Appraising transport strategies that induce land use changes

Estimating benefits of land use change from standard transport model outputs

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Abstract

Cost-benefit analysis (CBA) is a key component of transport planning and appraisal. Worldwide best practice transport CBA requires that any land use changes that any transport strategy induces must be ignored. This is in stark contrast to what evidently happens in real life. This paper proposes an adjustment to current methodologies to account for the welfare effects of transport induced land use change using data that is typically provided by transport models for CBA. The paper describes the findings from an initial application of the procedure, and new issues that arise for transport planning, modelling and appraisal.

Executive summary

Are transport projects that cause urban sprawl good or bad for economic welfare? What of those transport strategies that cause denser urban form? Prevailing economic cost-benefit analysis (CBA) methodologies for transport strategies do not shed light on such questions. That is because transport appraisal methods have not been adapted sufficiently to incorporate induced changes to land use (which encompasses economic activity, area population and spatial distribution).

The primary elements of CBAs of even the most potentially transformational transport projects in New Zealand assume that the projects have zero effects on the number of people that live, work, and play in each location. Thus analysts that measure transport benefits are essentially only measuring marginal effects to people that would have been travelling, and doing what they do, anyway. Transport CBA does not consider the effects on how a region evolves (i.e. the effects on regional population, economic activity, and locations), and what this means for transport outcomes and the ultimate net-benefits. It is possible then that some major projects may be much better, or much worse, than the currently estimated benefit-cost ratios would indicate.

Land transport infrastructure investments are subjected to well-established rigorous CBA methodologies. 'User benefits' are measured as the net-increase in social surplus following a reduction in the generalized cost of travel. The demand schedules that underpin appraisals are determined by forecasts of land use, economic activity, and population.

That these forecasts that determine the transport demand schedule must be exogenous is at odds with a commonly-known fact that transport strategies can have a strong influence on urban development patterns. The Auckland Harbour Bridge is a classic example of a project causing an explosion of development that surprised planning authorities of the time.

'Land use/transport interaction' (LUTI) modelling has long been established to represent this two-way relationship. There is a 'state of the art' LUTI model for the Auckland region. However, the knowledge gained from LUTI models is put aside and not permitted to play a direct role in a project's core CBA.

A project that substantially improves the accessibility from an urban area transport network can provide new production and consumption opportunities to firms and households. Take-up of these opportunities would occur over the longer term and involve locating activities in the vicinity of the improved facilities. In the spirit of Paul Romer the new and improved markets for land create, and increase, existing 'Dupuit triangles' (total consumer surplus). Romer argues Dupuit triangles are usually ignored in policy analysis 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'. As the facility induced the increases in social surplus in related markets, it is reasonable to consider that the new activities would depend on the facility. Transport is a 'derived demand'; the willingness to pay for a transport facility is determined by the demand for the activities it enables. The increased willingness to pay to use the improved facility should proxy the wider benefits it enables (at least if related markets are efficiently priced).

This research considers whether the standard outputs of a fit-for-purpose LUTI model could be used to estimate the welfare effects of transport strategies that change land use. A formula is derived to augment the existing 'rule of a half' that measures the additional welfare changes from land use effects (and equals the existing rule if there are none). The 'augmented rule of a half' formula includes a 'resource cost correction' (for tolls, charges, fuel taxes, public transport subsidies etc). It can be used to appraise the net-benefits of congestion charging policies that influence long-term urban development patterns.

The approach should better discriminate between projects that change urban development. Early applications using the full Auckland Transport Model suggest that the measured benefits will be higher (than traditional estimates) if the network can cope with the land use changes, and lower if the network is congested. This finding is analogous to conventional analysis of induced travel effects.

Major network improvements that can, and are expected to, cater for larger population bases without undue congestion will likely be considered more favourably under the proposed approach.

Those projects that cause development patterns that worsen long-term congestion externalities will be treated less favourably. Similarly will projects that aim to reduce congestion in the absence of congestion charging (because the roads fill up again from an inflow of new residents and increased transportation intensive production activity).

It is hoped that such a procedure as that proposed here will allow transport planners, modellers and economists to more constructively contribute to better analysis and decision making.

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1. Introduction and motivation

This research considered whether it was possible to appraise transport projects that induce land use changes knowing only the typical outputs of a transport model (supposing one knows sufficiently well what the induced land use changes would be).

Economic cost-benefit appraisals (CBA) of land transport strategies are a common part of transport planning and decision making frameworks around world. One of the key defining features of the methodologies used is that the factors that govern what is the demand schedule for transport in any one time period are required to be exogenous. These factors include regional population, economic activity, and the use of land for residential, business and other purposes. (For brevity the term ‘land use’ is used to represent all of these things.)

It is known that transport strategies can affect land use, and that land use affects transport demand. Building a motorway between a city’s hinterland and the city centre can induce housing development on the outskirts of the city, which are changes in how many people reside and work in each locality of the wider city region.

Although practice the world over rather strictly adheres to a position that induced land use changes cannot be considered in appraisals, there is no apparent reason why this should ideally be the case. For cases where induced land use effects may be material to overall benefits it is preferable to develop the existing appraisal methodologies to allow for induced land use changes. These should make use of the forecasts produced by the likes of ‘Land Use/Transport Interaction’ (LUTI) modelling.

This paper:

a) reviews the literature relating to the economic welfare appraisals of transport projects that induce land use changes
b) outlines the economic welfare position the authors take on this subject
c) develops, and interprets, a procedure to estimate the net benefits in accordance with (b) above using the same type of output from transport models that are used for conventional appraisals
d) describes the findings of an initial application of the approach, and questions and issues it poses for economists and the transport planning and modelling professions.

It is recognised that more theoretical rigour relating to point (b) would help further the case to the transport sector to adopt the methodology proposed (or a variant of it). Also the full welfare effects of the phenomena of increasing returns to scale (where a larger population increases a region’s amenity and productivity, such as outlined by Grimes (forthcoming)) are not claimed to be fully captured in the method proposed.

This paper does not focus on capital, operating, and maintenance costs, 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).

2. Literature review: the background for transport CBA

2.1 Introduction to transport cost-benefit analysis

The fundamental question for decision makers is whether or not society is better off by doing an initiative. An 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 (in its broadest sense).

Economists can calculate the increase in the value of consumption to the whole economy just by focusing on the demand, and thus willingness to pay, for the infrastructure provided. This affords a great deal of simplification for transport CBAs.

2.2 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 (combinations of travel time and vehicle operating costs and other factors) and the quantity of travel.

Figure 1 shows the basic structure of the model. An inverse demand schedule represents how much travel would be demanded on the transport link that is proposed to be improved for a given level of generalised cost.[1]

An average social cost curve (AC) represents total travel costs to everyone for different levels of use. The average cost curve is convex, and is flat and minimal for modest traffic levels, but its slope progressively increases as more people use the link, worsening congestion and slowing traffic.[2]

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[3] (CS) — the shaded area P_0ABP_1 (assuming no pricing or subsidies).

To generalise for non-linear demand schedules 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, so

1 'Generalised cost' is a combination of travel time, 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.

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

3 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).

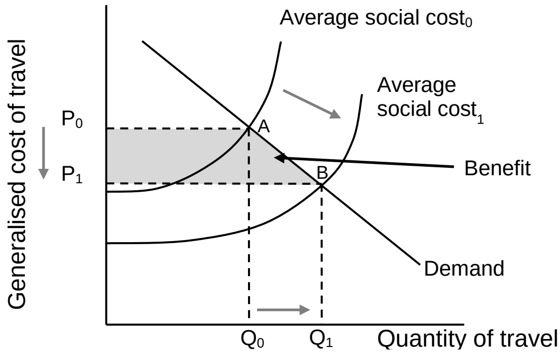
that the benefit may be written as ΔCS = $-\int_{P_0}^{P_1} f(P).dp$ (where *f(P)* is the demand schedule).

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':[4]

Equation 1 The rule of a half

$$1/2\,(P_0 - P_1)(Q_1 + Q_0)$$

Figure 1 The rule of a half for direct transport benefits



Source: Author

When there are taxes and subsides

It is common for there to exist fuel excise duties, road user charges, public transport subsidies 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):

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

$$1/2\,(P_0 - P_1)(Q_1 + Q_0) + Q_1(P_1 - AC_1) - Q_0(P_0 - AC_0)$$

This formula is based on Equation 1 and adds the net increase in revenues to the infrastructure operator.

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 the first instance, to a large extent such a criticism, in principle, is unwarranted.

[4] 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 (e.g. time plus expenses) as perceived by travellers, which in the absence of transfer taxes and subsidies 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.

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 in principle 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).

