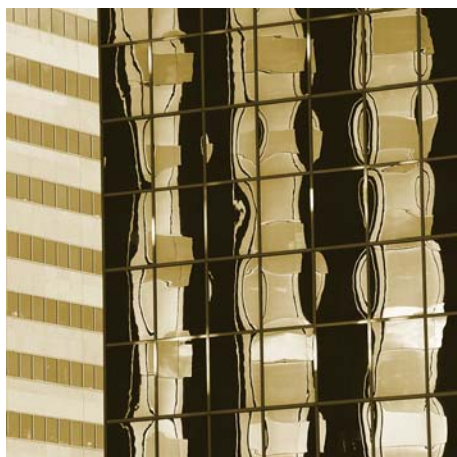# External benefits of CityRail services— Final report to IPART

Mike Smart and Eli Hefter
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About the Authors

Mike Smart is a director of Sapere Research Group in Sydney. He advises industry leaders in telecommunications, rail, gas, logistics, mining, electricity and aviation. Mike has given expert evidence in the Federal Court of Australia and the Australian Competition Tribunal. He is a member of the Competition and Consumer Committee of the Law Council of Australia and the Economics Society of Australia.

Mike is the author of previous reports for IPART on externalities for CityRail, Sydney Buses and Sydney Ferries.

Eli Hefter is a consultant at Sapere Research Group in Sydney.

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Sapere Research Group is one of the largest expert consulting firms in Australasia and a leader in provision of independent economic, forensic accounting and public policy services. Sapere provides independent expert testimony, strategic advisory services, data analytics and other advice to Australasia's private sector corporate clients, major law firms, government agencies, and regulatory bodies.

For information on this report please contact:

Name: Mike Smart

Telephone: +61 292340210

Mobile: +61 407246646

Email: msmart@srgexpert.com

Executive Summary

The rationale for the subsidy to commuter rail in Sydney is that public transport generates external benefits that are not properly captured in the price system. Forcing public transport prices to equal costs, so that there would be no need for subsidy funding, would make society worse off: more travellers would use private cars, contributing to road congestion, air pollution, and other disbenefits that are felt widely across the community as a result of the decisions of others.

This report employs an approach that has been used in previous studies for IPART to quantify the external benefits for CityRail, Sydney Buses and Sydney Ferries. The principal external effects for public transport in quantitative terms are road congestion and emissions—both of conventional air pollution with its associated local health costs, and greenhouse gases with their global impacts. Other externalities were considered, but judged to be of second-order importance in the present circumstances.

The 2008 estimation of CityRail external benefits has been revisited using 2011 data and with the benefit of improvements to the method that have been achieved in the intervening time. Notably, a newer version of the Strategic Travel Model of the NSW Bureau of Transport Statistics has enabled improved estimates of traffic flow patterns.

The comparison between total external benefits estimated in 2008 and now is presented in Table 5.3 below, which is presented here.[1]

	Rail 2008	**Rail 2012**
	$2008	$2011
Total ext rail $m/yr	1,528.2	1,866.6
congestion	1,390.8	1,857.6
air pollution	111.6	38.2
GHG	25.9	10.9
(less road pricing)	*N.C.* -	40.0

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[1]   These estimates do not include the countervailing effect of the external costs of raising tax revenues to fund the CityRail subsidy. In the 2008 study, the road pricing effect was not calculated.

It is possible to disentangle the separate patronage and inflation effects by presenting this comparison on a per-passenger journey basis and CPI-adjusting the 2008 figures. This comparison is presented in the table below.

	Rail 2008	Rail 2008	Rail 2012
	$2008	$2011	$2011
Total ext $/PJ	5.43	5.88	6.34
congestion	4.94	5.35	6.31
air pollution	0.40	0.43	0.13
GHG	0.09	0.10	0.04
(less road pricing)	*N.C.*	*N.C.*	- 0.14

This table shows that present estimates of the total congestion benefit are substantially higher than in 2008, even when changes in patronage and inflation are taken into account. This real per-journey change is driven, in part, by changes in traffic flow patterns since the 2006 Household Travel Survey on which the earlier version of the STM was based. However part of this change is also likely to be caused by improvements to the way the STM handles non-work purpose travel by car.

Relative to 2008, the emission externality benefits of rail are reduced. This change is driven mainly by an improved understanding of the emission performance of Sydney's bus fleet, which is relatively good and has been improving in recent years. There was also, in 2008, an overestimate of the amount of non-work purpose automobile travel that has since been corrected.

Calculations of optimal rail fares were also updated for the new data set and improvements to the optimisation method. The largest change to this calculation since 2008 is the explicit inclusion of a rough estimate of the long run marginal cost of expanding CityRail's systemic bottleneck, the CBD rail infrastructure capacity. In broad terms, a $10b capital cost annuitized over 50 years with a 5% discount rate, and an assumed resulting 33% lift in system capacity lead to an incremental long run cost of approximately $0.32/rail passenger-kilometre. This figure leads to a LRMC that is roughly double prior estimates of the SRMC.

