill back up again and negate any congestion reduction gains. This is described as the 'fundamental law of road congestion', which is largely driven by changes to economic activity, population and land use:

> *We investigate the relationship between interstate highways and highway vehicle kilometres travelled (VKT) in US cities. We find that VKT increases proportionately to highways and identify three important sources for this extra VKT:*
>
> *(a) an increase in driving by current residents*
>
> *(b) an increase in transportation intensive production activity; and*
>
> *(c) an inflow of new residents.*
>
> *The provision of public transportation has no impact on VKT. We also estimate the aggregate city level demand for VKT and find it to be very elastic. We conclude that an increased provision of roads or public transit is unlikely to relieve congestion.*

Duranton and Turner's finding that congestion relief is not something that can be sustained into the long-run is reinforced by the work of David Metz (2008). Metz, in his paper entitled 'The Myth of Travel Time Saving', argues that in the long-run it is not travel time savings that people value, but rather improved access. Metz finds that historically in the United Kingdom travel time per capita is remarkably constant. New infrastructure does not result in travel time being saved to allow other activities to be carried out; rather, travel time is conserved, allowing more distant destinations to be reached within the time available for travel. This means that the long-run impacts of transport investment is land use change rather than travel time savings.

Ignoring induced land use changes may bias appraisal results

Grimes and Liang (2010) used increases in property prices to estimate the net benefits of a motorway corridor that induced major land use changes. Grimes (2011) describes that research as follows:

> *Using relative land value increases as a measure of the present discounted value of the benefits of the motorway extension, Grimes and Liang (2010) calculated a benefit-cost ratio (BCR) for the motorway extensions of at least 6.3, and possibly as high as 21.9. Ex post estimates of benefits using this method were approximately double the ex ante estimates of benefits for the project.*

This kind of analysis implies that current appraisals may not provide an approach to measuring benefits that includes all of the relevant effects.

3. Current transport CBA literature

Chapter 2 considered empirical and theoretical analyses of transport inducing land use change in the longer term. This chapter reviews methods to estimate the costs and benefits of transport strategies that induce changes in land use.

The fundamental question for transport decision makers is whether or not society is better off through a transport intervention, such as investing in more infrastructure, or by pricing the network differently. A comparative economic welfare appraisal of costs and benefits will inform this. This considers the effects in dollar terms of the change in peoples' utility (satisfaction) from consuming goods and services (including non-market amenities such as the natural environment).

3.1. Appraising transport strategies when land use changes are not induced

The 'rule of a half'

Transport appraisals consider the relationship between the generalised cost of travel[3] and the quantity of travel. Figure 2 shows the basic structure of the model for a single transport link. An 'inverse demand schedule' represents the relationship between the quantity of travel demanded and the level of generalised cost of travel.

An average social cost curve (AC) represents total travel costs to everyone for different levels of use. The average cost curve is convex upwards: it is flat and minimal for modest traffic levels, but its slope progressively increases as more people use the link, worsening congestion and slowing traffic.[4]

A transport improvement shifts the AC curve down (say, by increasing average speeds) and/or to the right (say, by expanding capacity). In the case of a transport improvement that has no network effects, the welfare gains to society as a whole can be estimated by the increase in consumer surplus[5] (CS) — the shaded area P_0ABP_1 (assuming no taxes or subsidies).

The change in CS can be represented as the area under the demand curve, bounded below by the price (generalised cost) in the option scenario P_1 and bounded above by the baseline scenario price P_0.

3 'Generalised cost' is a combination of the opportunity cost of time spent travelling, vehicle operating costs, user chargers and other relevant costs. The generalised cost is specific to the context, as it will differ by the mix of travel purposes, the mix of vehicle types etc.

4 When congestion pricing is lacking, the private marginal cost of travel equals the private average cost of travel.

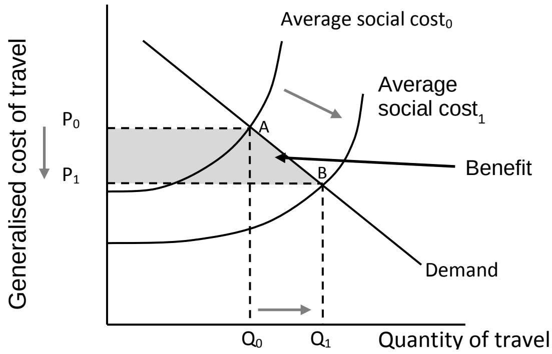
5 Consumer surplus is the difference between what consumers are willing to pay for a given quantity of a good or service and the amount actually paid. This is an adequate measure of welfare provided the price changes caused by the initiative are moderate and transport expenditure is a fairly small part of total consumption, which means the project does not have a material 'income effect'; Boardman et al (2006 pp 64–69).

If it is reasonable to assume that the demand schedule is linear over the interval *AB*, then the formula for calculating the area of a trapezium can be used. This is called the 'rule of a half':[6]

Formula 1 The rule of a half

$$\text{Consumer surplus benefits} = 1/2\,(P_0 - P_1)(Q_1 + Q_0)$$

Figure 2 The rule of a half for direct transport benefits



Source: NZIER

When there are taxes and subsidies

It is common for there to exist fuel excise duties, road user charges, public transport subsidies, road tolls etc. This means the perceived price of transport does not equal its resource cost. The rule of a half is adjusted to account for this by adding a 'resource cost correction' (ATC 2006a pp 55–57, and 73–75, and NZTA 2010 page A11–16):

Formula 2 The rule of a half with a resource cost correction

$$\text{Social surplus benefits} = 1/2\,(P_0 - P_1)(Q_1 + Q_0) + Q_1(P_1 - AC_1) - Q_0(P_0 - AC_0)$$

This formula is based on Formula 1 and adds the net increase in 'producer surplus' (accruing to those that govern the infrastructure).

[6] The area of the trapezium is the average width $1/2\,(Q_1 + Q_0)$ times the height $P_0 - P_1$. *P* is the generalised cost of travel as perceived by travellers, which in the absence of transfer taxes and subsidies etc equals the social average (resource) cost of travel; *Q* is the quantity of travel; and subscripts 0 and 1 denote the do-minimum and option scenarios respectively.

Note that our use of the term 'rule of a half' may differ from how some others use it. We mean it to relate to the total direct social surplus calculation, and not just to the triangle for new travellers.

The rule of a half applies to the total network

Neuberger (1971) and Bates (2004) show that the rule of a half for a single market generalises straightforwardly to a multimarket case. The change in CS for a non-linear function equals:

Formula 3 The change in consumer surplus with multiple markets

$$-\int_{\boldsymbol{P_0}}^{\boldsymbol{P_1}} \boldsymbol{f}(\boldsymbol{P}).d\boldsymbol{P}$$

where the integral is defined along a path between two positions $\boldsymbol{P_0}$ and $\boldsymbol{P_1}$ (bolded to represent a vector of prices, with a price for each disaggregation of the transport network, be they links, modes, routes, corridors, times of travel, etc), and $\boldsymbol{f}(.)$ is the vector of demand functions (one for each transport network disaggregation).[7]

It is common for CBA textbooks and manuals to warn of the dangers of double counting impacts in other markets (Boardman et al p114; Sugden and Williams 1978 p135; ATC 2006 p66–75). In the short-run a price reduction from a public intervention in one market shifts the demand schedule in related markets (e.g. demand for land increases following a transport improvement). Provided the related markets are priced efficiently (i.e. at short-run marginal social cost) these shifts in demand schedules in related markets do not constitute additional welfare gains over and above those measured directly.

Transport user benefits represent overall benefits to society

A criticism that people sometimes make about transport CBA is that it only focuses on transport demands and costs, and fails to account for the benefits transport has on the rest of the economy. In large part this criticism can be rebutted.

That a suitable CBA already broadly accounts for benefits wider than just the 'transport market' is the central thesis of BTRE's *Facts and Furphies in CBA: Transport* (1999). BTRE argue that if a transport scheme causes an increase in production in the broader economy, then this increase in production depends on the increased use of the transport scheme (because if it did not, then it would be occurring already). The willingness to pay for the extra transport represents the indirect benefits that accrue further down the supply chain, and this willingness to pay is represented by the demand schedule used for the CBA. If the economy is competitive, then the firms will fully pass on the gains to consumers who ultimately consume more/better goods and services (Rouwendal 2001).

Taking this into account leads to a clear idea of the notion of 'wider economic benefits' (e.g. Kernohan and Rognlien 2011), which primarily relates to prices in related markets not equalling short-run marginal cost. Examples are where there is imperfect competition in the wider economy, and if there are taxes on labour income. These imperfections may lead to additional costs and benefits as direct benefits ripple through the wider economy. Since the early 2000s there has been a move to try to appraise these sorts of impacts for major transport strategies to complement the transport user benefits estimated with no induced land use changes.

7 This follows from Hotelling (1938), and requires that the 'integrability condition' is met, whereby $\frac{\partial Q_1}{\partial P_2} = \frac{\partial Q_2}{\partial P_1}$ holds for all pairs of related markets 1 and 2 (Neuburger 1971, and ATC 2006a, p75).