There are also criticisms that traditional CBA practice as a whole fails to account for the full welfare impacts across society because CBA is only a 'partial equilibrium' analysis. Boardman et al (2006 p118) explain that this criticism, in principle, is also unwarranted:

- Boardman et al show that if the demand schedules are of an 'equilibrium' (rather than 'textbook') variety that account for changing prices in related markets, then the CS benefits approximate the true welfare change to society as a whole (if the 'integrability condition', described below, holds)
- Boardman et al argue that real world demand estimates are of the 'equilibrium' variety because it is usually too difficult for analysts to hold prices in all other markets constant.

The idea that the willingness to pay for the improved infrastructure link represents overall benefits across society (at least in an efficiently-priced economy) underpins the method we propose later to appraise induced land use changes.

The rule of a half for the rest of the network

Bates (2004) describes that the rule of a half generalises straightforwardly to a multimarket case. The change in CS equals:

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

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, one for each transport 'opportunity', be they links, modes, routes, corridors, times of travel, etc), and $\boldsymbol{f}(.)$ is the vector of demand functions unique for each transport 'opportunity'. 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* (ATC 2006a, p75).

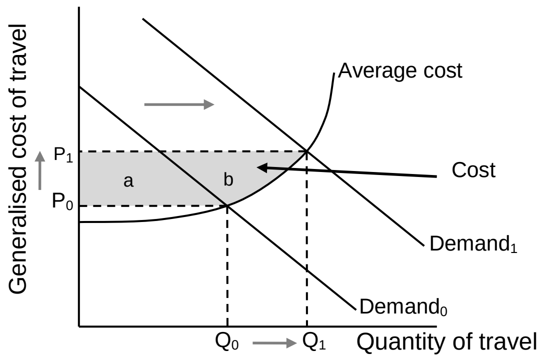
Illustrating the rule of a half for the rest of the network

It is common in transport CBA textbooks and guidelines to illustrate the effects of an improvement on the rest of the network, and to clarify how the effects are accounted for in the appraisal. Doing so helps to visualise the effects, and may aid intuition.

The Australian Transport Council (ATC) National Guidelines (2006a pp 66–75) makes use of a shifted demand schedule for related parts of the network.[5] Where one part of a network is a substitute for another then it can be regarded as 'parallel infrastructure', of which the demand schedule shifts left following the improvement. An improvement can cause a right shift in the demand schedule for usage on infrastructure that is 'upstream or downstream' from the new initiative.

Figure 2 shows the effects on upstream and downstream links. ATC (2006 pp 72–73) show that when these links are congested and congestion pricing is absent then this re-routing is detrimental by the area *a* + *b* — an area of approximately a trapezium that the rule of a half measures. In the case of the link being a congested parallel route, demand is reduced, making the analogous area *a* + *b* a benefit.[6]

Figure 2 The rule of a half for upstream /downstream infrastructure



Source: Author

What this means is that induced travel from a transport scheme may be a good thing, or a bad thing, depending on the capacity of the rest of the network. If the scheme induces travel onto uncongested parts of the network, then inducing travel is beneficial (ignoring externalities such as pollution). Induced travel demand lowers benefits if it causes more demand for unpriced congested parts of the network (links, modes, routes, peak periods etc).

ATC (2006 pp 68–69) show that if other transport links (routes and modes) were priced efficiently (i.e. where the perceived price equalled marginal social cost), then there are no net-welfare effects relating to them. The rule of a half with a resource

5 All demand schedules referred to in this paper are of the 'equilibrium' variety that do not hold prices across the economy fixed, as per Boardman et al (2006 pp 116–118), Mohring (1993), and ATC (2006 pp 66–67).

6 The area under the demand schedule for a 'related market' does not in itself constitute a welfare change. Counting it would result in double counting (Boardman et al p114, and Sugden and Williams (1978) p135). From ATC (2006 p68), in the context of a left shift of the demand schedule for a parallel link:

> *The area between the two demand curves… is not a loss of WTP [willingness to pay]. There is a drop in users' valuations because of an improvement in the alternative service due to the initiative, but users do not suffer any disbenefit. The marginal user, diverting to the improved infrastructure, does not experience a net loss in WTP either. Their WTP transfers to the market for the improved infrastructure.*

cost correction continues to apply in that case. (There are no road congestion charging schemes in New Zealand, and nor are they very common overseas.)

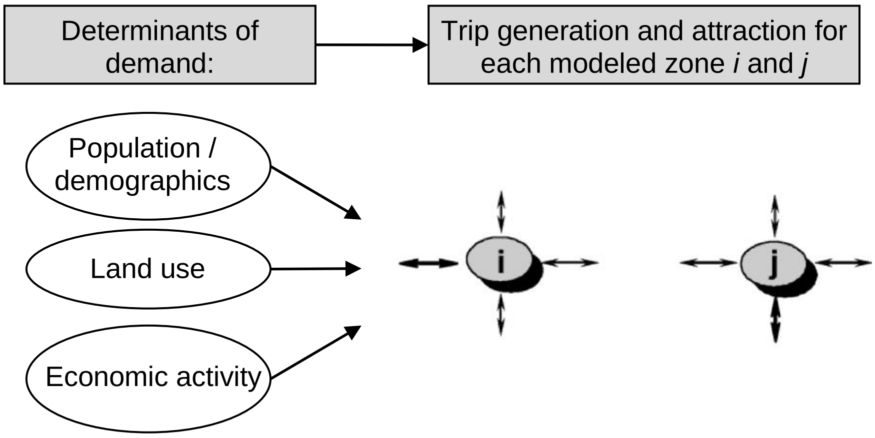
Other sources of benefits and detriments

There are other sources of welfare impacts, such as crash savings, pollution, labour taxation, imperfect competition etc that CBA can attempt to account for. For the remainder of this report we largely ignore these elements, and instead focus on the issue of induced land use changes.

2.3 Evidence that transport strategies can induce land use change

The demand for travel is primarily determined by population/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 3 provides a stylised representation of this.

Figure 3 Determinants of trip generation and attraction



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

The effects of major transport strategies on regional population and economic activity

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

Coleman (2010) reviewed the evidence on 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) in a paper for the *Handbook of Regional Science* describes the conceptual framework that population and employment increase following major net-beneficial improvements to transport networks. The work is underpinned by the theory of 'spatial equilibrium' in the urban economics literature; the idea that people will keep adjusting in response to a new development until the net benefits of locating in one place are equal to those from locating elsewhere. Grimes shows that if net amenity benefits are positively and highly related to region size, and if the economy exhibits a high degree of returns to scale, then it is possible for a region to experience 'explosive growth' following infrastructure investment for a finite period of time. The city of Shenzhen in China is an example of this, whereby the city population grew from 1,200,000 to 7,000,000 between 1990 and 2000.

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

- 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. Thus, in economic terms, New Zealand needs to be considered as a "subnational" component of the broader Australasian economy.

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

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

- Major new road schemes would generally 'induce' different patterns of land use development than would occur in the absence of the scheme, with the types of commercial development most attracted to the vicinity (say near motorway interchanges) of the scheme being:

- distribution/warehousing activities, serving national and regional markets
  - large mall (hypermarket) and superstore developments, that depend on large catchment areas
  - high-technology growth industries
  - offices requiring good access for employees and visitors, but not requiring central area locations
- This induced land use will result in increased traffic volumes using the new road. However there is very little ‘hard’ evidence on the extent to which this will happen:
  - 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)
- 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 well exceed the total of all other induced traffic components, in some situations.

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 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:*
>
> 1. *an increase in driving by current residents*
> 2. *an increase in transportation intensive production activity; and*
> 3. *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.*

Metz (2008) 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.

2.4 Why do transport CBAs ignore induced changes to demand schedules?

It is not common knowledge

Worldwide best practice transport CBA ignores any induced changes to transport demand. The assumption is evidently that it either does not happen, or if it does happen, it is immaterial to the CBA result.

This strong assumption is not common knowledge. For instance, the NZ Transport Agency's Economic Evaluation Manual (that prescribes how transport CBAs should be done) does not actually say as much. Nor do the Australian Transport Council National Guidelines.

It is only by working very closely with transport modellers on the CBAs of many major transport schemes, and engaging with overseas experts, that the author has learned how strictly applied this strong assumption is.

Where is the defence of 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 an explanation as to why.

Section 2.6 of the United Kingdom Department for Transport (DfT) WebTAG 3.1.3[7] 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 outline any defence of why land uses should be fixed.

The author has discussed this issue at length with Dr David Simmonds, who is based in England and is a world leader in the field of LUTI modelling (and helped lead the development of the Auckland LUTI model). Dr Simmonds suggested the following reason why people may be apathetic to consider incorporating land use change into appraisals. 'The impacts of transport change beyond those captured in transport models… are conventionally excluded from transport appraisal on the grounds that whilst they may change the form of benefits (eg from better accessibility to higher rents) or their distribution (eg occupiers vs landlords) they do not change total

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[7] 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*

benefits, and hence do not affect key results such as cost-benefit ratios' (Simmonds 2011).