Taking account of this LRMC, the optimal rail fare ignoring the marginal excess burden of taxation would be 29% higher than 2011 levels. If a plausible value of 0.1 is assumed for the marginal excess burden of State taxation generally, then the optimal rail fare would be 49% higher than 2011 levels.

Table of Contents

1 Background

This section contains an explanation of the nature of externalities, a summary of previous IPART work on externalities for public transport, and an outline of the remainder of the report.

1.1 What are externalities?

In some transactions there is an effect on people other than the buyer and seller. That effect is called an externality. It may make the other people better or worse off. The price paid in the transaction is not influenced by externalities because they do not directly impact the buying or selling parties. This phenomenon is important to economists: the net value to society of the transaction includes the externalities. Social costs and benefits are unable to affect decisions about how much to produce and how much to consume because of their invisibility in the price system.

Presently, "second-best" conditions apply, meaning that car users do not pay for the full external costs they impose.[2] Under second-best conditions externalities provide a rationale for public transport ticket prices that may differ significantly from the cost of providing a passenger journey. Where public transport helps to mitigate the external costs of car use, socially optimal pricing would be below cost, implying a subsidy.

All government-provided public transport in Sydney is subsidised.[3] In this respect, Sydney's experience is quite typical of urban public transport worldwide. The sheer budgetary size of this subsidy demands investigation into whether its level represents the social optimum.

The prime motivation for the present study of rail externalities is to understand the optimal level of subsidy to CityRail. External benefits[4] from Sydney rail services determine the optimal gap between ticket prices and journey costs. If they can be

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[2]   Road user charges, including fuel levies and tolls, can be used as a means of requiring motorists to pay something toward the external costs they impose.

[3]   As are some privately provided commuter bus services.

[4]   These benefits are mainly in the form of reductions to external costs imposed by other transport modes.

estimated accurately, then the optimal level of subsidy to CityRail can also be determined.

Putting this in a slightly different way, public transport services that generate positive externalities or help to avoid negative externalities are paid for partly by the traveller and partly by the taxpayer. The part paid by the taxpayer represents the external benefit. It is important that the taxpayer does not pay too much or too little. If too much, then resources are wasted and taxation is higher than it needs to be. If too little, then an opportunity to reduce the social burden of less efficient forms of transport is missed.

1.2 Previous work on public transport externalities

IPART's December 2008 Final Determination of CityRail fares and regulatory framework for 2009 – 2012 was the first such decision in Australia to take explicit account of quantitative estimates of externalities. The basic externality methodology used in that inquiry was articulated in Smart (2008).

IPART's December 2009 Final Determination of metropolitan and outer metropolitan bus fares also took account of quantified external benefits. The externality methodology first developed for CityRail in the previous year was adapted to buses and extended in Smart (2009).

IPART's 2012 Determination of Sydney Ferry fares also took account of external benefits. The externality methodology was further extended to cater for the unique circumstances of ferries, which include the high proportion of tourism-purpose travel. That work was documented in Smart (2012).

The principal external benefits identified in these studies were a reduction in traffic congestion and air pollution that would result from traveller decisions to use public transport instead of private motor vehicles. The approach used in this study follows the previous IPART studies. It has been refined in the light of experience, and further adapted to handle some specific characteristics of rail service.

1.3 Structure of this report

The analytical method is set out in the next section. Further technical details are provided in the Appendix. Section 3 summarises the changes to methods and input data since rail externalities were analysed for IPART in 2008. Section 4 contains the main empirical work for this study. It explains how each of the external costs is calculated, summarises the data and tools employed, then sets out the estimates for marginal external cost for each mode. These marginal external cost figures are used in Section 5 to develop estimates for total external costs and benefits for rail. Section 6 summarises prior work on marginal costs for each transport mode, noting

in particular the estimated Long Run Marginal Cost of commuter rail service. Section 7 sets out the estimation of road pricing based on current levels of fuel excise tax, tolls, and other taxes on automobile use. Section 8 applies the results of the earlier sections to estimate optimal rail fares.

2 Analytical approach

This section sets out the analytical approach used in this report in broad terms, including an explanation of data sources and tools. Appendix 1 sets out the equations that are used, in order to put things into a more precise framework.

The main externalities considered here are reductions in traffic congestion, air pollution and motor accidents. The extent of benefit depends on the extent of modal shift between private car and public transport usage. To a lesser extent, the benefit may also depend on shifts between public transport modes.

A traveller's choice of transport mode depends on that person's preferences, the journey characteristics and relative price for each mode. One of the most important journey characteristics is the availability of a given mode at the traveller's residential location. Within the timeframe of the rail fare determination, journey characteristics are assumed to be constant for each mode.

There are two policy levers potentially available to influence the relative price of private car and public transport journeys: road user charging and ticket prices. Road user charging has been discussed at length in Australia and overseas, and there is much to recommend it on grounds of economic efficiency. Nevertheless, the political impediments to extending it appear, for now at least, to be insurmountable. Some progress has been made on parking space levies, time of day tolling for the Sydney Harbour crossings and fuel excise reform, but the introduction of more systematic road user charging does not appear likely within the next few years. Road user charges in force at present are assumed to remain constant.