3.2. Why do transport CBAs typically ignore induced land use changes?

It is not common knowledge that induced land use must be ignored

It seems that worldwide best practice transport CBA ignores any induced changes to transport demand that occurs over a period of time and is not (for all intents and purposes) instantaneous. The assumption would seem to be that transport-induced land use change in the longer-term either does not happen, or if it does happen, it is immaterial to the CBA result. This is in stark contrast to the discussion in the previous section, showing that transport can have a large effect on longer-term land use development, which makes it a strong assumption.

That such a strong assumption is being made is not common knowledge. There is no single authoritative source of transport appraisal guidance that recommends explicitly that induced land use change be ignored. For instance, the NZ Transport Agency's Economic Evaluation Manual (prescribing how transport CBAs should be done in New Zealand) does not actually say as much.[8] Nor do the Australian Transport Council National Guidelines (2006).

It is only by working closely with transport modellers on the CBAs of major transport schemes, and by engaging with overseas experts, that we have learned how strictly applied is this strong assumption in practice.

Why make this strong assumption?

It is not clear why transport CBAs the world over ignore any induced changes to transport demand. There are references in the literature that induced land use changes should be ignored, but it is difficult to pin down explanations why.

Section 2.6 of the United Kingdom Department for Transport (DfT) WebTAG 3.1.3[9] states (p10):

> *…it is currently not possible to conduct a CBA in which land-use changes feed through into travel demand changes. The reason is that, at present, the way in which land-use responses and transport responses are represented mathematically in land-use/transport interaction models are not sufficiently consistent to allow the calculations to be undertaken in a manner which accords with the theory on which transport cost/benefit is currently based.*

It is not clear from this statement the reason *why* this *should* lead to the restriction to fixed land-use.

SDG (2011) describes recent discussions on this subject in the United Kingdom, but does not give any reasons as to why land use should be fixed.

Simmonds (2011) suggested that people may be apathetic about incorporating land use change into appraisals, as 'The impacts of transport change beyond those captured in

[8] The closest advice that can be found in the NZTA's EEM is in section 2.15 'Evaluating congested networks and induced traffic effects'. The discussion in that section is not about the determinants of demand *per se*, but on forecasts of the 'trip matrix' in the presence of very high levels of congestion. The advice appears to leave much to 'professional judgement'.

[9] The 'WebTAG' units are the United Kingdom Department for Transport's equivalent of the NZ Transport Agency's Economic Evaluation Manual. They are an authoritative source of guidance for transport appraisal. *dft.gov.uk/webtag*

transport models… are conventionally excluded from transport appraisal on the grounds that whilst they may change the form of benefits (e.g. from better accessibility to higher rents) or their distribution (e.g. occupiers vs landlords) they do not change total benefits, and hence do not affect key results such as cost-benefit ratios'.

Dr Simmonds describes potentially relevant issues missing from the simplistic view that land use change does not affect overall benefits. One is that people value having more choice as to where and how to live, work and play. This would mean the measured travel time savings is a conservative estimate of benefit; of those that prefer to convert travel time savings into living in more amenable housing further out, most would benefit over and above the short-run travel time savings. Another issue is the land use induced traffic may potentially be associated with mispriced congestion and pollution externalities. Moreover, it may also affect the distribution of who gains and who loses, which may be relevant to policy makers when considering equity issues.

What is known is that the prevailing approach does not work if land use changes are induced

The best explanation of why CBA ignores land use change is because the existing method of the 'rule of a half' in isolation is insufficient to account for the full welfare impact. David Simmonds Consultancy and John Bates Services (Simmonds and Bates 2001) say that 'as soon as we introduce changes that are not represented in generalised [transport] cost, the conventional approach becomes less reliable, and may give wholly misleading results'. They (piii) go on:

> *"the methods conventionally used to estimate user benefits arising from transport strategies are inapplicable if those strategies are expected to have impacts upon the distribution of land-uses. This is an increasingly serious problem in transport appraisal practice."*

Simmonds and Bates use a simple example of a transport scheme changing the accessibility to a zone and causing additional trip-attracting land-uses to locate there. These changes bring about increased trips and increased congestion. They demonstrate that nobody is made worse off, and many are made better off, but the normal rule of a half estimates negative net-benefits. They conclude that the rule of a half applied only to transport costs "*cannot in any way be regarded as an approximation to the true value: it is merely one component of the calculation and, in this instance, has the "wrong" sign.*"

The reason the 'rule of a half' fails is because it is only a valid measure if there is a unique (and thus exogenous) demand schedule[10] and it is only the supply schedule that shifts. In that case the net effect is a change in consumer surplus[11] approximated by the shape of a trapezium – Figure 2 (which represents a single market for illustrative purposes). If an initiative causes both the demand and supply schedules to shift (i.e. differ with and without the initiative, and thus not be unique), then a different approach is needed.[12]

---

[10] This is certainly so in the single market situation. Where network effects occur then one can regard the rule as applying to a single demand schedule with both price and quantity being multi-dimensional.

[11] With producer surplus being accounted for straightforwardly via the 'resource cost correction'.

[12] Simmonds and Bates proposed an alternative methodology to appraise transport schemes that induce land use change, as described further below.

3.3. Alternative appraisal methodologies proposed in the literature

Attempts to account for induced land use changes in transport appraisals include the following:

- using the outputs of a LUTI model to measure the total change in social surplus
- the DfT's WebTAG 3.16 proposed methodology to appraise transport projects that 'unlock' the potential for housing development when there is excess demand for housing.

Estimating social surplus from LUTI modelling

As well as providing a basis for the 'rule of a half' as it applies to networks in equilibrium (section 3.1 above), Neuberger (1971) outlined a more general method to appraise transport strategies that induce land use change.

For non-marginal changes to transport costs, including those induced by land use change, Neuberger developed a generalised measure of consumer surplus change based on gravity models[13] for consumer demand. The land use changes manifest as changes in trip attraction and trip generation. Trip attraction (for work trips) considered all aspects of each destination zone as a place to work, such as the wage level and the type of employment offered, except its nearness to residences; trip generation referred to the desirability of each zone for residence, ignoring only its accessibility, but considering factors such as density of development, age of housing etc. Neuberger and Wilcox (1976) added some further clarification to this approach.

Williams (1976) extended this work by considering a larger class of spatial interaction gravity models, and developed alternative formulas to the rule of a half. Martinez and Araya (2000) furthered the approach of Williams, with different appraisal formulas for the short-run (where land use is a given) and the long-run (where land use change is induced). Geurs, van Wee and Rietveld (2000) applied the Martinez and Araya approach to a case study in the Netherlands.

Simmonds and Bates noted (2001, p4) noted that although some of these earlier papers (and others) are interesting they "*do not provide a full response to the issues. In particular:*

- *the studies which have added further calculations to conventional transport benefit measures do not sufficiently explain their reasoning, or demonstrate why their methods are sufficient to measure all benefits without double counting*
- *those which propose alternative methods require, at the very least, greater changes in appraisal practice, and they may be compatible only with particular land-use/transport models."*

Rather than use the utility functions within a LUTI model, Simmonds and Bates (2001) (followed by ITE 2003) sought to augment conventional transport benefits with benefits from improvements to destinations visited (attractions) and in the places where people

13 In a gravity model the number of trips between two zones is greater the larger the number of trips to and from each zone and the lower the cost between those two zones. Neuberger (1971) showed that a gravity model meets the integrability requirement of Footnote 7.

live (productions/ residences). They stated that the rule of a half can apply to each of these three sets of impacts, but the analysis relates to utility rather than prices for the latter two sets. The challenge with using this approach has been in trying to measure the changes in utility for “productions/residences” and “attractions”, and establishing a common intuition of those definitions.

Various other papers describe the use of what is called the ‘logsum’ as a measure of welfare change, which is derived directly from the utility functions that drive the behaviour of the agents that are modelled. (de Jong et al 2005 reviews the general basis of the logsum as a measure for CBA.) Transport models typically use logit choice probability modelling to forecast transport decisions (transport mode, time of day, route choice etc), and in addition LUTI models typically use logit modelling to forecast employment location and residential decisions.

de Jong et al and Guers et al (2010) explain that in a standard multinomial logit model the choice probabilities for decision maker n from alternatives $j\epsilon[1,\dots,J]$ that each provides ‘representative utility’ V_{nj} are given by:

$$P_{nj} = \frac{e^{V_{nj}}}{\sum_j e^{V_{nj}}}$$

The log of the denominator has the convenient interpretation of providing the expected utility of a choice from a set of alternatives. The change in expected consumer surplus for person n can be calculated by comparing the logsums before and after the project and converting it into dollar terms by dividing it by the marginal utility of money α_n (assuming this is the same with or without the intervention).

$$\Delta CS_n = \frac{1}{\alpha_n}\left(\ln\left(\sum_{j=1}^{J1} e^{V_{nj}^1}\right) - \ln\left(\sum_{j=1}^{J0} e^{V_{nj}^0}\right)\right)$$

where superscript 0 and 1 refer to before and after the change.