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 implies that all else equal the measured travel time savings presents the minimum benefit, of which many people will have a surplus over and above. Another issue is the land use induced traffic may potentially be associated with congestion and pollution externalities. 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 closest we have found to an explanation of why CBA ignores land use change is because the existing rule of a half in isolation is insufficient to account for the full welfare impact. David Simmonds Consultancy and John Bates Services (DSC and JBS 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'. DSC and JBS (2001 piii) state that:

> *"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."*

The reason the rule fails is because it only works if demand schedule is exogenous and it is the supply schedule only that shifts; in that case the net effect is a change in social surplus approximated by the shape of a trapezium. If both the demand and supply schedules shift, then a different approach is needed. Simmonds and Bates proposed an alternative methodology to appraise transport schemes that induce land use change, as described further below.

Some problems caused by a fixed land use assumption

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 a complete approach to measuring benefits.

2.5 Alternative appraisal methodologies proposed in the literature

Two relatively recent constructive attempts to account for induced land use changes in transport appraisals are the following:

- DSC and JBS (2001) (followed up by ITE (2003)) who propose to use various aspects of a land use/transport interaction model to measure the sum of conventional transport benefits and benefits related to land use improvements at trip destinations and at residences
- 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.

DSC and JBS note some earlier attempts at developing transport CBA methodologies when land use changes are induced, such as Neuberger (1971) and others that are based upon LUTI modelling. DSC and JBS (p4) note that although those earlier papers 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.*"

The Simmonds and Bates approach

Essentially, the position is as follows (following the arguments leading up to Eq (51) in Appendix B of DSC & JBS, 2001). Following a change in land-use induced by a transport change, the total user benefit can be calculated as ΔCS(transport) + ΔCS(productions/residence) + ΔCS(attractions). Each item may be approximated by the rule of a half, but different costs/utilities will be used. The terms relating to productions and attractions are concerned with intrinsic utility associated with location. In line with the standard rule of a half, locations where there has been no change in this intrinsic utility will not make a contribution to benefit.

Given the currently perceived problems in measuring any change in intrinsic utility, the current measure of user benefits assumes that these are zero, and the implications of zero change are that the land-use is unchanged. Under these circumstances, ΔCS(transport) can be validly interpreted as the benefit of the transport scheme assuming no induced change in land use. If the transport demand in the "with scheme" case were to make allowance for changed land use, the standard calculation of ΔCS(transport) on its own would give the wrong result.

The Simmonds and Bates approach has not yet achieved buy-in from the wider transport sector. Having discussed this with the authors the issue seems to be the difficulty of defining the appropriate cost changes for ∆CS(productions/residence) and ∆CS(attractions) in order to carry out the calculations, and the intuition of those definitions.

The DfT's 'unlocking dependent housing' approach

DfT's proposed methodology appraises 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). (DfT do not explain what these principles are). The approach considers the land use value uplift as a benefit additional to the transport benefits, and subtracts the congestion detriment the land use change causes.

The DfT approach is only used when neither the transport nor the development can be justified in the absence of the other scheme (given prevailing appraisal methods). The approach is not suitable for applying generally to transport projects that induce land use changes when those changes are permissible.

2.6 Summary

There is no clear reason why induced land use changes should be ignored. Such changes would induce shifts to the demand schedule for the improved facility over time (as distinct from exogenous changes that would occur anyway, say from population growth). An initiative that is evidently so significant to people that they change how they live their lives (where they live, work, and play) to become more dependent on that facility is likely to have additional welfare impacts compared to what is currently estimated when these impacts are ignored. In the next chapters we propose a CBA methodology to try to take account of these effects.

3. The direct benefits of a transport project with land use changes

3.1 The key proposition

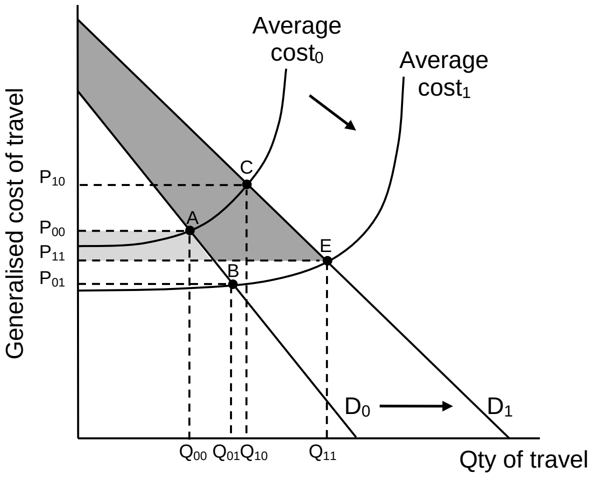
Induced shifts in the demand schedule

If a project progressively over time causes employment and household intensification in its vicinity,[8] then the determinants of the demand for the transport link change. Figure 4 shows the impact at some time in the future when, if the scheme had been built earlier, there has been sufficient elapsed time for induced land use changes to come into play. The demand schedule in the option scenario will likely lie to the right of the do-minimum demand (respectively D_1 and D_0 in Figure 4) following an improvement in transport accessibility.[9] We take as a given that the difference in the two demand schedules 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 4 points A and E can be interpreted as the predicted outcome in the absence of, and with, the scheme, respectively.[10] The points B and C are different kinds of intermediate counterfactuals.

Figure 4 Direct transport benefits when land use change induced

Social average cost pricing



Source: Author

[8] We presume that in the first instance the intensification occurs because of better accessibility, rather than because of increasing returns to scale (agglomeration). We consider incorporating agglomeration economies to be a subsequent, but nonetheless potentially important, extension.

[9] A transport capacity constriction could have opposite effects to that described here, but the analytics do not change.

[10] 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.

Proposition: the change in total consumer surplus measures a change in economic welfare

It is proposed that the net-benefit can be calculated as the change in CS when allowing for induced land use changes (using the integral formula given earlier) as:

Equation 3 The change in consumer surplus

$$\int_{P_{11}}^{\infty} f^1(P).dP - \int_{P_{00}}^{\infty} f^0(P).dP$$

where f^1 and f^0 denote the demand functions for the scheme and no-scheme land use configurations respectively. In other words, this is the difference between the total consumer surplus for the scheme with induced land use and that for no scheme with no induced land use.

Each of the two demand schedules represents the (equilibrium) amount of travel demanded for any given level of generalised cost where land use is regarded as being held fixed as at that point in time. (The demand schedules could be time-indexed, but this is omitted for ease of notation.) The only difference between the two equilibrium demand schedules is that in the long-run land use is permitted to change in response to the project. This means the two demand schedules are consistent and comparable.

The area of consumer surplus under each demand schedule represents the net-social benefit of the facility for a given land use scenario (as it represents total willingness to pay less total social costs, and assuming for the moment that there are no charges, taxes or subsidies etc).

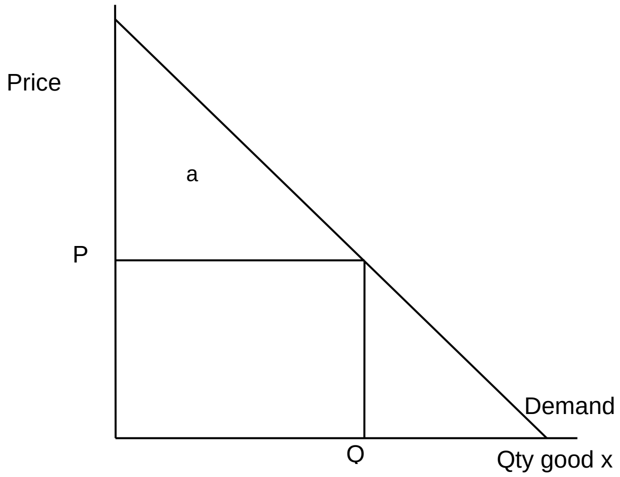
That the difference in consumer surplus only comes about from the scheme having being built early enough for land use changes to have occurred means the change in social net-benefit can be attributed to the scheme. Care would be needed to prevent a spurious benefit calculation based (for example) on two demand schedules relating to different populations not attributable to the project, or in different years.

Estimating welfare changes from new and/or altered demand schedules?

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, such that 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 (area *a* in Figure 5 below). 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). 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).

Figure 5 Dupuit triangle for a newly emerged good or service



Source: Author

Romer argues that accounting for the different evolution of markets following a policy can lead to actual welfare effects that are potentially multiple times larger in scale than those estimated when the markets in the economy are regarded as exogenous.

The increase in WTP in the 'primary market' approximates new Dupuit triangles in related markets

A transport project that substantially improves the accessibility to certain locations can provide new production and consumption opportunities to firms and households. New ways that resources, such as land, can be used creates new markets for those resources. These new markets bring into existence Dupuit triangles.