The remaining policy lever for optimising transport externalities is to adjust fares. A change in fares would change modal market shares by altering the relative prices of transport modes. Changing modal shares would alter traffic congestion, fuel consumption, related emissions of greenhouse gases and conventional pollutants, the frequency and severity of traffic accidents.

Because traffic congestion is such a spatially specific phenomenon, it is necessary to simulate it using a detailed traffic model that has been tailored to the street and rail geometry of Sydney and to the origin-destination movement patterns of Sydney residents. The Sydney Strategic Travel Model (STM) designed by the NSW Bureau of Transport Statistics is used for these traffic simulations.

The modal choice logic is incorporated in the STM, which is used to derive public transport usage by mode and the following properties of automobile traffic:

- vehicle kilometres travelled;
- vehicle occupancy rates;
- person-hours of travelling time;
- the distribution of traffic among different velocity bands.

These usage indicators are calculated for several different rail availability scenarios. They are capable of being broken down further by purpose of travel, time of day, and geographic regions. For each scenario, this information can be used to determine congestion costs by calculating the value to motorists of the additional travel time they are forced to endure because of congestion. It can also be used to determine fuel consumption, which correlates directly to emissions of greenhouse gases and conventional air pollutants.

Comparison of STM results for different scenarios makes it possible to calculate the marginal external benefit or cost associated with a small increase or decrease in public transport use. The marginal external benefit is the sum of avoided automobile congestion, pollution and accident costs less the sum of congestion, pollution and accident costs associated with public transport. The marginal external benefit rate will depend, among other things, on the current level of car and public transport use. The lower the starting automobile modal share, the smaller the effect on road congestion of a given shift to public transport.

Once certain characteristics of rail demand have been established, along with rail marginal costs and marginal external benefits as a function of rail patronage, it is possible to perform a mathematical optimisation of the rail fares. These optimal fares, in conjunction with fixed costs, patronage and marginal cost levels at the optimal fare, implicitly determine the optimal quantum of Government subsidy to rail services.

3 New since prior rail externality study

Since CityRail externalities were last estimated there have been several important improvements in both the methods and data employed. Starting with the ferry study (Smart, 2012) a new, more general analytical framework has been adopted. That framework is set out in the Appendix, and the relevant citations are in the References section.

The treatment of road pricing is improved in this externality study by two events. Following the approach used in the ferry study, the relevant government charges have been clearly isolated and quantified using budget data. Also, the new STM runs have permitted a more exact estimation of the proportion of car journeys that

are liable to pay the NSW Government parking space levy and tolls on the Sydney Harbour crossings. The details are provided in section 7.

A newer version of the STM has been available since just before the ferry study was done. This STM version provides a more realistic analysis of travel for purposes other than journey to work, and therefore offers a more realistic summation of values across all journey purposes.

An improved set of estimates of unit costs for conventional air pollution is employed in this study. The 2009 bus study introduced a more refined set of diesel-related air pollution costs that reflected the current fleet mix for Sydney Buses and the fact that both fuel and engine specifications have improved significantly over the past few decades in Sydney. This study takes that work one step further, introducing a more exact set of air pollution costs for automobiles using unleaded petrol.

Finally, the Commonwealth Government's July 2012 introduction of a carbon pricing mechanism has established a hard dollar figure for the price of carbon dioxide emissions.

4   Marginal external costs

The primary focus of this study is the estimation of marginal external costs that are avoided by a traveller's use of public transport. This chapter presents estimates of these marginal external costs. There is one subsection devoted to each of the most commonly cited externalities of transport: congestion and pollution. Within each of these subsections, the method, the data, and then the results are presented.

The third subsection argues that marginal external costs for motor accidents are too small to measure reliably. The final subsection summarises the overall marginal external cost results.

4.1 Traffic congestion externalities

Broadly speaking, transport gives rise to two types of external costs: those experienced by other travellers, and those experienced by non-travellers. Congestion is in the former category, while air pollution is in the latter. When one more car journey is added to an already busy stream of traffic, it slows the other cars down by a small but measurable amount. This slowing effect causes the occupants of those other cars to consume more time and petrol than they otherwise would have to complete their journeys. The cost of this additional time and petrol is an externality.

Consider the possibility that a person who had been a passenger in a car in a busy traffic stream yesterday decides to drive her own car instead today. As a result of

that decision, that person will experience a slower journey today, because there is more traffic on the road compared to yesterday. The additional travel time experienced by that person is not an externality. In deciding whether to drive her own car or to car pool, this person will consider the additional cost of petrol, tolls, and of her own travel time. The switching motorist's travel time is just part of the "price" that is taken into account in determining her choice of transport mode.