Geurs et al used a LUTI model’s logsums for each of trip production, transport cost, and destination utility and found far greater welfare changes than the standard rule of a half with exogenous land use. They explain that the transport rule of a half only relates to transport costs and not to trip production or destination utility. They also state that their approach is equivalent to Martinez and Araya (2000) evaluation framework, with the major differences between the two being the transport demand modelling framework and the level of detail of estimation. They applied the framework to major transport and land use strategies in the Netherlands in response to climate change and their logsum estimates were *more than an order of magnitude greater than the rule of a half estimates, and sometimes of a different sign* (Table 1). The accessibility impacts from the land-use scenarios are largely due to changes in trip production and destination utility, and they conclude that the standard rule of a half measure may be completely wrong when used to appraise transport projects that change land uses.

Table 1 Example of using a LUTI model to estimate welfare impacts

Findings of Geurs et al (2010) analysis comparing a logsum measure to a rule of a half

Logsum and rule-of-half accessibility benefits from the different land-use scenarios in 2020 and 2040 compared to baseline scenario.

	Benefits, in € million per year	
	Rule-of-half	Logsum
2020		
Compact Urban Development scenario	27	697
Controlled Flooding scenario	26	107
Uplands scenario	31	−579
2040		
Compact Urban Development scenario	27	1535
Controlled Flooding scenario	0	539
Uplands scenario	81	−1343

Source: Geurs et al (2010), Table 4

Hensher, Truong, Mulley and Ellison (2012) and Simmonds (2012) each used the logsum of residential location choice decisions as the basis for estimating the *long-term* welfare gains of transport strategies that induce land use change. Truong and Hensher (2012 p16) explain that only the residential logsum measure is relevant for long-term welfare change in their LUTI model because short-run decisions of when and how to travel, and medium-term decisions of where to work were automatically included because of the nested structure of the logit functions.

Simmonds (2012) cautiously applied the logsum approach to a subset of model outputs and concluded that the results are plausible and intuitive. Simmonds said that the full set of results need to be calculated before anything could be said about whether the overall scale of benefits was different than the conventional rule of a half.

With regards to the recent applications of logsums from 'residential' and 'attractions' modelling, neither Truong and Hensher, Hensher et al, nor Geurs et al directly discuss how their approach reconciles with the standard CBA model (discussed briefly in section 3.1).

A clear reconciliation of conventional CBA and logsum measures within LUTI modelling would be an important step before the latter is likely to appeal to practical decision-makers. This comparison would have to address the question of the origin of the utility functions and how they are parameterized.

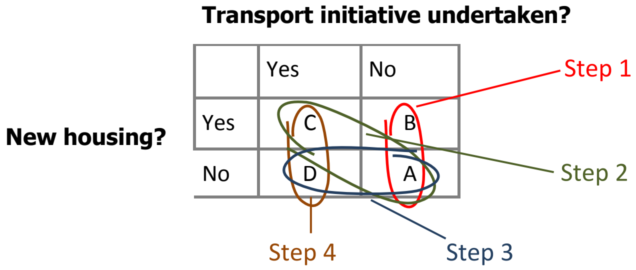
The United Kingdom Department for Transport's 'unlocking dependent housing' approach

The Department for Transport (DfT) proposed a methodology to appraise some elements of induced land use change whilst claiming to not violate 'the principles of transport appraisal' by using different land uses in do-minimum and option scenarios (WebTAG 3.16, para 3.7.2).[14] The approach considers the land value uplift as a benefit additional to the transport benefits, and subtracts the congestion detriment the land use change causes.

Four scenarios are required, outlined in the table below, and then four steps are undertaken in the CBA.

[14] DfT do not explain what these principles are.

Table 2 DfT's 'unlocking dependent housing' approach



Step 1 (dependency) involves comparing Scenario B (with the new housing but without any form of transport intervention) against A (without the new housing or transport intervention) to determine if and where the new housing has the greatest impact on network level of service. If travel costs in key locations increase exceptionally, the network has reached a critical point and this can be taken as evidence of dependency.

Step 2 (option development) involves comparing Scenario C (with the new housing and with the transport intervention) against A to determine if each possible transport intervention resolves the dependency. The expectation is that, in Scenario C, the network will provide a level of service in those locations that is at least as good as that in Scenario A.

Step 3 (transport benefits in isolation) involves comparing Scenario D (without the new housing but with the transport intervention) against A, ignoring the impacts of the new housing, to determine the benefits of transport intervention to existing travellers only (*S[T]* below).

Step 4 (housing development benefits and disbenefits) involves comparing Scenario C against D to consider the negative transport externalities the new houses generate on existing travellers (*TEC* below). This, as well as other kinds of externalities (*OE*), is subtracted from the increase in land values to the new houses (*PG*).

The approach to capture all the benefits of unlocking new housing through transport is:

$$S[T\&L] = S[T] + S[L/T],$$

where *S[T]* is the benefit of the transport intervention without the land use development, and *S[L/T]* is the benefit of the land use development assuming that the transport intervention already exists. *S[L/T]* is defined as:

$$S[L/T] = PG - TEC - OE,$$

where *PG* is the 'planning gain' arising from the land use development, estimated as increase property prices; *TEC* is the transport external costs of a land use development (congestion externalities) and *OE* are other externalities. The formula for the total benefit is:

$$S[T\&L] = S[T] + PG - TEC - OE.$$

DfT are cautious about this constituting the full economic [top-line[15]] benefits. This is because *S[L/T]* is 'likely to result in a large estimated value for the benefits of the dependent housing' and because other infrastructure items such as water, sewage, and

[15] Recall in the introduction we said the discussion here relates to the top line of a BCR only; as distinct from infrastructure investment, operating, and maintenance costs that are reasonably straightforward to estimate.

electricity are also necessary, and thus 'it is not appropriate to attribute all of the benefits of the dependent housing to the transport intervention in isolation'.

The DfT advise that this approach is only used when neither the transport nor the development can be justified in the absence of the other scheme. DfT do not propose that this approach is suitable for applying generally to transport projects that induce land use changes when those changes are permissible.

In summary, the potential large gains that could arise appear attributable not to a transport project *per se*, but to a relaxation of land use planning rules that prevent housing development.

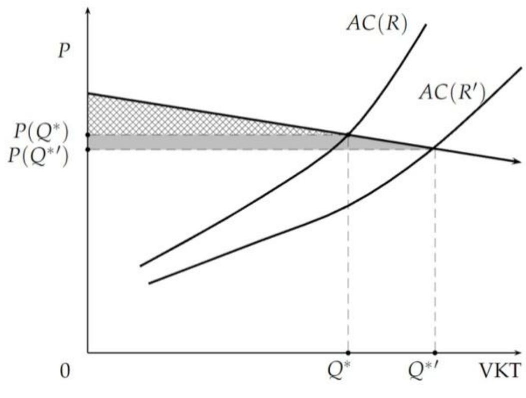
3.4. A role for long-run demand schedules?

As noted above, Duranton and Turner (2009) estimated a highly elastic relationship between the demand for VKT and the amount of lane-kilometres of interstate highways in the United States (an implication of the 'fundamental law of road congestion'). They attributed this to changes to population and economic activity, and by implication, to land use change.

Duranton and Turner posit a long-run demand schedule for travel that allows for land-use change. The empirical analysis indicates that such a curve is very nearly flat, as per Figure 3. They then use the rule of a half to estimate the change in consumer surplus resulting from the change in transport costs as a result of the project. As might be expected, there is very little area under such a flat demand schedule from a highway expansion project. Thus there is a very poor BCR (of 0.44) from such a capital intensive investment.[16]

Figure 3 Duranton and Turner's rule of a half analysis

R denotes lane kilometres of roads in a city (*R'* is the option scenario); *Q* denotes vehicle kilometres travelled (VKT); *P(Q)* is the inverse demand for VKT; *AC(R)* is the average variable cost curve; *Q** is the equilibrium VKT.



Source: Duranton and Turner (2009 p36)

There are two problems[17] with using a long-run demand elasticity in a CBA in this way:

[16] They estimate $227,000 of welfare gains per extra lane kilometer annually and an annual equivalent cost of about $519,000.

[17] Duranton and Turner (p37) noted that their analysis was limited by the fact that they ignored any costs or benefits relating to 'improved land access' because it was 'beyond the scope of this paper and would require additional detailed land market

1. The reasons offered for the flat demand schedule are transport-induced land use change (such as an inflow of new residents and an increase in transportation intensive production activity). But Simmonds and Bates (2001) demonstrate that one must not use the rule of a half in this way when land use changes; the results may be entirely misleading, especially when the infrastructure is capacity constrained, as it is here.
2. The logic is contradictionary. A relatively flat long-run demand schedule implies that people willingly make considerable changes to their lifestyles and business practices to capitalise on the improved infrastructure. As such, a highly elastic long-run demand schedule indicates that the facility is of some considerable benefit to consumers. However, using the rule of a half on an elastic long-run demand schedule necessarily calculates minimal consumer surplus change — a contradiction.

3.5. Summary

To make a sound decision about transport induced land use changes over the longer term should be included. An initiative that is so significant to people that they change how and where they live, work, and play in order to become more dependent on that facility is likely to have significant welfare impacts via those changes. There are likely to be gains to those that choose to make more use of the improved infrastructure, as well as the possible negative congestion spill-overs to existing network users [in the absence of efficient pricing].

In the next chapters we propose a CBA methodology to try to take account of these effects.

information'. They note that an increase in consumption of land per capita would increase people's utility (ignoring any other positive or negative spillovers).