The challenge is how to measure and aggregate these CS effects.

We propose that these can be estimated by the increase in the Dupuit triangle for the primary market (i.e. the transport market(s) that incur the rightward shift of the average cost curve). In a multi-good economy it is not the simple sum of social surpluses that are added across all markets. Rather it is the 'line integral', which has the property that although the change in CS in related markets represents a welfare effect, it is already accounted for in the WTP of the primary market (Boardman et al 2006 p113–118).

It would thus follow that if new (or larger) Dupuit triangles emerge over time as areas evolve in response to a new area being opened up by a transport improved facility, then the WTP to use the transport facility will increase proportionately. By measuring the increased WTP of the facility itself, we are indirectly estimating the wider consumption gains that come about from the new land use developments.

To conclude, as the facility induced the increases in social surplus in related markets, it is reasonable to consider that the new activities would depend on the facility. Transport is a 'derived demand'; the willingness to pay for a transport facility is determined by the demand for the activities it enables. The increased willingness to pay to use the improved facility should proxy the wider benefits it enables (at least if related markets are efficiently priced).

How good is this measure at fully accounting for the net-benefit of induced land use changes?

Intuitively we would expect that the induced increase in willingness to pay by a scheme caused by changes in the structural determinants of the demand for the scheme is a good first approximation of the net-benefits of the scheme. In the very least, we suggest that this measurement of social value would be a much closer approximation of actual net-benefits than is the case under prevailing appraisal methods.

It is not immediately apparent whether the approach proposed here is compatible with the DSC and JBS (2001) approach. Since no explicit account is taken of the additional utilities associated with the land-use changes in the welfare appraisal proposed here it is the case that the additional utilities are assumed to be implicit in the shift of the demand curve from D_0 to D_1.

3.2 Some assumptions

We assume that separate modelling analysis has established suitably robust expectations as to the land use implications of the transport scheme over time. Here we take this as given (without wishing to understate the difficulties in such modelling), and focus on what the implications are to measuring net benefits.

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

3.3 Estimating the direct benefits

It is possible to approximate the benefits from Equation 3 above using the standard outputs of a transport model, if we assume that the vertical difference between each of the two equilibrium demand schedules in a given future year is linear.

In any year in the appraisal period the transport model can produce not only the transport costs and travel demands with and without the scheme, but can also produce the transport costs and travel demands with and without the induced land use changes.

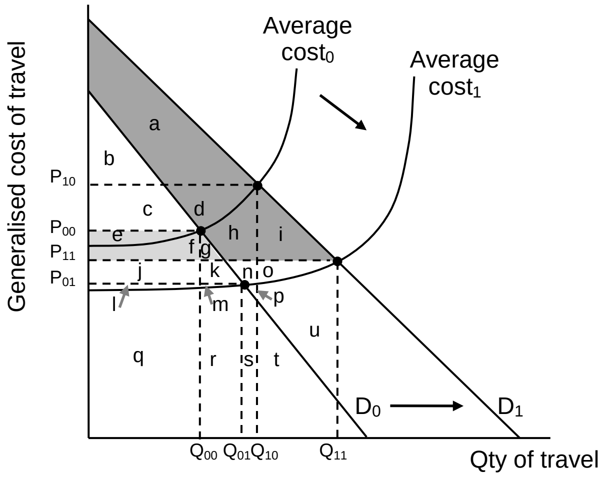
There will be eight pieces of data available, corresponding to four points in quantity-price space. These are summarised in Table 1:

Table 1 Transport costs and quantities

		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}**

Figure 6 plots these points:

Figure 6 Determining benefits from transport model outputs



Source: Author

A three step process is proposed to measure the benefits, which are equal to area *a* + *d* + *e* + *f* + *g* + *h* + *i* (further explanation is available in Appendix A.1).

Step 1: Undertake a traditional analysis with the do-minimum land use only

We can first determine the change in consumer surplus for the do-minimum demand and option transport cost. The 'rule of a half' $1/2\,(P_{00} - P_{01})(Q_{01} + Q_{00})$ establishes this, and it equals area *e* + *f* + *g* + *j* + *k.*

Step 2: add the total consumer surplus with option demand and option transport cost

We need to estimate the total area beneath demand schedule D_1 and above price P_{11} using only the information in Table 1 above.

We can estimate the area of the small triangle *i* using $1/2\,(P_{10} - P_{11})(Q_{11} - Q_{10})$. We know how far out to the right triangle *i* is, and so we can scale it larger accordingly.

Multiplying $1/2\,(P_{10} - P_{11})(Q_{11} - Q_{10})$ by the term $[Q_{11}/(Q_{11} - Q_{10})]^2$ results in area *a* + *b* + *c* + *d* + *e* + *f* + *g* + *h* + *i*. The resulting formula is $1/2\,Q_{11}^2(P_{10} - P_{11})/(Q_{11} - Q_{10})$.

Step 3: subtract the total consumer surplus with do-minimum demand and option transport cost

We apply the Step 2 logic to the other pair of data points:

$$1/2\,(P_{00}-P_{01})(Q_{01}-Q_{00})*\left(Q_{01}/(Q_{01}-Q_{00})\right)^2 = 1/2\,Q_{01}^2(P_{00}-P_{01})/(Q_{01}-Q_{00})$$

This results in area *b* + *c* + *e* + *f* + *g* + *j* + *k*.

Putting it all together

This formula results in Equation 4, which we call the 'augmented rule of a half':

Equation 4 The augmented rule of a half

$$1/2\,(P_{00}-P_{01})(Q_{01}+Q_{00}) + 1/2\left[\frac{Q_{11}^2(P_{10}-P_{11})}{(Q_{11}-Q_{10})} - \frac{Q_{01}^2(P_{00}-P_{01})}{(Q_{01}-Q_{00})}\right]$$

The formula results in area *a* + *d* + *e* + *f* + *g* + *h* + *i*, as highlighted in Figure 6.

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 equation cancels out, leaving just the conventional rule of a half for the one land use scenario.

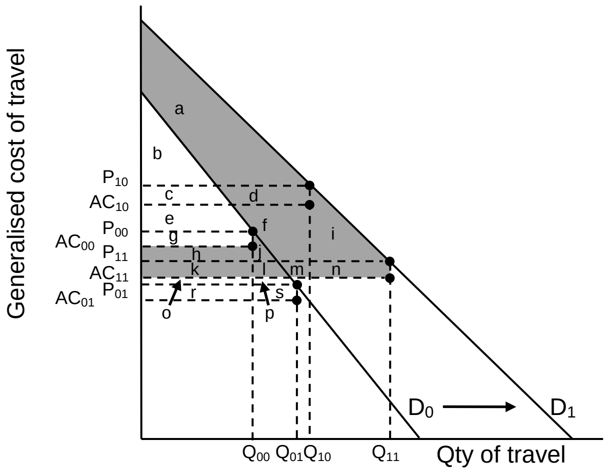
In a nutshell, it could be described as '*the big triangle, less the smaller triangle, plus the normal rule of a half*'.

3.4 Including taxation and subsidies

Figure 7 shows the benefit from inducing land use changes into the facility's locality when a charge such as fuel excise causes private costs to exceed resource costs.

The shaded area *a* + *d* + *f* + *h* + *i* + *j* + *k* + *l* + *m* + *n* represents the net-benefit required by the 'gainers and losers' and 'social welfare' approaches outlined in Appendix A.2.

Figure 7 Direct benefits from land use changes with taxes



Source: Author

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

Table 2 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, resource costs	AC_{11}, Q_{11}	AC_{10}, Q_{10}
	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}

A three step process is proposed to measure the benefits:

- Step 1: apply the rule of a half formula with a resource cost correction for the do-minimum land use scenario $1/2\,(Q_{01}+Q_{00})(P_{00}-P_{01})+Q_{01}(P_{01}-AC_{01})-Q_{00}(P_{00}-AC_{00})$, which equals area *h + j + k + l + o + p + r + s*
- Step 2: *add* the total social surplus from the option land use and option transport scenario, via the formula $\frac{1/2Q_{11}^2(P_{10}-P_{11})}{(Q_{11}-Q_{10})}+Q_{11}(P_{11}-AC_{11})$, which equals area *a + b + c + d + e + f + g + h + i + j + k + l + m + n*
- Step 3: *subtract* the total social surplus from the do-minimum land use and option transport scenario via the formula $\frac{1/2Q_{01}^2(P_{00}-P_{01})}{(Q_{01}-Q_{00})}+Q_{01}(P_{01}-AC_{01})$, which equals area *b + c + e + g + h + j + k + l + o + p + r + s*.