Putting this logic in a more precise way, the sluggishness of traffic can be measured by the number of hours taken on average to travel one kilometre on a typical commuting journey. The greater the congestion, the larger this figure will be. In general, in a given traffic network in a given time period, the average hours per kilometre will increase as the total number of car passenger kilometres increases. The total travel time for all car drivers and their passengers is the average hours per kilometre multiplied by the number of passenger kilometres (counting each driver as a passenger also). The increase in total travel time with a small increase in car passenger kilometres has three components:

A.   The initial passenger kilometres multiplied by the increase in hours per kilometre;

B.   The increase in passenger kilometres multiplied by the initial hours per kilometre; and

C.   The increase in passenger kilometres multiplied by the increase in hours per kilometre.

Of these components, only A is a true external cost of car travel. B and C are experienced only by the occupants of cars newly joining the traffic, so they would be taken into account by a rational person deciding whether to travel by her own car. It is very important to recognise the distinction between these types of congestion costs. Otherwise congestion externalities will be overestimated.

Figure 4.1 illustrates these points conceptually.

Figure 4.1 Travel time burden of congestion on existing motorists

Area A: external travel time

Area C

hours / km

Area B

Δ q

automobile passenger kilometres travelled
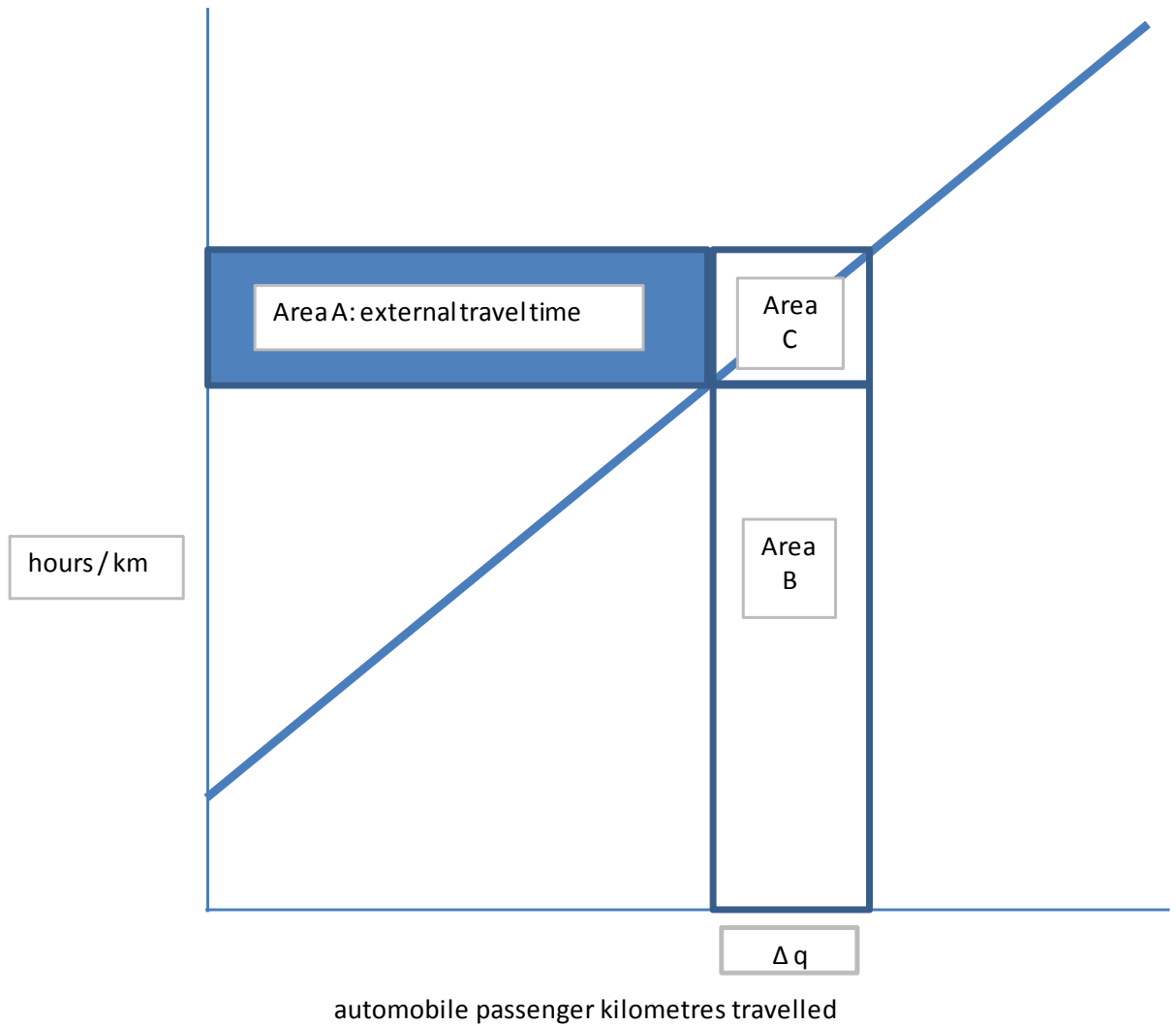
4.1.1 Method for congestion

The marginal external congestion cost for motorists primarily consists of excess travel time. The value of travel time lost due to congestion is the value of a traveller's time, expressed in dollars per hour, multiplied by the number of hours lost as a result of the decisions of others. To evaluate the latter for existing motorists, let Q be the total number of automobile passenger kilometres travelled

during a work day. Let Y be the average number of hours required to travel one kilometre in average traffic conditions. $Y = Y(Q)$ is an increasing function of Q. The total travel time is simply $Q * Y$.