4. Benefits of transport induced land use change

The theory underlying transport CBA is not unique to transport. Thus appraising transport strategies that induce land use change will have counterparts in other areas of public policy.

This chapter considers the more general issue of how to appraise initiatives when the short-run price response differs from that in the long-run. Various goods and services share the property that their long-run demand schedule is flatter than the short-run. Section 4.1 makes a case to consider the total change in consumer surplus under short-run demand schedules induced by an initiative as a measure of welfare change.

Section 4.2 then considers how this relates to the demand and supply of transport facilities and derives more general formulas for estimating the total social surplus change using the same kinds of transport model outputs as conventionally used in transport CBA.

Key assumptions

We assume that separate modelling analysis has established suitably robust forecasts of the land use implications of the transport scheme over time.

We assume that all of the secondary markets that relate in one way or another to the land use changes are efficiently priced (i.e. perceived price equals short-run marginal social cost). So, for instance, we are ignoring any negative externalities from new developments on existing housing amenity (e.g. spoiling views). We ignore, for the time being, any land use planning restrictions that are inefficient from an economics perspective.

We also ignore any intertemporal externalities, such as induced land use changes bringing forward further public capital investment elsewhere in the network.

4.1. Total change in consumer surplus as a welfare measure

This section recasts the transport/land-use issue as a special case of a broader problem of how to appraise interventions that have different effects in the long-run than in the short-run. Martinez and Araya (2000) made a similar distinction between short-run transport benefits and long-run, where the latter differs from the former because land use changes can occur.

The general CBA literature we found did not cover off adequately the issue of long-run effects differing from short-run effects. In the case where a project’s short and long-run effects differ, then its demand curve in a future period had it occurred will differ from what it would be had it not occurred earlier. This difference comes about because the benefit would differ for those consumers that have had the time to learn, innovate, and adapt their circumstances to better exploit the possibilities the project provides. We argue that the total change in willingness to pay — the difference in consumer surplus calculated from two different demand schedules — is a valid measure of welfare change.

Should we use long-run or short-run demand schedules in CBA?

It is well established in the empirical literature that for some goods and services long-run demand elasticities differ from their short-run counterparts. For instance this is true for petrol (e.g. Kennedy and Wallis 2007, Goodwin 1992), electricity (e.g. Polemis 2007), transport (e.g. Bekken and Fearnley 2005), gas (e.g. Trost et al 2009), and is no doubt true of various other goods and services.

Long-run and short-run elasticities of particular commodities differ because over time consumers vary aspects of how they live, work and play in response to changes in availability or quality. If it is positive (an improvement) it can be regarded as equivalent to a price reduction and the normal response is to become more dependent on the good/service in order to maximise their utility. For instance, forecast sustained changes in petrol prices lead to some people over the long-run changing various aspects of lifestyle such as the type of vehicle they own, where they live, and how far away they are prepared to commute for work.

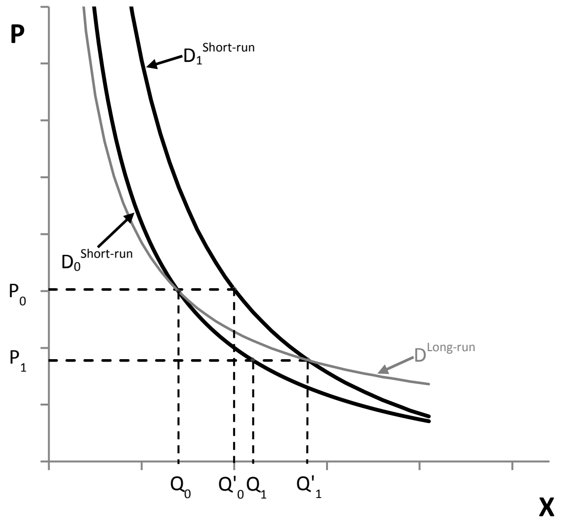
A more elastic long-run demand means multiple short-run demand schedules. Consider Figure 4 as an example of a sustained price decrease from P_0 to P_1, whereby the short-run demand response would have been to increase quantity from Q_0 to Q_1 but in the long-run quantity demanded would be Q'_1. If the price were to increase back to P_0 in the short-term, the quantity demanded is not the original Q_0, but the larger quantity Q'_0.

This raises a question of which kind of demand schedule should be used in CBA? We searched the literature but found very little guidance that was directly relevant.[18] The New Zealand Commerce Commission (2000) estimated the change in consumer surplus from an outward shift of the demand schedule for a market as part of an appraisal for a merger application; the approach was simple and stylised. We described in section 3.4 our concerns with the Duranton and Turner (2009) application of high demand elasticity for interstate highways in the United States in a CBA.[19]

18 Key words in our literature search included long-run versus short-run demand (elasticities, schedules, curves), CBA, cost-benefit analysis/appraisal, welfare economics, normative economics, dynamic efficiency, path dependence, and structural change.

19 That is, it is a contradiction to suppose that a facility can induce major changes to people's lifestyles and they willingly become more dependent on the facility over time, and yet provide little to no benefit to people.

Figure 4 Long-run vs short-run demand schedules



Source: NZIER

When an intervention induces different short-run demand schedules, then CBA should compare them

This section argues that it is valid to measure a project's benefits as the total change in Hicksian compensating variation when a project induces change to people's indifference curves.

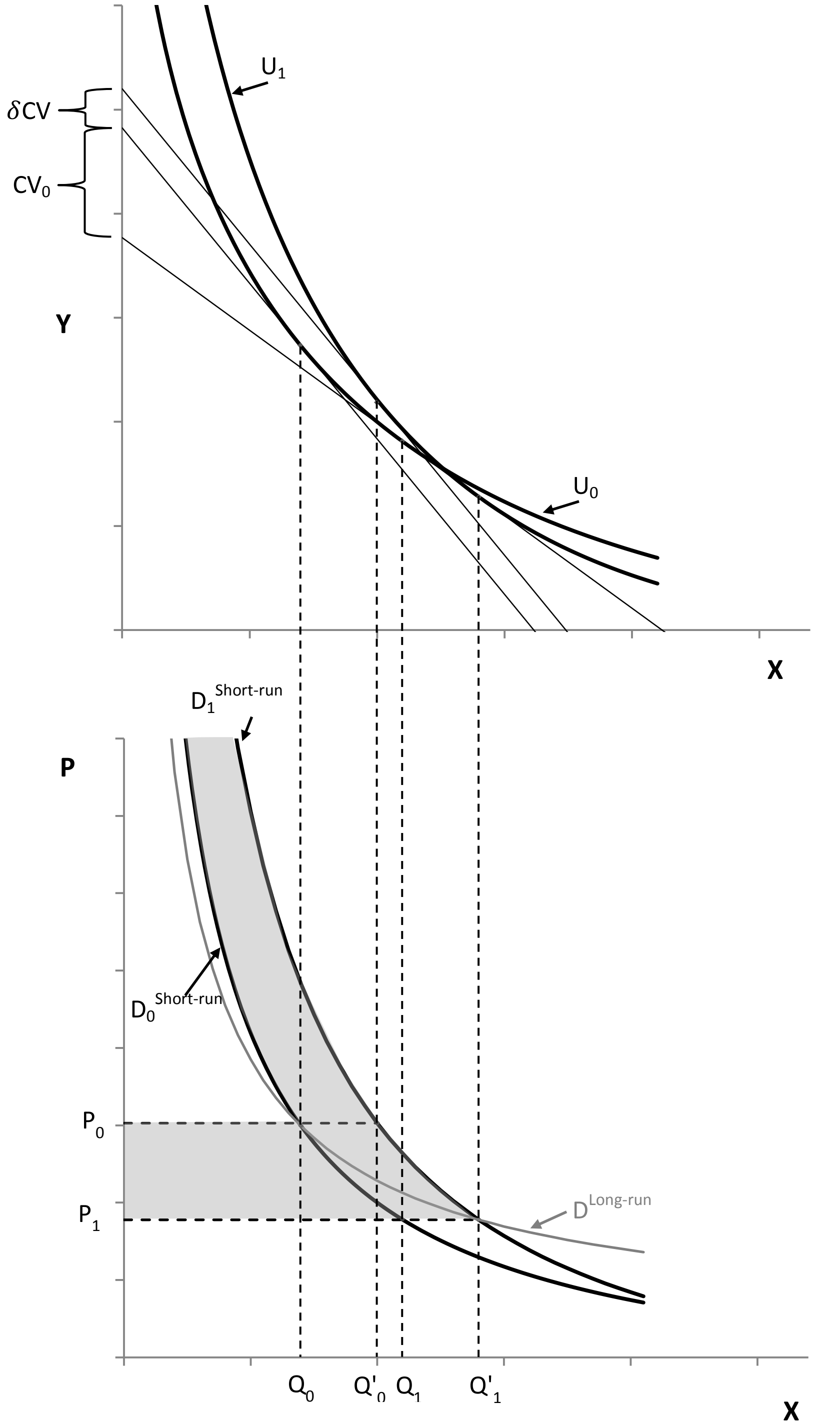
We propose that the role of long-run demand elasticities is limited to helping to forecast the price and quantities in a market in the long-run, but that they have no role in measuring welfare. That is, it is useful for positive economics but it is not directly useful for normative economics. Assuming that the short-run demand schedules in Figure 4 are Hicksian compensating variation demand schedules[20] for an individual consumer (e.g. see Boardman et al 2006 pp 64–69), then the entire area under each demand schedule and above price P_1 is a measure of the compensating variation[21] — the benefits — the commodity provides that individual. That the area under curve $D_1^{Short\text{-}run}$ is larger than the area under $D_0^{Short\text{-}run}$ implies the consumer would value the commodity more in the long-run following their lifestyle adaption had the price been lowered 'a long time earlier' relative to the price being lowered a short time earlier.