This results in the following equation:

Equation 5 Augmented rule of a half with a resource cost correction

$$[1/2\,(P_{00}-P_{01})(Q_{01}+Q_{00})-Q_{00}(P_{00}-AC_{00})] + \left[\left(\frac{1/2\,Q_{11}^2(P_{10}-P_{11})}{(Q_{11}-Q_{10})}+Q_{11}(P_{11}-AC_{11})\right)-\left(\frac{1/2\,Q_{01}^2(P_{00}-P_{01})}{(Q_{01}-Q_{00})}\right)\right]$$

The total benefits equal *a + d + f + h + i + j + k + l + m + n*, as required.

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

Although the formula may at first appear effort-intensive, the terms within the formula use outputs that are routinely produced by transport models for CBAs. However, additional modelling effort is needed to assess the intermediate counterfactuals of option land use/do-minimum transport network and vice versa.

3.5 Appraising the introduction of optimal congestion pricing

The augmented rule of a half with a resource cost correction can also apply to the introduction of optimal congestion charging. How the formula applies is outlined in Appendix B and it is analogous to the conventional estimation of congestion charging benefits, as is outlined in, say, ATC (2006a pp62–64). The difference is that the area of change between the two demand schedules (if there are any induced land use changes) constitutes as an additional welfare effect.

4. Cross modal and network effects

As described in Bates (2004), Hotelling (1938) showed that the method to estimate social surplus change in a single market will generalise across all markets straightforwardly. Like the conventional rule of a half, the augmented formula can be applied to all origin-destination zone pairs, modes, routes, and pricing policies.

However it is helpful to illustrate how the approach applies to related infrastructure.

In this chapter we describe that:

- changes in demand to related links does not change net-benefits if they are efficiently priced, but given they typically are not, then there will be welfare changes when there is congestion
- the 'augmented rule of a half' correctly captures these welfare changes.

4.1 Two dimensions of related effects – not one

Demand shifts do not only come about by short-term price/cost changes in the primary market; they also come about by longer-term changes to land use.

Land use changes that (all else equal) increase demand for related infrastructure are called 'intensified land use', and reduce demand are called 'dispersed land use'.

Table 3 summarises the range of outcomes expected:

Table 3 Increase in demand to related infrastructure

	Upstream/downstream infrastructure (+)	Unrelated infrastructure (N/a)	Parallel infrastructure (–)
Intensified land use (+)	+ +	+	+/–?
No effect from any possible land use changes (N/a)	+	N/a	–
Dispersed land use (–)	+/–?	–	– –

4.2 Network effects with efficient congestion pricing

Land use change has no welfare effects if congestion is priced efficiently

Boardman et al (2006), Mohring (1993), and ATC (2006) describe that one should ignore benefits and costs to related infrastructure when price equals marginal social cost, provided that the benefits in the primary market are measured from an equilibrium demand schedule.

In Appendix B.1 we demonstrate that this welfare change equals zero *even if land uses change* if there is optimal congestion charging applied to every link, route, and mode in the entire network (ignoring any imperfections or externalities in any other related markets, and any increasing returns to scale from agglomeration).

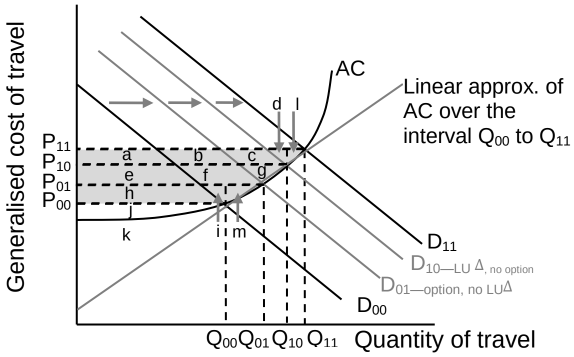
4.3 Network effects with social average cost pricing

Intensified land use on up/downstream infrastructure

Figure 2 on p5 above shows that inducing a right shift of the demand schedule on a congested upstream or downstream link is detrimental. In Figure 8 below this detriment corresponds to area *h* + *i* + *m*.

However a two-fold effect of intensifying land-use on an upstream link that is congested is particularly detrimental. If both induced land-use changes and transport flows reinforce each other, the detriment is the larger area *a* + *b* + *c* + *d* + *e* + *f* + *g* + *h* + *i* + *l* + *m*.

Figure 8 Intensified land use and up/downstream infrastructure



Source: Author

Assuming that the AC curve is linear over the interval Q_{00} *to* Q_{11}, which is reasonable if the changes are not too large, Equation 4 (repeated below for convenience) estimates these benefits:

$$1/2\,(P_{00} - P_{01})(Q_{01} + Q_{00}) + 1/2\left[\frac{Q_{11}^{2}(P_{10} - P_{11})}{(Q_{11} - Q_{10})} - \frac{Q_{01}^{2}(P_{00} - P_{01})}{(Q_{01} - Q_{00})}\right]$$

This first part of the equation calculates the net-benefits to travellers using the improved link if there were no land use changes, area – (*h* + *i* + *m)*. The second half of the equation adds the additional net-detriment of the land use change worsening congestion, in the absence of pricing, as follows:

- scaling up the (negative) triangle *l* to become the large area – (*a* + *b* + *c* + *d* + *e* + *f* + *g* + *h* + *i* + *j* + *k* + *l* + *m*)
- but netting off from this the area – (*h* + *i* + *j* + *k* + *m*), which is triangle *m* scaled up.

The net-benefits is area – (*a* + *b* + *c* + *d* + *e* + *f* + *g* + *h* + *i* + *l* + *m*), as is required.

Other land use and infrastructure combinations

The value of detriment in Figure 8 above would be a gain if it is parallel infrastructure that experienced dispersed land use (relative to what would have occurred).

The augmented rule of a half can also be illustrated for nearly all of the other combinations of land use and types of infrastructure outlined in Table 3 above. So too can cases where taxes and subsidies apply.

However, there are possible situations where one or both denominators in the latter part of the augmented rule of a half are zero, invalidating the formula. This could happen if:

1. a transport project has no effect at all on a part of a network (meaning $Q_{00} = Q_{01} = Q_{10} = Q_{11}$); or
2. if the land use changes induced a change in the demand schedule, but demand would not change otherwise (meaning $Q_{11} = Q_{01}$ and/or $Q_{01} = Q_{00}$).

In the instances where the augmented rule of a half is applied to, say, origin-destination zone pairs where the result is undefined, then:

- those instances should be obvious to the analyst;
- the 'divide by zero' error should not in the first instance be ignored, because there are welfare impacts likely in the second situation;
- an adjustment to the normal rule of a half can apply:

Equation 6 Adjusted rule of a half to use when divide by zero errors occur

$$1/2\,(P_{00} - P_{11})(Q_{11} + Q_{00}) + Q_{11}(P_{11} - AC_{11}) - Q_{00}(P_{00} - AC_{00})$$

Using this adjustment to the normal rule of a half for just these problematic aspects of the transport network will determine the trapezium area for related infrastructure without the risk of dividing by zero. It should only apply to those specific network components that are otherwise undefined. Using it too liberally will risk underestimating the benefits that arise from induced land use changes.

5. Initial applications of the methodology

5.1 Outline of the practical application

The approach was applied to the appraisal of a major transport scheme using the Auckland LUTI model ART/ASP.[11] (For the time being the project in question will not be named, but this is not specifically relevant to this paper in any case.)

The analysis was undertaken for two regional growth assumptions (medium and high, corresponding to the forecasts undertaken for the ‘Auckland Plan’), and for two construction timing scenarios (stylised timings of about 2020 and 2030). The intent of the analysis was to determine if doing the project sooner would provide superior economic development benefits. It was clear that prevailing methodologies were not well suited to addressing such a question because they regard broader economic development as exogenous.

The actual results raised more questions than answers, and would require more work to understand what was driving the results. Compared to the standard CBA the results were mixed (sometimes higher, sometimes lower), with a reasonably wide range across the different growth scenarios and timing options. There was insufficient time to investigate fully what was driving the analysis results. As such the numerical findings were not reported because without more investigation to determine what drove the appraisal results we cannot reply to obvious (and reasonable) questions that people would have of them.

Some of the results may be artefacts of the underlying structure and assumptions of the models; we were attempting to use them for purposes that they were not originally designed to represent. A complication also arose when applying the procedure to the outputs of the ART model, which is explained below.

The nature of the results had similarities with the agglomeration analysis NZIER also undertook for the project. The project’s agglomeration benefits in the modelled year 2041 were lower in the ‘high growth’ than in the ‘medium growth’ scenario, which was likely caused by high levels of congestion, particularly in some isolated areas.

We first discuss a technical issue experienced, before discussing broader questions and issues for the modelling technologies and planning and policy approaches.