We are interested in the increase in travel time experienced by existing motorists when the total number of automobile passenger kilometres increases by a small amount $= \Delta q$ (Area A in figure 4.1). This increase in travel time is equal to

$$Q * (Y(Q+\Delta q) - Y(Q))$$

The marginal external cost of congestion-related travel time is

$$mec = VOTT * Q * (Y(Q+\Delta q) - Y(Q)) / \Delta q$$

where VOTT is the average value of time to automobile occupants. If Y were a linear function of Q, say $Y = A * Q + B$, then the marginal external cost would be

$$mec = VOTT * Q * A$$

4.1.2 Data for congestion

The relationship between automobile passenger-kilometres and passenger hours is subtle. It depends not only on the specific geometry of Sydney's roads, which is substantially fixed at all times of day (apart from lane changes on the Harbour Bridge, etc.), but also on the origin-destination patterns of journeys, which change substantially during the day.

New STM runs were conducted for a typical workday. All journey purposes were combined, as were all times of day. Total automobile passenger hours and automobile passenger kilometres travelled on that typical workday were estimated for five different scenarios, involving progressive increases in automobile traffic demand:

- 50% rail fare reduction, all other fares held constant (least car use);
- Business as usual;
- 100% rail fare increase;
- 200% rail fare increase; and
- No rail service provided (most car use).

For each scenario, the ratio of automobile passenger hours to automobile passenger kilometres (equivalent to 1/speed) was calculated. The five scenarios were then used to determine a line of best fit to the points (1/speed) vs automobile passenger

kilometres. This line is the diagonal line shown conceptually in figure 4.1 above. The slope of this line is the parameter A described in section 4.1.1.

The relevant value of Q is simply the number of automobile passenger kilometres travelled in a normal workday in the Business as usual scenario. The VOTT figure chosen was the Value of Travel Time used in the 2008 CityRail externality study: $15.80/hr, indexed by inflation from 2008/9 to 2011/12. The resulting value of the marginal external congestion cost (mec) is expressed in units of $/automobile person kilometre in Table 4.1 below, along with the other inputs.

Table 4.1 Calculation of congestion parameters

VOTT ($/hr)	16.87
Q (auto pk)	105,568,300
A (quadratic coeff)	7.73E-10
mec	1.377

The results of employing these values are summarised in section 4.4 below.

4.2 Emission effect externalities

External costs, such as pollution, that are experienced primarily by non-travellers can be estimated straightforwardly. While the car driver and her passengers may experience some air pollution if they drive with the windows down, the greater effect is felt by people living near a busy road. In the case of greenhouse gas emissions, the effects are felt by everyone on the planet. The dispersion of air pollution is so great that most of the polluting effects created by a given car are felt by people other than that car's occupants.

A car's emissions are directly proportional to the amount of fuel consumed, since pollution (both conventional and greenhouse) is the result of a chemical reaction. [5] Therefore, total air pollution depends on car passenger kilometres in a direct way. More passenger kilometres mean more litres of fuel consumed, which imply more pollution. The incremental impact on pollution of an additional car passenger

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[5]   This fact arises from the chemical equations for fuel combustion. The proportionality between quantity of pollution and litres of fuel consumed, while strong, is not quite exact. It depends also on the thoroughness of combustion of the fuel. In turn, this depends to some extent on the condition of each vehicle, how fast it is travelling, and whether the engine is warmed up. These second-order complications are ignored.

kilometre is proportional to the additional fuel that must be consumed to produce that passenger kilometre. There are some subtleties arising from the influence of congestion on the relationship between car passenger kilometres and fuel consumption, and from the fact that health impacts of air pollution may not be linearly related to the concentration of pollutants in the air.

The implications of these facts are illustrated in figure 4.2.