The shaded area in the bottom graph of Figure 5 shows the induced change in benefits to this consumer in the current period from the project having been undertaken earlier. This represents the entire change in consumer surplus to the consumer.

[20] If the price change is moderate and the good in question accounts for a fairly small part of total consumption, then a Marshallian demand schedule (which is what empirical demand elasticities usually relate to) is a sufficient proxy for a Hicksian compensated variation demand schedule (Boardman et al pp 67–68). Otherwise additional analysis is required to refine the welfare estimate (eg Irvin and Sims 1998).

[21] The compensated variation is a theoretically correct measurement of the benefits a consumer obtains from a good or service (equivalent variation being the other). It represents the value of a lump-sum payment (positive or negative) that could be paid to a consumer following a price change of a good or service to make them indifferent to the price change. It represents a monetary measure of the change in utility (welfare) to the consumer. The entire benefit a commodity provides a consumer at a given price P is the full area under the compensating variation demand schedule above price P.

Figure 5 Inducing context changes to preferences



Source: NZIER

The upper graph of Figure 5 illustrates the same using indifference curves. The induced change over the long-run in how the consumer lives, works, and/or plays (in the case where short-run and long-run demand elasticities differ) changes the context that the preferences are expressed within. U_0 is the indifference curve had prices stayed at P_0, and U_1 represents the preferences if price P_1 had been sustained. The consumer's indifference curves tilt towards a greater amount of consumption of good *X* after a sufficient time lapse. This means the total benefit the commodity provides the consumer is larger than it would have been if a preference change had not been induced. We cannot fit this in the scale of the illustration, but we have illustrated the difference in compensating variation if the price were immediately raised from P_1 back to P_0. The measure CV_0 in the top graph is the estimate of how much worse off the consumer would be if induced long-run changes in their preferences were ignored. This estimate is smaller by the amount δCV if the consumer's increased dependence on the commodity was correctly accounted for (which equals the area below P_0 and D_1 and above P_1 and D_0).

Note that this discussion does not rely on inducing changes to the consumer's tastes, which is (as Neuberger 1971 p68 noted in a similar context) inscrutable to welfare economists. The argument only relies on inducing changes to circumstances that influences the consumer's expressed preferences — predictable contexts that feature in the domain of the consumer's utility function. For instance, people's willingness to pay for food at a moment in time generally differs depending on how hungry they are. Such behavioural variations can be anticipated and regarded not as changes in tastes, but rather as changes in circumstance.

There is support in the welfare economics literature to include total changes in consumer surplus as a benefit

It is not a new idea to consider changes in social surplus arising from the different evolution of demand schedules from an earlier policy as being valid welfare effects. Romer (1994) argues that when policy affects the evolution of markets, new goods and services can come into existence, then the entire area under the demand schedule for those goods and services is an increase in welfare. These areas Romer calls 'Dupuit triangles', in honour of Jules Dupuit's initial development of the idea of consumer surplus when estimating the overall social merits of potential roads, bridges and canals.

Romer argues they are typically ignored in policy appraisals because economists seem to 'assume, unless instructed otherwise, that all of the relevant goods already exist' (p21).[22] This occurs because of 'the deep philosophical resistance that humans feel toward the unavoidable logical consequence of assuming that genuinely new things can happen and could have happened at every date in the past' (p5).

In a developing economy context Romer argues that accounting for the different evolution of markets following a policy can lead to actual welfare effects that are much greater (up to 20 times greater in one numerical example) than those estimated when the number of markets in the economy is taken as a given. In other words, dynamic efficiency gains (by providing better conditions for growth to emerge) can well exceed static allocative efficiency gains.

22 That said, however, Harvey (2002) is an example of an attempt made to estimate the full consumer surplus for new (rather than improved) transport schemes.

4.2. Induced transport demand shifts as a measure of benefits

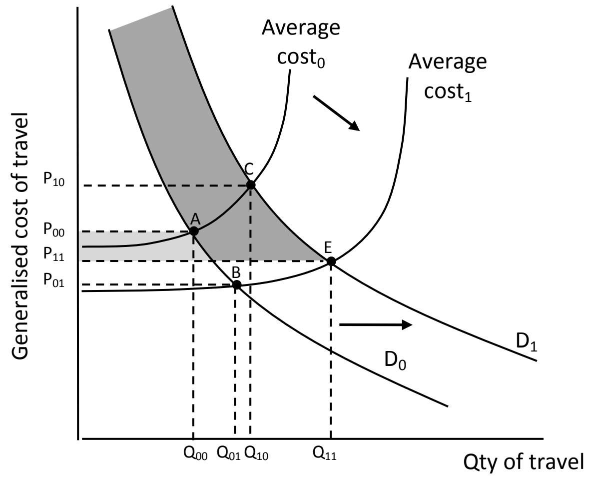
4.2.1. Induced shifts in the demand schedule

Consider a transport expansion project that increases accessibility and causes progressively more employment and household intensification in its vicinity. Figure 6 shows the impact some number of years after the project was completed, such that the short-run demand schedule D_1 lies to the right of what the demand schedule would have been if the project had never occurred, D_0. We take as a given that the difference between the two demand schedules at any point in time is attributable only to the project, and not to anything else (such as other exogenous factors, different initiatives undertaken, or different land use polices on what rate, and what kind, of growth is allowed).

In Figure 6 points *A* and *E* can be interpreted as the predicted outcome in the absence of, and with, the scheme, respectively.[23] The points *B* and *C* are different kinds of intermediate counterfactuals.

Figure 6 Direct transport benefits when land use change induced

Social average cost pricing



Source: NZIER

As argued in section 4.1, the total change in benefits to transport consumers from the scheme is the change in total consumer surplus:

Formula 4 The change in consumer surplus

$$\int_{P_{11}}^{\infty} D_1\,(P)dP - \int_{P_{00}}^{\infty} D_0\,(P)dP$$

[23] The prices and quantities have two subscripts each. The first subscript refers to the land use scenario, being 0 for the do-minimum and 1 for the option. The second subscript relates to the transport network configuration, again 0 for do-minimum and 1 for the option.

where $D_1(P)$ and $D_0(P)$ denote the demand functions for transport at a common point in time with and without the induced land use configurations respectively. (An allowance for producer surplus is made later in the chapter. The demand schedules could be time-indexed, but this is omitted for ease of notation.)

4.2.2. Estimating the direct benefits

We progress on the basis that the only useable information resulting from that analysis are the four coordinates *A, B, C*, and *E* in Figure 6 above. The notation we use is summarised in the table below:

Table 3 Transport costs and quantities

The key for the symbols used in the following equations

		Transport network (latter subscript)	
		Option network	Do minimum network
Determinants of demand (first subscript)	Demand with induced land use	P_{11}, Q_{11}	P_{10}, Q_{10}
	Demand without induced land use	P_{01}, Q_{01}	P_{00}, Q_{00}

Source: NZIER

To actually estimate the total consumer surplus change we must make strong assumptions about the functional form of the demand schedules. Three standard contenders are constant-elasticity, linear, and log-linear demand schedules.

Constant-elasticity demand schedules

Constant-elasticity demand schedules take the form:

$$Q = AP^{\varepsilon}$$

where A is a constant, Q is quantity, P price and ε the elasticity. One can calculate the equation of the entire iso-elastic demand schedule from observing two points along it[24], and then use integration to develop a standard formula to estimate the area under it and above the relevant price.

However, the area of total consumer surplus under an iso-elastic demand schedule is infinite whenever the elasticity is less than 1. Given that we need to use short-run demand elasticities, and given that these are usually less than 1, this method would be unworkable in this context.