5.2 A technical issue encountered

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

As discussed at the conclusion of the previous chapter, there are possibilities of OD pairs being such that a ‘divide by zero’ error would occur. No divide by zero errors were actually encountered. However what was encountered were instances where the net benefit figure became extremely large, some positive and some negative, as the difference in the number of trips tended towards zero.

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

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

It was judged that using Equation 6 on page 23 above would not be ideal to address these occurrences because even though the number of trips between the OD pairs was small the trips in question could still be travelling over the improved transport link.

Using a cut-off threshold was considered, whereby the OD pairs would be ignored if the difference in the number of trips was very small. However, without more work to understand the outputs there was no basis to make a judgement (either on theory or from experience) on what the right cut-off should be, if one were to exist at all.

What could be driving this issue is something akin to 'white noise' in the number generating process the Auckland Regional Transport (ART) model uses. We experienced what we believe to be similar issues when using the ART model to estimate agglomeration benefits for the Additional Waitemata Harbour Crossing (AWHC) using the NZTA's procedure (NZIER and PwC 2010).[12]

What is common in the procedure developed in this paper and in the NZTA's agglomeration procedure is that *ratios* of cost differences between zones are used. Traditionally transport benefits are simply the summation of the OD pair impacts across the network.

Thus there may be a general issue about using the fully disaggregated outputs of wide area transport models in procedures that manipulate the data using multiplication, division etc.

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. Also different regional transport models will have their own quirks, and so any approach to aggregate zones could be unique to each model.

5.3 Questions about the appropriate context of modelling

In our attempts to interpret the analysis results we raised some questions that, in hindsight are fairly obvious, but frankly fall outside of the current frame of reference in transport CBA. These are described below.

[12] We hypothesised that the more disaggregated the zones (there are 512 in the ART model), the more exaggerated the resulting agglomeration benefits were. We tested that hypothesis on a subsequent agglomeration calculation (for the Northern Busway Extension) and found that aggregating zones can indeed reduce the estimated benefits. Other agglomeration estimates were lower than ours, such as the Kernohan and Rognlien (2011) for the AWHC. But those lower estimates were based on ~110*110 square OD matrices, which is less than one 20th of the size of the dataset we used.

Capacity, congestion, and efficient pricing

Auckland's transport network is generally congested, and there is no congestion charging. Promoting growth within a network that is already at, or over, capacity is challenging. A relevant result from the history of economics is that complex systems of sentient agents are best managed with efficient pricing; they cannot be centrally planned efficiently.

Building new major roads in inefficiently-priced congested networks in order to drive economic growth is quite possibly a high-risk investment strategy. There is a risk that the transport strategy causes land uses to develop in ways that worsen and lock-in congestion externalities in the long-term.

Applying efficient congestion charging across a wide urban region would provide appropriate price signals for firms and households to include in their location decisions. With such prices, people's decisions to locate in places that worsen congestion will, in theory, occur only if it is net-beneficial to society as a whole. With efficient pricing, any induced development by a transport strategy would not come at the net-cost of congestion to society overall.

Modelling more 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. As noted, this could be an artefact of the modelling rather than a reflection of reality. The ASP land use model assumes a fixed regional population and fixed amount of economic activity. 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. This attraction of people could offset (to at least some extent) the decreases in demand 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

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 would be responded to by transport planners sensing the need for system tuning and expansion as they go. They would 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 the current modelling shows up the latter, which may unrealistically lower 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. The transport sector is specified wholly-externally, and once the land use system starts to be modelled, the natural response of transport capacity following land use development is absent.

All-embracing CBA of major transport strategies in urban areas would need to regard this issue of anticipating and managing the induced demand for transport capacity improvements as important. If the project planning failed to consider this appropriately then the transport strategy could cause problems in the long-run that could have been avoided or mitigated.

6. Conclusion

6.1 Overall comments

This paper sought to explain the shortcomings in current transport CBA, propose a way to address these that only marginally expands on existing methodologies, and describe what was learned from an initial application of the approach.

If it is judged that it is appropriate to regard the change in total social surplus induced by the initiate as a welfare benefit, then appraisals can take more account of major changes to where and how people live, work and play.

At the moment some of the most significant debates about major transport strategies are had in the political spectrum. “Motorways cause sprawl, and therefore they are bad” and “public transport doesn’t match how people travel now, and therefore motorways are better” have been thrashed out in varying forms for the last four years (in particular) since the ‘Roads of National Significance’ policy came into play. To date there has been relatively little economists have said on the matter.

It is hoped that such a procedure as that proposed here will allow transport planners, modellers and economists to more constructively contribute to better analysis and decision making.

6.2 Some areas for further research

Relaxing the assumption of linear demand schedules

The augmented rule of a half applied to the primary link is based on a linear demand schedule. That is because it is based on extrapolating only two observations of price-quantity pairs from the transport modelling from a given land use scenario (i.e. with and without the project).

More fully developed transport models often have utility functions (specifically, logit models) that help to predict people’s behaviour. The research in this paper could be extended to consider how more of the information contained within the relevant transport model can be leveraged to represent a richer picture of what the option and base case demand schedules may be.

Taking account of income effects when there are large changes to welfare

Boardman et al (2006, pp 64–69) describe that consumer surplus under an equilibrium demand framework is usually a reasonable approximation of society’s economic welfare. This is the case if 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’.

However, major transport schemes that induce large changes in land use and property investment may cause ‘income effects’. In that case extra effort to adjust the measured effects may be appropriate.

Taking account of imperfections in property markets

We have assumed that property markets are efficient. Thus if there are any restrictions on uses of land then we had a charitable assumption that this was appropriately correcting market failures.

It is possible that there exist restrictions on uses of land that are not warranted on economic grounds. A research extension is to consider the applicability of the augmented rule of a half in the presence of such 'government failures'.

Accounting for agglomeration: land use effects and welfare effects

When areas affected by a transport strategy are subject to increasing returns to scale in production and amenity, then the resulting land use effects can be larger than what they would have been, all else equal (e.g. Grimes (forthcoming)). The additional people attracted to an area because of these subsequent agglomeration multiplier effects are not doing so because of the direct benefits the transport strategy provides. There are likely to be welfare effects relating to agglomeration that still need to be estimated separately and in addition.

More work is needed to clarify if there is any potential overlap in the welfare benefits calculated from 'augmented rule of a half' procedure and separate agglomeration benefit analysis, and if so, how to manage it.

Considering how to appraise new areas previously undeveloped

The augmented rule of a half works when there are reasonable generalised costs of travel between locations with and without the project. However the augmented rule of a half would not apply well to opening up a new area of land that was not previously accessible. That's because there would be no useful price/quantity coordinate in the do-minimum scenario to help estimate what the increase in social surplus would be for that link and origin-destination pairs to/from that area. More research on this issue is warranted.

Improving the forecasting of induced changes to demand — modelling regional population and economic activity

The forecasting of induced changes to regional population and economic activity needs to improve. As described in section 2.3 (p6), major transport strategies can have material effects on population flows and employment in the affected region.

There would seem a more pressing need for CGE (computable general equilibrium) modelling of employment, economic output, investment, productivity etc to help forecast the effects of projects on the determinants of travel demand. To be of use for a transport strategy appraisal a CGE model should separately model the region in question dynamically (i.e. model effects over time). Data limitations in New Zealand currently preclude that, but such models exist in other countries.

Modelling of the economy and of regional population can integrate with a LUTI model to potentially provide better estimates of the changes to the determinants of travel demand caused by major transport strategies. Such a model should also account for increasing returns to scale in production and amenity.

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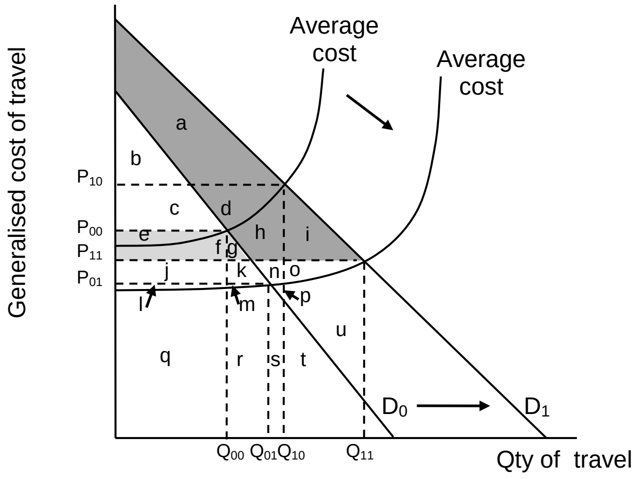
Appendix A Direct transport benefits to the improved link

A.1 Establishing the benefits conceptually

Figure 9 Primary market benefits of induced land use change



Source: Author

The benefits are the area under the two demand curves plus the reduced costs to existing travellers. It is based on ATC (2006):

1. the social welfare approach, where net benefit equals the increase in willingness to pay (WTP, defined in generalised cost terms) less the increase in social generalised costs (SC), and
2. the gainers and losers approach, where net benefit equals the net gains to consumers (consumer surplus, CS) + net gains to producers + net gains to governments + net gains to third parties.