Figure 4.2 Estimation of emission externalities

litres fuel / km

Area A: litres of fuel consumed

Area C

Area B

Δ q
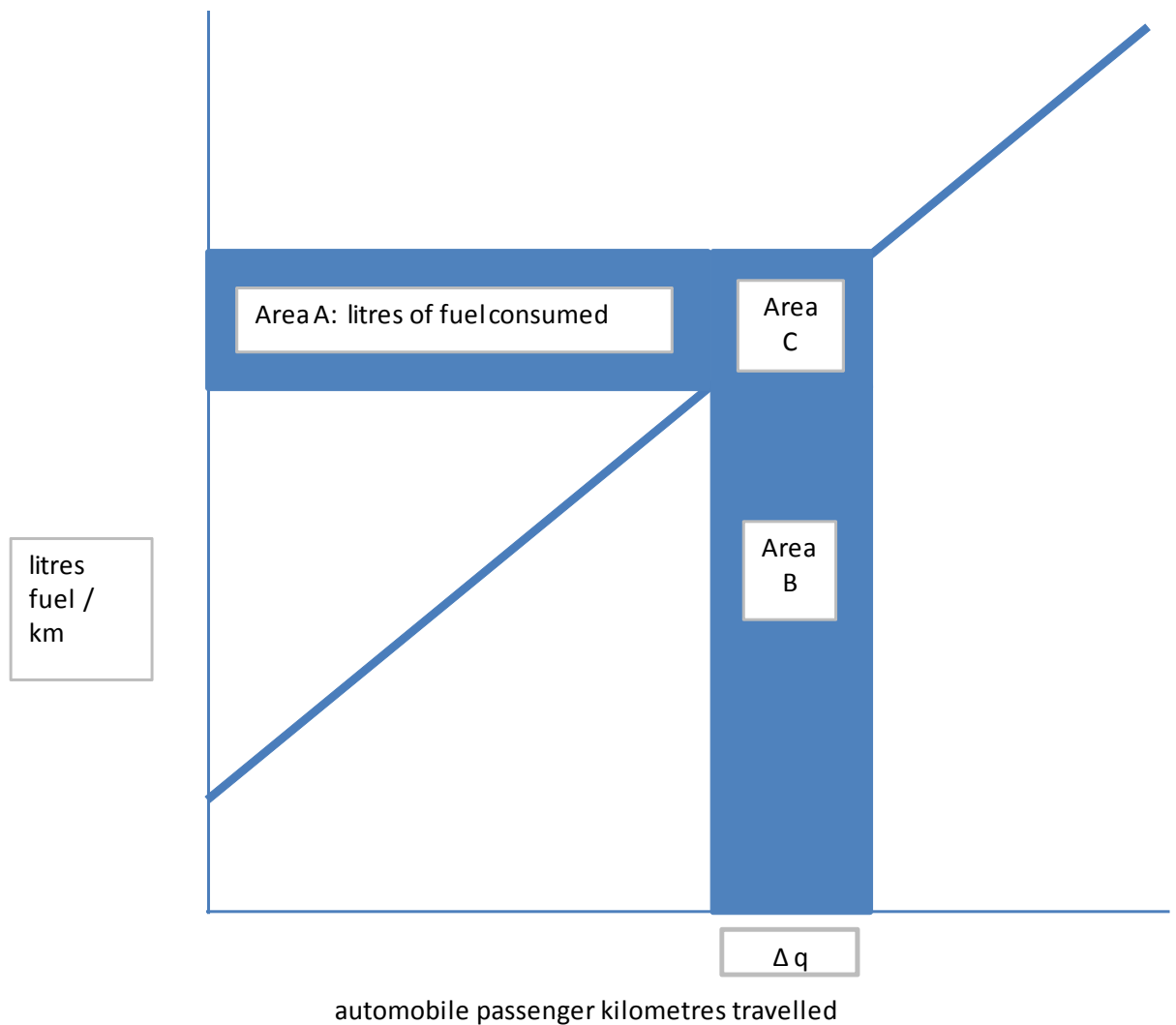
automobile passenger kilometres travelled

Figure 4.2 is similar to figure 4.1, apart from the fact that the units on the vertical axis are litres of fuel consumed per automobile passenger kilometre. In figure 4.2,

areas represent litres of fuel consumed. As air pollution is proportional to the fuel consumed, these areas are proxies for air pollution. The external cost of an increase of Δq in total automobile passenger kilometres travelled is the sum of areas A, B and C because the population at large is affected adversely not only by the emissions from existing car users, but also by emissions from new car users. All fuel consumption causes external costs.

4.2.1 Method for quantifying emission effects

Cars and buses emit conventional air pollutants (including fine particulate matter, volatile organic compounds, and nitrous oxides) that have adverse health consequences for the urban population generally. They also emit greenhouse gases that make some contribution to global climate change. The amount of air pollution and greenhouse gas emission from a given type of vehicle burning a given type of fuel is proportional to the number of litres of fuel burnt, for the simple reason that all of these pollutants are the by-products of the chemical reactions that accompany internal combustion. Quantifying the emission externalities is a simple matter of calculating the following ratios, and combining them:

- Health cost per kg of each conventional pollutant;

- Kg of each conventional pollutant per litre of fuel consumed;

- Carbon price ($/kg);

- Kg of carbon emitted per litre of fuel consumed;

- Litres of fuel consumed per car-km or bus-km;

- Average vehicle occupancy for cars and buses.