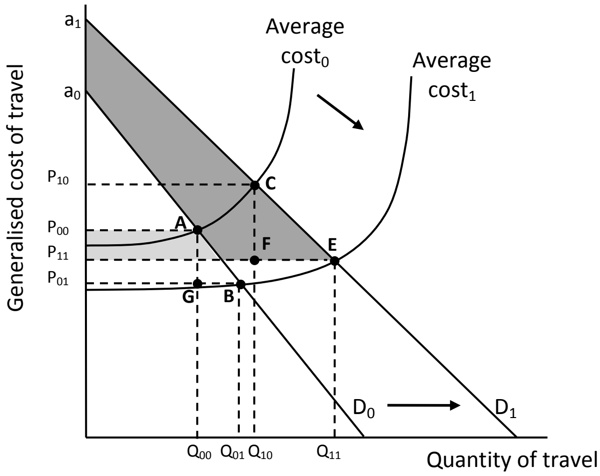
Linear demand schedules

Linear demand schedules take the form:

[24] For a given demand schedule ($i = 1{,}2$ for the land use scenario), $Q_{i1} = A_i P_{i1}^{\varepsilon_i}$ and $Q_{i2} = AP_{i2}^{\varepsilon_i}$. Substituting for A_i leads to $\varepsilon_i = \ln(Q_{i2}/Q_{i1})/\ln(P_{i2}/P_{i1})$, and $A_i = Q_{ij}/P_{ij}^{\varepsilon_i}$ where $j = 1{,}2$ (network scenario).

$$Q_{ij} = a_i + b_i P_{ij}$$

Figure 7 Determining benefits from transport model outputs



Source: NZIER

From Figure 7, the area of the large triangle a_1EP_{11} can be calculated by scaling up triangle *CEF* to become:

$$\frac{1/2\, Q_{11}^2 (P_{10} - P_{11})}{Q_{11} - Q_{10}}$$

From this can be subtracted the area of the smaller triangle a_0BP_{01} (which can be estimated by scaling up triangle *ABG*):

$$\frac{1/2\, Q_{01}^2 (P_{00} - P_{01})}{Q_{01} - Q_{00}}$$

To complete the calculation the area of trapezium $P_{00}ABP_{01}$ is calculated using the rule of a half:

$$1/2\,(P_{00} - P_{01})(Q_{01} + Q_{00})$$

The total change in consumer surplus with linear demand is:

Formula 5 The augmented rule of a half (no resource cost correction)

$$\int_{P_{11}}^{a_1} D_1\,(P)dP - \int_{P_{00}}^{a_0} D_0\,(P)dP$$
$$= 1/2\,(P_{00} - P_{01})(Q_{01} + Q_{00}) + 1/2\left[\frac{Q_{11}^2 (P_{10} - P_{11})}{(Q_{11} - Q_{10})} - \frac{Q_{01}^2 (P_{00} - P_{01})}{(Q_{01} - Q_{00})}\right]$$

If a project does not cause land use changes then there is only one demand schedule, and $P_{00} = P_{10}$, $P_{01} = P_{11}$, $Q_{00} = Q_{10}$, $Q_{01} = Q_{11}$. The second half of the formula cancels out, leaving just the conventional rule of a half for the one land use scenario. This means this formulation is a generalisation of the existing rule for linear demand.

Log-linear demand schedules

Log-linear demand schedules take the form:

$$ln\, Q_{ij} = \alpha_i + \beta_i P_{ij}$$

where $\alpha_i > 0$ and $\beta_i < 0$ are finite constants; $i = 0{,}1$ for counterfactual and option land uses; $j = 0{,}1$ for counterfactual and option transport scenarios; Q is quantity; and P is price. The elasticity increases as the price rises, and finite consumer surpluses are ensured.

To estimate the functional form of D_i we use the two observed price/quantity points to solve for α_i and β_i:

$$\beta_i = \frac{ln\, Q_{i1} - ln\, Q_{i0}}{P_{i1} - P_{i0}}$$

$$\alpha_i = ln\, Q_{i0} - \beta_i P_{i0}$$

The total consumer surplus in scenario i (where $j = i$, so that we consider either the option or the do-minimum land use and transport scenarios jointly), is:

$$\int_{P_{ij}}^{\infty} D_i\, dP = \int_{P_{ij}}^{\infty} e^{\alpha_i + \beta_i P}\, dP$$

$$= -\frac{1}{\beta_i} e^{\alpha_i + \beta_i P_{ij}}$$

Substituting α_i and β_i results in:

$$\frac{Q_{ij}(P_{i0} - P_{i1})}{ln\, Q_{i1} - ln\, Q_{i0}}$$

The total change in consumer surplus when demand is log-linear is:

Formula 6 Total consumer surplus change with log-linear demand

$$\int_{P_{11}}^{\infty} D_1\,(P)dP - \int_{P_{00}}^{\infty} D_0\,(P)dP = \frac{Q_{11}(P_{10} - P_{11})}{ln\, Q_{11} - ln\, Q_{10}} - \frac{Q_{00}(P_{00} - P_{01})}{ln\, Q_{01} - ln\, Q_{00}}$$

When there are no induced land use impacts the first subscript vanishes, and the log-linear version of the (linear) 'rule of a half' results:

Formula 7 Log-linear version of the 'rule of a half'

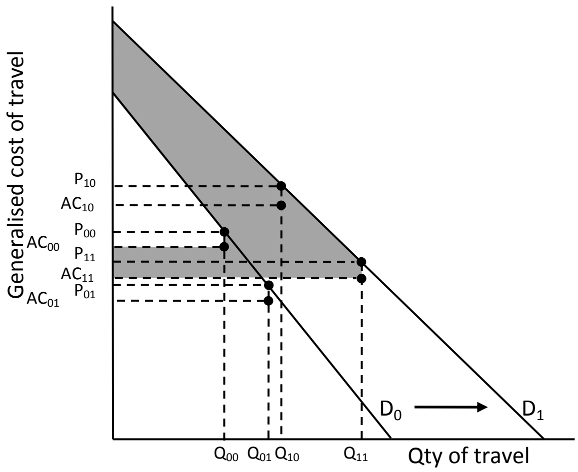
$$\int_{P_1}^{P_0} D\,(P)dP = \frac{(P_0 - P_1)(Q_1 - Q_0)}{ln\,Q_1 - ln\,Q_0}$$

4.3. Including taxation and subsidies

Transport is usually subject to various taxes and subsidies, and this needs to be taken into account. Figure 8 shows the benefit from attracting more land use intensification upstream and/or downstream of an improved facility when a charge such as fuel excise causes private costs to exceed resource costs.

Further, an allowance akin to 'producer surplus' needs to be added to the consumer surplus formulas derived above. This can be measured by the difference between the perceived price and the average social generalised cost of travel (which equals the charge levied) multiplied by quantity, $(P_{ij} - AC_{ij})Q_{ij}$. The change in total social surplus is shaded in Figure 8 for linear demand schedules.

Figure 8 Direct benefits from land use changes with taxes



Source: NZIER

There will be sixteen pieces of data available from the modelling, corresponding to eight quantity–price coordinates. These are summarised in the following table:

Table 4 Transport costs and quantities with taxes & subsidies

	Transport network (latter subscript)		
		Option network	Do minimum network
Determinants of demand (first subscript)	Demand with induced land use, perceived prices	**P_{11}, Q_{11}**	**P_{10}, Q_{10}**
	Demand with induced land use,	**AC_{11}, Q_{11}**	**AC_{10}, Q_{10}**

	resource costs		
	Demand without induced land use, perceived prices	**P_{01}, Q_{01}**	**P_{00}, Q_{00}**
	Demand without induced land use, resource costs	**AC_{01}, Q_{01}**	**AC_{00}, Q_{00}**

Source: NZIER

Linear demand

The area of total consumer surplus in the *option* land use and transport network scenario $\int_{P_{11}}^{a_1} D_1\,(P)dP$ has the full producer surplus of $Q_{11}(P_{11} - AC_{11})$ added. For linear demand this results in:

$$\frac{1/2\,Q_{11}^2(P_{10} - P_{11})}{(Q_{11} - Q_{10})} + Q_{11}(P_{11} - AC_{11})$$

By the same logic, total social surplus with the *do-minimum* land use and option transport network is:

$$\frac{1/2\,Q_{01}^2(P_{00} - P_{01})}{(Q_{01} - Q_{00})} + Q_{01}(P_{01} - AC_{01})$$

The rule of a half with a resource cost correction for the do-minimum land use scenario is:

$$1/2\,(Q_{01} + Q_{00})(P_{00} - P_{01}) + Q_{01}(P_{01} - AC_{01}) - Q_{00}(P_{00} - AC_{00})$$

The total change in social surplus for linear demand is:

Formula 8 Total social surplus change with linear demand

$$\begin{aligned}
\int_{P_{11}}^{a_1} D_1\,(P)dP - \int_{P_{00}}^{a_0} D_0\,(P)dP \\
&= [1/2\,(P_{00} - P_{01})(Q_{01} + Q_{00}) - Q_{00}(P_{00} - AC_{00})] \\
&+ \left[\left(\frac{1/2\,Q_{11}^2(P_{10} - P_{11})}{(Q_{11} - Q_{10})} + Q_{11}(P_{11} - AC_{11})\right)\right. \\
&\left. - \left(\frac{1/2\,Q_{01}^2(P_{00} - P_{01})}{(Q_{01} - Q_{00})}\right)\right]
\end{aligned}$$

If a project does not cause land use changes and there is only one demand schedule, then the formula reduces to the conventional rule of a half with a resource cost correction.

Log-linear demand

Adding the respective producer surpluses to the formula for total log-linear consumer surplus change results in:

Formula 9 Total social surplus change with log-linear demand

$$\int_{P_{11}}^{\infty} D_1 (P)dP - \int_{P_{00}}^{\infty} D_0 (P)dP$$
$$= Q_{11}\left(\frac{P_{10}-P_{11}}{ln\, Q_{11} - ln\, Q_{10}} + P_{11} - AC_{11}\right)$$
$$- Q_{00}\left(\frac{P_{00}-P_{01}}{ln\, Q_{01} - ln\, Q_{00}} + P_{00} - AC_{00}\right)$$

If there are no land use effects this reduces to:

Formula 10 Log-linear social surplus change with exogenous land use

$$\int_{P_1}^{P_0} D\,(P)dP = \frac{(P_0 - P_1)(Q_1 - Q_0)}{ln\, Q_1 - ln\, Q_0} + Q_1(P_1 - AC_1) - Q_0(P_0 - AC_0)$$

4.4. Cross modal and network effects

In principle the total social surplus change measures derived (Formula 8 and Formula 9) for a 'single market' generalise to the multi-dimensional case, where a single demand schedule allocates among various network components (Hotelling 1938 and Bates 2004).