The two approaches are outlined below and culminate in the same area of benefit:

Table 4 Determining the total benefits of a transformational project

Social welfare approach		Gainers and losers approach	
WTP_2		(Consumer surplus$_2$) CS_2	
a + b + c + d + e + f + g + h + i + j + k + l + m + n + o + p + q + r + s + t + u	ΔWTP (= WTP_2 – WTP_1)	a + b + c + d + e + f + g + h + i	ΔCS (= CS_2 – CS_1)
WTP_1	a + d + g + h + i + k + m + n + o + p + r + s + t + u	CS	a + d + e + f + g + h + i
b + c + e + f + j + l + q		b + c	
Social cost$_2$ (SC_2)			
j + k + l + m + n + o + p + q + r + s + t + u	ΔSC (= SC_2 – SC_1)		
SC_1	k + m + n □ o + p + r + s + □ + u – (e + f)		
e + f + □ + l + q			
Total benefit	ΔTP □ S a + d + e + f + g + h + i	Total benefit	ΔCS a + d + e + f + g + h + i

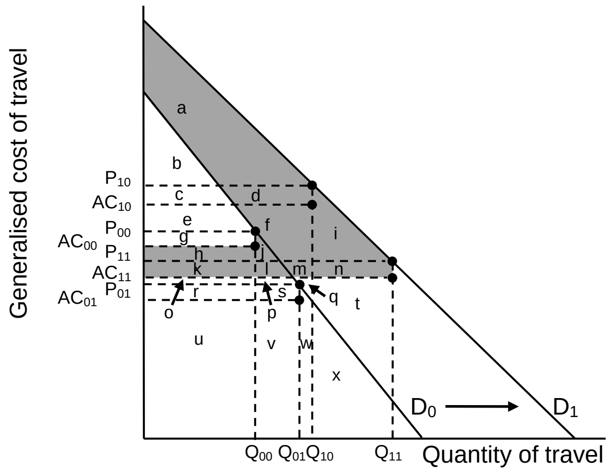
Source: Author

A.2 Including taxes and subsidies in the primary market

This appendix section derives the three stages of formulas that together comprise Equation 5 in section 3.4 on page 18.

Table 5 uses the social welfare approach and the gainers and losers approach to show the net benefits from Figure 10.

Figure 10 Primary market benefits from land use changes with taxes



Source: Author

Table 5 Determining the total benefits of a project inducing land use changes with tax/subsidies

Social welfare approach		Gainers and losers approach	
WTP_2		(Consumer surplus$_2$) CS_2	
a + b + c + d + e + f + g + h + i + j + k + l + m + n + o + p + q + r + s + t + u + v + w + x	ΔWTP (= $WTP_2 - WTP_1$)	a + b + c + d + e + f + g + h + i + j	ΔCS (= $CS_2 - CS_1$)
WTP_1	a + d + f + i + j + l + m + n + p + q + s + t + v + w + x	CS_1	a + d + f + g + h + i + j
b + c + e + g + h + k + o + r + u		b + c + e	
Social cost$_2$ (SC_2)		T_2	
o + p + q + r + s + t + u + v + w + x	ΔSC (= $SC_2 - SC_1$)	k [illegible] l + m + n	ΔT (= $T_2 - T_1$
SC_1	p + q + s + t + v + w + x – (h + k)	T_1	k + l + m + n – g
h + k + o + r + u		g	
Total benefit	$\Delta WTP - \Delta SC$ a + d + f + h + i + j + k + l + m + n	Total benefit	$\Delta CS + \Delta T$ a + d + f + h + i + j + k + l + m + n

Source: Author

Appendix B Congestion charging

B.1 Wider land use change welfare neutral if optimal congestion pricing already in place

This section demonstrates that applying either version of the rule of a half with resource cost correction to related infrastructure with optimal congestion pricing leads to zero net benefit even if land uses change.

As discussed in section 4.3, for related links applying the augmented rule of a half is the same as applying the normal rule of a half to the two equilibrium points 00 and 11 (a resource cost correction applies throughout). This means we only need to consider two demand schedules (00 and 11) for related links.

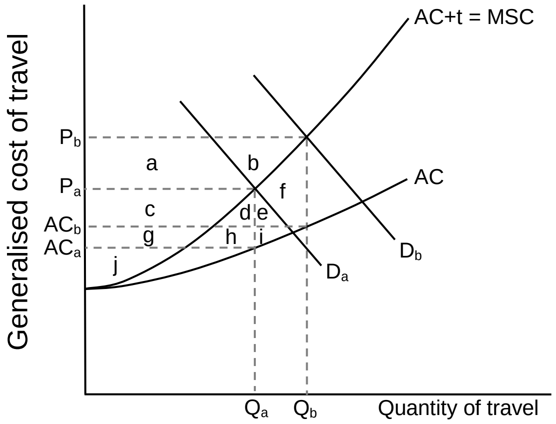
Consider Figure 11 which represents a related link that has an optimal congestion charge *t* which equates the curve *AC+t* to marginal social cost (MSC). The area below the MSC curve equals total cost, which is also equal to average cost times quantity. Using this fact we know that:

a) *d* + *h* = *j*

b) *d* + *e* + *f* = *g* + *j*

c) *e* + *f* = *g* + *h* (which follows from substituting (a) into (b)).

Figure 11 No net-welfare impact from land use change to related links if efficiently priced



Source: Author

Situation 1 of 3

Let D_a be the base case (00) demand and D_b be the option (11) demand. The conventional rule of a half with resource cost correction to the two equilibrium outcomes is:

$$1/2\,(P_{00} - P_{11})(Q_{11} + Q_{00}) - [Q_{00}(P_{00} - AC_{00}) - Q_{11}(P_{11} - AC_{11})]$$

which in this instance equals:

$$1/2\,(P_a - P_b)(Q_b + Q_a) - [Q_a(P_a - AC_a) - Q_b(P_b - AC_b)]$$

This equals area *e + f – (g + h) = 0* (which follows from (3) above).

Situation 2 of 3

If D_a was the option (11) demand and D_b was the base case (00) demand, then the conventional rule of a half with resource cost correction equals:

$$1/2\,(P_b - P_a)(Q_a + Q_b) - [Q_b(P_b - AC_b) - Q_a(P_a - AC_a)]$$

The net benefits are *g + h – (e + f) = 0*.

Situation 3 of 3

If there are no changes to demand, then there are no net-benefits. The augmented rule of a half would be undefined in this instance ('divide by zero' errors), but the conventional rule of a half with a resource cost correction applied to the two equilibrium outcomes would apply.

B.2 Appraisal of introducing optimal congestion pricing that induces land use changes

This section shows that the augmented rule of a half with a resource cost correction can be used to estimate the net benefits of introducing optimal congestion pricing that induces land use changes. In this case all the links that have the congestion pricing applied are 'primary links', meaning the area between the demand curves represents a welfare change. The 'social welfare' and 'gainers and losers' approach is used in the same way as it is used in ATC (2006a).

B.2.1 Intensifying land use

We would expect that more people would be included to work and/or live in places that have lower congestion charges. Figure 12 and Table 6 below shows the area of net benefit for such a link that incurs an increase in its travel demand. (It might, for instance, be a road link to a railway station that has commuter rail services.)

The net benefits are equal to:

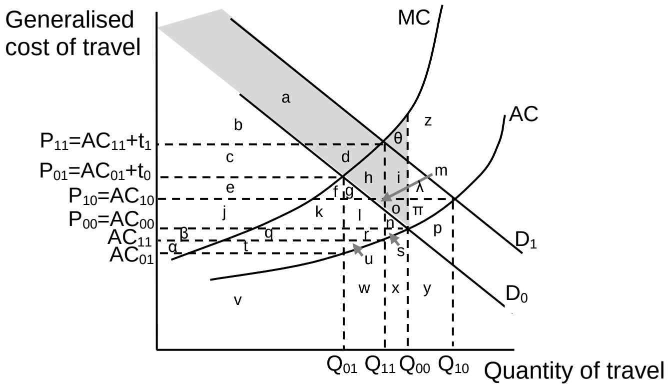
$$(a + d + h + m) + (\beta + q + r - n)$$

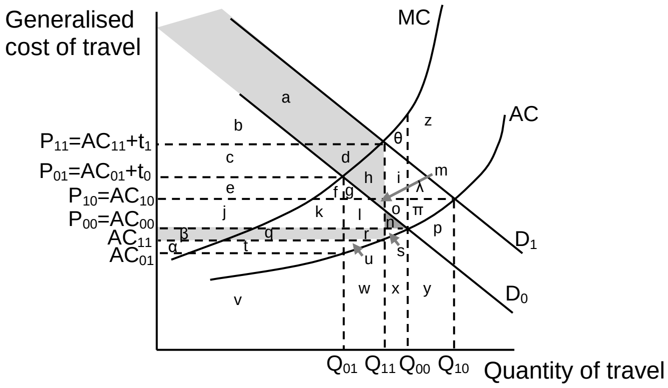
This is interpreted as follows:

- Area $\beta + q + r$ is the saving in resource costs for traffic that remains on the road (analogous to area *d + e* in Figure 2.15 on page 63 of ATC (2006a)).
- Area *n* is the lost consumer surplus for the travellers priced off the network (analogous to area *j* in Figure 2.15 on page 63 of ATC (2006a)).
- Area *a + d + h + m* is the increase in welfare arising from the land use change caused by the congestion pricing policy applied to this link some years earlier.