The marginal external emission cost rates are:

$$\mathrm{mec}^{\text{car emissions}} = (\mathrm{vkt/pax\text{-}km})\,(l_{\mathrm{ulp}}/\mathrm{vkt})\left\{(\mathrm{Cost}_{\mathrm{GHG}}/\mathrm{kg}_{\mathrm{GHG}})\,(\mathrm{kg}_{\mathrm{GHG}}/l_{\mathrm{ulp}})\right.$$

$$\left.+ \sum_{\mathrm{pollutant}} (\mathrm{Cost}_{\mathrm{pollutant}}/\mathrm{kg}_{\mathrm{pollutant}})\,(\mathrm{kg}_{\mathrm{pollutant}}/l_{\mathrm{ulp}})\right\}$$

$$\mathrm{mec}^{\text{bus emissions}} = (\mathrm{bus\text{-}km/pax\text{-}km})\,(l_{\mathrm{diesel}}/\mathrm{vkt})\left\{(\mathrm{Cost}_{\mathrm{GHG}}/\mathrm{kg}_{\mathrm{GHG}})\,(\mathrm{kg}_{\mathrm{GHG}}/l_{\mathrm{diesel}})\right.$$

$$\left.+ \sum_{\mathrm{pollutant}} (\mathrm{Cost}_{\mathrm{pollutant}}/\mathrm{kg}_{\mathrm{pollutant}})\,(\mathrm{kg}_{\mathrm{pollutant}}/l_{\mathrm{diesel}})\right\}$$

A similar formula applies to ferry emissions.

The empirical determination to be made is whether rail usage reduces the costs of emissions and by how much. The emissions externality calculation is performed once the change in road vehicle-kilometres is determined by the STM runs. The core steps in the analytical approach are:

1. Estimate the fuel savings per passenger-kilometre associated with a mode shift from automobile to rail;

2. Quantify the associated reduction in emissions of carbon dioxide and conventional pollutants such small particulate matter, sulphur dioxide, nitrogen oxides, carbon monoxide, benzene, and lead;

3. Cost the avoided externality on the basis of an assumed carbon price and published values of the marginal external health costs per litre of fuel consumed.

4.2.2 Data for emission effects

Watkiss (2002) calculated air pollution costs for Australian Vehicles. Watkiss distinguished between emission rates from vehicles manufactured between 1980-89, 1990-95 and 1996-99. The bus figures cited below are taken from Watkiss' Table 25, p. 39. Air pollution costs in cents per litre were given for four geographical bands, of which Band 1 is of interest. Band 1 is the inner areas of larger capital cities, including Melbourne, Sydney, Brisbane, Adelaide and Perth. For heavy buses manufactured between 1996-99, the air pollution costs were $0.58/litre diesel. The Watkiss figures for cars (med sulphur fuel, Pre-Euro 1 standard petrol car) in Band 1 were given in Table 29, p. 46: $0.16/litre ULP. These figures were CPI indexed to 2011/12 dollars: buses = $0.72/litre diesel, and cars = $0.20/litre ULP. As Watkiss is the authority cited by the Australian Transport Council's 2006 <u>National Guidelines for Transport System Management in Australia</u> (Appendix C: default externality values) this report adopts these Watkiss air pollution cost estimates.

Smart (2009) employed CO_2 emission rates of 2.34 kg CO_2/l_{ulp} and 2.68 kg CO_2/l_{diesel}. Since that report, the Commonwealth Government has introduced a legislated carbon pricing scheme setting the level at $23/tonne CO_2. Average fuel consumption rates per automobile kilometre and ferry kilometre are used. An increasing proportion of Sydney buses uses compressed natural gas instead of diesel, with some reduction in emissions.

An overall estimate of external costs for train services was obtained from figures contained in Karpouzis (2007). The results of the emission externality calculation are summarised in section 4.4 below.

4.3 Accident externalities

It is widely understood that another benefit of public transport is a reduction in the number and cost of automobile accidents. Simplistically, less automobile traffic would seem to imply fewer accidents. Accident cost reduction is, in fact, a significant factor in social cost benefit studies for highway construction projects. The forecast reduction in automobile accidents that is attributable to a new road's existence is part of the benefit expected from building it.

Translating this concept into a rationale for subsidising public transport is, however, far from straightforward. There are two main problems. First, the relationship between traffic density and accident cost is complicated. It is not even possible to say, in general, whether increased density increases or decreases accident cost. Second, many of the costs of motor accidents are internalised and are therefore not a valid grounds for subsidising public transport. In unpicking these issues it is helpful to return to the dichotomy introduced earlier between externalities that primarily impinge on other motorists, and those that impinge primarily on non-motorists.

Let us first consider accidents in which the injured party is the driver or passenger of a car. Several factors suggest that important parts of the costs faced by such a party are not external:

- The injury cost is the indirect result of a decision by the driver or passenger to travel by car. A rational traveller would have taken into account the risk-weighted possibility of this accident when choosing a mode of travel.

- Damage to the car is likely to have been insured, as is damage to other cars affected by the accident. The insurance premium tends to internalise this cost, in terms of bringing it into the motorist's private cost-benefit calculus supporting the decision to drive or travel by public transport.

- Some significant proportion of the medical cost of the accident is also likely to be covered by insurance, and therefore internalised.