Like the conventional rule of a half, the augmented formula can be applied to all origin-destination zone pairs, modes, routes, and pricing policies.

Under the methods proposed in this paper, induced land use changes that increase traffic growth would exaggerate the conventional finding that induced traffic lowers benefits (relative to no induced traffic) when networks are congested and not priced efficiently. Land use changes that reduce demand on other congested parts of the transport network would lead to additional net-benefits.

Some issues that may require further research relating to network effects are:

- In some circumstances one or more denominators in the linear and log-linear social surplus measures could equal zero. This could occur when a transport project has no effect at all on a part of a network (meaning $Q_{00} = Q_{01} = Q_{10} = Q_{11}$ somewhere in the network); and/or if there is an effect elsewhere in the network only because land use changes but demand would not change otherwise (meaning $Q_{11} = Q_{10}$ and/or $Q_{01} = Q_{00}$, but $Q_{11} \neq Q_{00}$).
- The generalised travel cost curves across transport networks are generally convex upwards, as the rate of congestion externalities accelerates with traffic flows; they are not linear, as is assumed with the current rule of a half (ATC 2006 p72). Determining the best functional form to use for the demand schedule (linear, log-linear, or something else) needs to have regard to the shape and nature of the actual cost curves (which will be situational).

- There is a question of how robust the total social surplus change measures are to transport model outputs across the whole modelled transport network. The measures use point estimates to scale up to the full consumer surplus; small margins of error could potentially be scaled up to large margins of error. (Note that this is a problem with all 'scale up' models.) If this proves to be a potential problem then some mitigation measures may need to be developed, such as adjusting the formulas or aggregating transport model zones to reduce relative variability.

5. Initial applications of the methodology

The approach was applied to the appraisal of a major roading scheme on behalf of the NZ Transport Agency (NZTA) using the Auckland LUTI model ART/ASP.[25]

The analysis was undertaken for two construction timing scenarios and for two regional growth assumptions (medium and high, corresponding to the forecasts undertaken for the 'Auckland Plan'). The intent was to determine if doing the project sooner would change net-benefits by stimulating economic development. It was clear that conventional appraisal methodology of using the rule of a half in tandem with exogenous land use, economic activity and population assumptions was not well suited to addressing such a question.

Only the linear demand formulation was used, and the effect on net-benefits was mixed. Relative to the conventional CBA results the net-benefits were greater under the delayed-timing/medium growth scenario but were lower than conventional benefits in both high growth scenarios (early and late construction) and also the early construction/medium growth scenario.

Some of the results may have been artefacts of the underlying structure and assumptions of the models, and the compatibility with the linear demand appraisal framework employed. These are discussed below.

However, to the extent that any methodological or modelling issues can be set aside, the findings would indicate that inducing land use change that leads to increased demand on congested transport networks in the absence of congestion charging may be a net-cost depending on the circumstances. That is, the additional benefits measured by the increased willingness to pay to use the improved network facility may not always be enough to cover the increased congestion externalities they cause.

Issues with origin-destination (OD) zone pairs that had small numbers of trips

Instances of origin-destination zone pairs were encountered where the net benefit figure became extremely large, some positive and some negative, as the difference in the number of trips got close to zero. (There were no origin-destination pairs that had zero change in trips.)

This is likely caused by the procedure taking very small differences in prices and quantities within the margins of error, and then extrapolating them.

One way forward is to determine how to aggregate zones to just the extent that the differences in costs and quantities between OD pairs fall outside the margins of error, and so that any extrapolating of the data is reasonable. Aggregating too much will dampen the overall result unduly. Any such aggregation would be on a project-specific basis, as areas close to the project are more likely to experience significant effects, whereas areas on the other side of the network are less likely to notice the existence of the project.

[25] ART = Auckland Regional Transport model, and ASP = Auckland Strategic Planning model.

Modelling more accurately the features of economic growth

The analysis found that there were detriments in some areas of the transport network of a similar order of magnitude to the benefits in others. This could be an artefact of the modelling rather than a reflection of reality. The ASP land use model assumed (as at 2012) a fixed regional population and fixed amount of economic activity (at any moment, but growing over time). Thus where demand increases in one area, it is at the expense of another. Urban economic theory would suggest that a significant improvement to an area would attract more people overall. This attraction of people could offset (to at least some extent) the decreases in demand in some areas that the model predicts. Thus if the LUTI model captured more of these sorts of effects then one might expect the procedure to better reflect the resulting economic benefits.

Accommodating induced growth and development through further transport network expansion

If one seeks to assess the costs and benefits of transport-induced land use change then it will be necessary to create some endogeneity[26] of future transport networks into the transport modelling. Otherwise, projects may seem to create congestion that would in practice be avoided or mitigated through economically net-beneficial investments.

The LUTI modelling results highlighted pinch-points in the local road network upstream and downstream of the transport improvements. In the real world, such increases in travel costs arising from earlier developments could be responded to by transport planners sensing the need for system tuning and expansion as they go. They could act accordingly within the funding allocation frameworks that govern them. In many instances the network capacity would be expanded where needed (though perhaps with a delay), rather than system costs escalating unduly.

However in the modelling undertaken, only the latter case holds, which unrealistically lowers the measured user-benefits. How modelling is done now is that any additional capacity expansions in future resulting from the growth the strategy causes need to be specified by the modeller from the outset as a part of the 'project'. The transport sector is specified wholly-external, and once the land use system starts to be modelled, the 'natural' response of transport capacity following land use development is absent.

In contrast, modelling of electricity networks routinely account for capital investment in generation capacity (dams, new wind farms etc). Some generation expansion models are relatively simple, whereby they rank potential projects in ascending order of their long-run marginal costs (LRMC). When the forecasted market price rises above the marginal project's LRMC then it comes on-line, which affects market prices in different parts of the network and so forth. Lessons from this kind of modelling could, and should, be applied to transport strategy modelling.

[26] I.e. make them outputs of modelling, rather than inputs.

6. Conclusion

This paper sought to explain that there are shortcomings in the methods of current transport CBA, which ignore the fact that transport strategies can change land use patterns in the long-run. The paper proposes a way to address these shortcomings using an extension to existing methodologies.

The approach recognises that long-run impacts can differ from short-run impacts, and when that happens there is no longer a unique short-run demand schedule after the initial periods. Existing CBA literature is quiet on how to appraise schemes that have different effects in the long- and short-run. We argued that one can use the total induced change in willingness to pay (the difference between two short-run demand schedules at the same point in time) as a measure of benefit.

We developed some methods to estimate this that would use only the typical outputs of a transport model when it is based on the land use scenarios that would transpire with and without the project. Estimating the induced land use changes is challenging, but we have assumed this can be done; our focus has been on how to turn those modelling outputs into welfare impacts.

The formulations derived depend on the functional forms of the demand schedules assumed. The best function form to use is an empirical question, and needs further work; the formulas provided could be regarded as examples.

In principle the methods should apply straightforwardly to full network transport modelling. However, this requires confirmation in practice.

There are some potential complications, and some of these seemed to play out in an initial application of the method to an actual project appraisal. We do not believe these complications to be game breakers, but further research is needed to confirm our belief.

We expect that the kind of appraisal method proposed would lead to quite different CBA results for different kinds of transport projects. It would show that ‘dynamic efficiency’ impacts could possibly be as important, if not more important, than the short-run static allocative and productive efficiency measures used now as the basis of decisions.

In the absence of efficient transport pricing (pricing at short-run marginal social cost), projects that seem beneficial under conventional appraisals may prove to create problems, currently ignored, that offset to a small or large extent these benefits. Major transport projects that induce land use change create complexities that are difficult to anticipate, attribute, and address. This complexity is compounded by the lack of price signals for people’s location decisions. These location decisions can influence the need for general infrastructure network upgrades whose capital cost is socialised across the relevant consumers — not internalised. A further complication is land use planning rules, some of which may have a dubious rationale.

One parting observation is that the benefits of congestion charging may be considerably greater than it is currently understood to be using static measures of economic welfare. To the extent that congestion charging has long-run ‘place-shaping’ effects, then the dynamic efficiency gains could be considerably larger — in terms of locking in less congestion and there being possibly less infrastructure spending to support a sprawling urban form.

7. References

ATC (2006a) *National guidelines for transport system management in Australia – Document 5 Background material.* Sydney: Austroads. 222pp.

ATC (2006b) *National guidelines for transport system management in Australia – Document 4 Urban transport.* Sydney: Austroads. 138pp.

Bates, J (2004) *Economic evaluation and transport modelling: theory and practice.* Resource paper for 10th IATBR: Moving through Nets.