Figure 12 Benefit from optimal congestion pricing with intensified land use change

Both figures show the same area of benefit





Source: Author

Table 6 Determining net-benefits of introducing optimal congestion charging intensifying land use

Social welfare approach		**Gainers and losers approach**	
WTP_1		(Consumer surplus$_1$) CS_1	
a + b + c + d + e + f + g + h + j + k + l + m + β + α + q + r + t□+ u + v + w	ΔWTP (= WTP_1 – WTP_0)	a + b	ΔCS (= CS_1 – CS_0)
WTP_0	a + d + h + m – (n + s + x)	CS_0	a – □c + e + f + □ + j + k□+ l + n)
b + c + e + f + g + j + k + l + n + β + α + q + r + s + t □ □ + v + w + x		b + c + e + f + g + j +□k +□l + n	
Social cost$_1$ (SC_1)		T_1	
α + t + u + v + w = q + r + t +□u + v + w + k + l + m + f + g + h	ΔSC (= SC_1 – SC_0)	c + d + e + f + g + h + j + k + l + m + β + q + r	ΔT (= T_1 – T_0)
SC_0	– (β + q + r + s + x) = – (s + x + n + o + i + θ)	T_0	c + d + e + f + g + h + j + k + l + m + β + q + r
β + α + q + r + s + t + u + v + w + x = q + r + s + t + u + v + w + x + k + l + m + n + o + f + g + h + i + θ			
Total bene□it	ΔWTP – ΔSC a + d + h + m + β + q + r – n = a + d + h + m + o + i + θ	Total benefit	ΔCS + ΔT a + d + h + m + β + q + r – n

Source: Author

The augmented rule of a half with resource cost correction is applied in three steps:

$$[1/2\,(P_{00} - P_{01})(Q_{01} + Q_{00}) - Q_{00}(P_{00} - AC_{00})] + \left[\left(\frac{1/2\,Q_{11}^{2}(P_{10} - P_{11})}{(Q_{11} - Q_{10})} + Q_{11}(P_{11} - AC_{11})\right) - \left(\frac{1/2\,Q_{01}^{2}(P_{00} - P_{01})}{(Q_{01} - Q_{00})}\right)\right]$$

This first part of the equation calculates the net-benefits to travellers using the improved link if there were no land use changes, area – *(e + f + g + j + k + l + n)*.

The second half of the equation adds the additional net-detriment of the land use change worsening congestion, in the absence of pricing, as follows:

- scaling up the triangle *i + λ* to become the large area *a + b* and adding area *c + d + e + f + g + h + j + k + l + m + β + q + r*
- but netting off from this the area b + c (which is triangle *g + l + n* scaled up)

The net-benefits is area *a + d + h + m + β + q + r – n*, the same as that required by the ‘social welfare’ and ‘gainers and losers’ approaches.

B.2.2 Reducing land use intensity

We would expect that people would be more reluctant to locate in areas that are poorly accessible if an efficient congestion charge was also levied on the network.

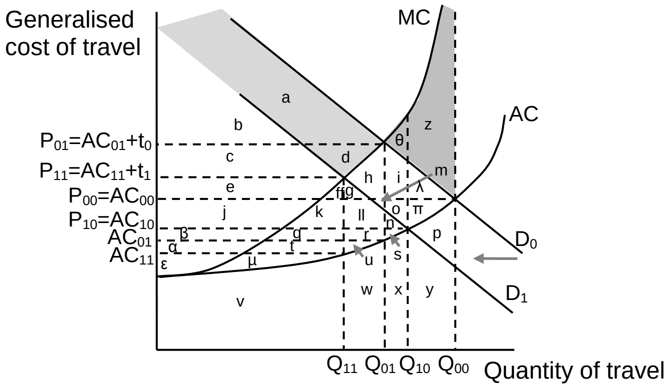
Figure 13 below outlines a case of introducing optimal congestion pricing dispersing land use and shifting demand to the left. Table 7 establishes what the net-benefits are using the ‘Social Welfare’ and ‘Gainers and Losers’ approaches, and beneath that we demonstrate that the augmented rule of a half with a resource cost correction correctly estimates these net-benefits.

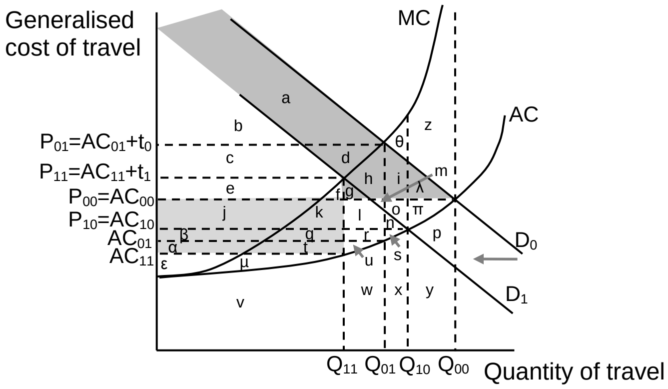
The net benefits is area:

$j + k + \beta + \alpha + q + t - (a + d + g + h + i + \lambda)$

Figure 13 Benefit from optimal congestion pricing with dispersed land use change

Both figures show the same area of benefit





Source: Author

Table 7 Determining net-benefits of introducing optimal congestion charging dispersing land use

Social welfare approach		**Gainers and losers approach**	
WTP_1		(Consumer surplus$_1$) CS_1	
b + c + e + f + j + k + β + α + q + t + v + ε + μ	ΔWTP (= WTP_1 – WTP_0)	b + c	ΔCS (= CS_1 – CS_0)
WTP_0	– (a + d + g + h + i + λ + l + m + n + o + p + π + r + s + u + w + x + y)	CS_0	– (a + d + e + f + g + h + i + λ)
a + b + c + d + e + f + g + h + i + λ + j + k + l + m + n + o + p + π + β + α + q + r + s + t + u + v + w + x + y + ε + μ		a + b + c + d + e + f + g + h + i + λ	
Social cost$_1$ (SC_1)		T_1	
ε + μ + v = f + k + q + t + v + μ	ΔSC (= SC_1 – SC_0)	e + f + j + k + β + q + α + t	ΔT (= T_1 – T_0)
SC_0	– (j + k + l + m + n + o + π + p + β + α + q + r + s + t + u + w + x + y) = – (l + m + n + o + π + p + r + s + u + w + x + y + g + h + i + λ + θ + z)	T_0	e + f + j + k + β + q + α + t
j + k + l + m + n + o + π + p + β + α + q + r + s + t + u + v + w + x + y + ε + μ = k + l + m + n + o + π + p + q + r + s + t + u + v + w + x + y + f + g + h + i + λ + θ + z + μ			
Total benefit	ΔWTP − ΔSC j + k + β + α + q + t – (a + d + g + h + i + λ) = θ + z – (a + d)	Total benefit	ΔCS + ΔT j + k + β + α + q + t – (a + d + g + h + i + λ)

Source: Author

The augmented rule of a half with a resource cost correction is applied as follows.

$$[1/2\,(Q_{01} + Q_{00})(P_{00} - P_{01}) - Q_{00}(P_{00} - AC_{00})] + \left[\left(\frac{1/2\,Q_{11}^2(P_{10} - P_{11})}{(Q_{11} - Q_{10})} + Q_{11}(P_{11} - AC_{11})\right) - \left(\frac{1/2\,Q_{01}^2(P_{00} - P_{01})}{(Q_{01} - Q_{00})}\right)\right]$$

This first part of the equation calculates the net-benefits to travellers using the improved link if there were no land use changes, area – *(c + d + e + f + g + h + i + λ)*.

The second half of the equation:

- adds area *b + c + e + f + j + k + β + q + α + t*
- subtracts *a + b*

The net-benefits is area *j + k + β + α + q + t – (a + d + g + h + i + λ)*, the same as that required by the ‘social welfare’ and ‘gainers and losers’ approaches.