Baum-Snow, N. (2007). "Did Highways Cause Suburbanization?" *Quarterly Journal of Economics* 122(2), 775-805

Blanchard O.J. & L.F. Katz (1992). "Regional Evolutions", *Brookings Papers on Economic Activity* 1, 1-61

Boardman, A, D. Greenberg, A. Vining and D. Weimer (2006) *Cost-benefit analysis: concepts and practice*. L. Jewell (Ed). New Jersey: Prentice-Hall. 560pp.

Bureau of Transport and Regional Economics (1999). *Report 100: Facts and furphies in benefit-cost analysis: transport*. Accessed 9 February 2012. *www.bitre.gov.au/publications/24/Files/r100.pdf*

Cochrane, William, Arthur Grimes, Philip McCann & Jacques Poot (2010). "The Spatial Impact of Local Infrastructural Investment in New Zealand", Motu Working Paper 10-12, Wellington: Motu

Coleman, Andrew (2010) Transport infrastructure, lock-out and urban form: Highway development in Auckland and the United States. *Policy Quarterly*, volume 6, No 4

Commerce Commission (2000) Decision No 410, *Ruapehu Alpine Lifts Limited and Turora Ski Resort Limited*, 14 November 2000

David Simmonds Consultancy and John Bates Services (DSC and JBS) (2001) *Appraisal in Land-Use/Transport Interaction: Design.* Report to Government Office for the North-West.

De Jong, G, Pieters, M, Daly, A, Graafland, I, Kroes, E, Koopmans, C (2005) *Using the Logsum as an Evaluation Measure: Literature and Case Study*, Prepared for AVV Transport Research Centre, Working Paper WR-275-AVV

Department for Transport (DfT) (2010a). *WebTAG unit 3.1.3: Land-Use / Transport Interaction Models*. Accessed 9 January 2012. *www.dft.gov.uk/webtag/documents/expert/unit3.1.3.php*

Department for Transport (DfT) (2010b). *WebTAG unit 3.16: Appraisal in the Context of Housing Development*. Accessed 9 January 2012. *www.dft.gov.uk/webtag/documents/expert/pdf/unit3.16d.pdf*

Duranton, G. & M.A. Turner (2007). *Urban Growth and Transportation*. University of Toronto Department of Economics Working Paper 305

Duranton, G and Turner, A (2009) The fundamental law of road congestion: evidence from US cities. *NBER Working Paper Series*. Working Paper 15376. Accessed 19 February 2012. *www.nber.org/papers/w15376*

Geurs, K, van Wee, B, Rietveld, P (2006) Accessibility appraisal of integrated land-use/transport strategies: methodology and case study for the Netherlands Randstad area. *Environment and Planning B: Planning and Design* 33, pp 639–660

Geurs, K, Zondag, B, de Jong, G, and de Bok, M (2010) Accessibility appraisal of land-use/transport policy strategies: More than just adding up travel-time savings, *Transportation Research Part D: Transport and Environment*, 15(7) pp 382–393

Glaeser E.L. & J. Gottlieb (2009). "The Wealth of Cities: Agglomeration Economies and Spatial Equilibrium in the United States", *Journal of Economic Literature* 47(4), pp983-1028

Goodwin, P B (1992) A Review of New Demand Elasticities with Special Reference to Short and Long Run Effects of Price Changes, *Journal of Transport Economics and Policy*, Vol. 26, No. 2 (May 1992) pp 155–169

Grimes, A and Liang, Y (2010) Bridge to somewhere: Valuing Auckland's Northern Motorway Extensions, *Journal of Transport Economics and Policy*, 44:3, pp 287–315

Grimes, A (2011) *Building bridges: Treating a new transport link as a real option*. Motu Working Paper 11-12

Grimes, Arthur, Mark Holmes & Nicholas Tarrant (2010). "New Zealand Housing Markets: Just a Bit-Player in the A-League?". Motu Working Paper 10-07, Wellington: Motu

Grimes (forthcoming) Infrastructure and Regional Economic Growth. *Handbook of Regional Science.* M Fischer and P Nijkamp (Eds). Springer

Harvey, M (2002) *Measuring the benefits of new transport services*. 25th Australian Transport Research Forum; Incorporating the BTRE Transport Policy Colloquium, Canberra 2–4 October 2002

Hensher, D, Truong, T, Mulley, C, and Ellison, R (2012) *Assessing the wider economy impacts of transport infrastructure investment with an illustrative application to the north-west rail link project in Sydney, Australia*, Institute of Transport and Logistic Studies Working Paper ITLS-WP-12-05

Hotelling, H S (1938) The general welfare in relation to problems of taxation and of railway and utility rates, *Econometrica*, 6, pp 242-269

Institute of Transport Economics (ITE) (2003) *Developing Sustainable Land Use and Transport Strategies: A Methodological Guidebook*. Accessed on 7 January 2011. *www.infra.kth.se/courses/1H1402/Litteratur/pr_del14mg.pdf*

Irvine, I, and Sims, W (1998) Measuring Consumer Surplus with Unknown Hicksian Demands, *The American Economic Review*, Vol. 88, No. 1 (March 1998), pp 314–322

Joutz, F, Trost, R, Shin, D, and McDowell, B (2009) *Estimating Regional Short-run and Long-run Price Elasticities of Residential Natural Gas Demand in the U.S.* United States Association for Energy Economics (USAEE) working paper 09-021

Kennedy, D and Wallis, I (2007) *Impacts of fuel price changes on New Zealand transport*, Land Transport NZ Research Report 331

Kernohan, D and Rognlien, L (2011) *Wider economic impacts of transport investments in New Zealand*. NZ Transport Agency research report 448

Maré, David, Arthur Grimes & Melanie Morten (2009). "Adjustment in Local Labour and Housing Markets", *Australasian Journal of Regional Studies*, 15(2), pp 229-248

Martinez, F, and Araya, C (2000) *A note on trip benefits in spatial interaction models*, Journal of Regional Science 40, pp 789–796

Metz, D (2008) The Myth of Travel Time Saving. *Transport Reviews*, Vol. 28, No. 3, pp 321–336

Mohring, H (1993) Maximising, measuring, and not double counting transportation-improvement benefits: a primer on closed- and open-economy cost-benefit analysis. *Transportation Research* 27B, No. 6, pp 413–424

Neuberger, H (1971) User benefit in the evaluation of transport and land use plans. *Journal of transport economics and policy*, vol 5, no 1

Neuberger, H, and Wilcox, J (1976) The economic appraisal of land-use plans. *Journal of transport economics and policy*, pp 227–236

Noland, R and Lem, L (2001) *A review of the evidence for induced travel and changes in transportation and environmental policy in the United States and the United Kingdom*. Accessed 14 June 2012: *wenku.baidu.com/view/3826d56a011ca300a6c39012*

Nordås, H, S Miroudot and P Kowalski (2006) *Dynamic Gains from Trade*, OECD Trade Policy Papers, No. 43, OECD Publishing. http://dx.doi.org/10.1787/276358887412

NZIER and PwC (2010) *Additional Waitemata Harbour Crossing — Economic Benefits and Funding Options Report*. Report for NZTA (Auckland Office).

NZTA (2010) *Economic Evaluation Manual (volume 1)*, *www.nzta.govt.nz*

Parker, C (2012, forthcoming) *Implications of Road Investment — Review of economic appraisal methods* Research report for NZ Transport Agency

Polemis, M (2007) Modeling industrial energy demand in Greece using cointegration techniques. *Energy Policy* 35(8) pp 4039–4050.

Romer, P (1994) New goods, old theory, and the welfare costs of trade restrictions. *Journal of Development Economics*, 43 pp 5–38

Rouwendal, J (2001) *Indirect welfare effects of price changes and cost-benefit analysis*. Tinbergen Institute Discussion Paper, TI 2002-011/3. Accessed 9 February 2012. *www.tinbergen.nl/discussionpapers/02011.pdf*

Simmonds, D (2011) Viewpoint (in response to Metz 2008 and Wenban-Smith 2010). *Local Transport Today*. Issue 574, 1 July 2011

Simmonds, D C and O Feldman (2011) Alternative approaches to spatial modelling. *Research in Transport Economics*, vol 31 pp 2-11

Simmonds, D C (2012) *Developing land-use/transport economic efficiency appraisal.* Paper presented to the European Transport Conference, Glasgow, 8-10 October 2012. Accessed 15 March 2013: www.davidsimmonds.com

Standing Advisory Committee on Trunk Road Assessment (SACTRA) (1994) *Trunk roads and the generation of traffic*, United Kingdom Department of Transport, London

Steer Davies Gleave (2011) *Transport Appraisal Summit 2011*. Accessed 9 February 2012. *www.steerdaviesgleave.com/sites/default/files/UKTA_Summary_paper.pdf*

Sugden, R and Williams, A H (1978) *The principles of practical cost-benefit analysis*. Oxford University Press

Wallis, I, D Wignall and C Parker (2012) *The implications of road investment*. NZ Transport Agency Research Report 507

Wenban-Smith, A (2010) Where's the evidence that time savings from new roads deliver tangible economic benefits? *Local Transport Today*, March 2010.

Williams, H C W L (1976) Travel demand models, duality relations and user benefit analysis, *Journal of Regional Science*, vol 16, no 2, pp 147–166