Nevertheless, there are undoubtedly parts of the accident cost that cannot be fully internalised in the driver's mode choice decision. For example, the loss suffered by the driver's family and workplace as a result of injury or death is external to the driver's decision. The additional strain on emergency services arising from the accident is likewise an external cost.

In order to progress further, it is necessary to return to a version of figure 4.1 above. As in figure 4.1, the horizontal axis would be automobile passenger kilometres travelled on a given network within a given period of time. The vertical axis, however, would be the average traffic accident cost borne by motorists per automobile passenger kilometre. The key question is this: would the diagonal line

have a positive or negative slope? Would the average rate of accident cost increase or decrease with passenger kilometres?

Almost certainly, this line would have a negative slope. The accident rate would decrease with an increase in passenger kilometres travelled because the average traffic speed would decrease. The severity of any accidents would be reduced by the square of the velocity, and the likelihood of accidents would probably also be reduced as drivers would have more time to react to any incidents. Therefore, any external effect of increased traffic on accident costs that are borne by motorists would actually be a *benefit*.

Let us then consider the other case: the injured party is not a car occupant, but rather either a non-motorised traveller (such as pedestrian or cyclist), a bystander, or the owner of damaged property near the roadway. Some of these costs would be met by third party insurance. Accepting the likelihood that an injured party would be worse off injured with an insurance payout than never injured in the first place, part of this accident cost could be considered to be a true external cost of motoring.

For this case, the relevant diagram is a version of figure 4.2 above. The horizontal axis would again be automobile passenger kilometres. The vertical axis would be the average traffic accident cost borne by non-motorists per automobile passenger kilometre. It is less clear in this case whether the slope of the diagonal line would be positive or negative. Certainly single-impact damage to stationary and slow-moving persons or property by the roadside would be reduced by the traffic calming effect of congestion. The more cars there are on the road, the greater the number of opportunities for such collisions to occur. However, on a per automobile passenger kilometre basis, it seems likely that the accident cost borne by non-motorists would also decrease with increasing traffic density.

Considering the areas A, B, and C on this version of figure 4.2, it is clear that area A will be negative, that area B will be positive, and area C will probably be small enough to ignore. Whether the net external effect of traffic density on accidents is positive or negative will depend on the relative size of areas A and B, which may cancel each other out to some extent.

In general it is difficult to say whether this balance will be net positive or negative, since much depends on the particulars of the road design. However, it is clear that the marginal external accident cost (that is the increase in accident cost caused by an increase in automobile passenger kilometres travelled in a given space and time) faced by motorists will be negative. Whether the marginal external accident cost faced by non-motorists is positive or negative, it is likely to be small because of third party insurance and the partial cancellation between areas A and B.

Overall, we conclude that a conservative position (erring on the side of overstating the external benefits of public transport) is to assume that marginal external accident costs are near zero. Note that this statement is not equivalent to a declaration that total external accident costs are zero. It only says that increasing traffic density does not increase total external accident costs. There is not necessarily any conflict between this viewpoint and the use of total accident externalities to justify road (or rail) construction projects.

4.4 Summary of marginal external costs

The results of the marginal external cost calculations in this chapter are summarised in table 4.2 below.

Table 4.2 Summary of marginal external cost calculation for all modes

	mec ($/person-km in each mode)			
	congest	air pol	GHG	Other
car	1.377	0.020	0.005	-
bus	-	0.008	0.001	-
ferry	-	0.099	0.008	-
rail	-	0.007	-	-

5 Total external benefit

An alternative perspective on optimal subsidy funding for a public transport service can be obtained by examining the total external benefits created. The taxpayer would ideally pay an amount equal to the external benefits generated by the service, while users of the service would pay for the remainder of the efficient cost of service. Under this conceptual framework, the Government would also bear the cost of inefficient operation, but could exert its power to change management of the service to motivate efficiency increases.

Figures for total cost and total subsidy to CityRail are readily available from official documents. It remains to translate the marginal external cost estimates derived in chapter 4 into total externalities in order to compare present subsidies with external values.

The calculation of total external benefit is performed in the series of tables below.

5.1 Base case for 2011/12

The calculation of total external benefit created by rail is done in two parts. For the total congestion benefit, it is simply:

$$\text{Total congestion benefit} = \int mec \, dQ = VOTT \, A \int Q \, dQ = VOTT \, A \, [Q^2_{NR}/2 - Q^2_{BAU}/2]$$

where the bounds of integration are from Q_{BAU} (total auto passenger kilometres in the Business as usual scenario) to Q_{NR} (total auto passenger kilometres in the No rail scenario.)

For emission benefits, the calculation is somewhat more involved since each mode has some marginal external emissions cost:

$$\text{Total emission benefit} =$$

$$RPK \, [\, dX_c/dX_r \, (mec_r - mec_c) + dX_b/dX_r \, (mec_r - mec_b) + dX_f/dX_r \, (mec_r - mec_f)]$$

Subscripts c, r, b, and f refer to car, rail, bus and ferry respectively. RPK is the number of rail passenger kilometres per typical workday. "mec" refers to the marginal external emissions cost of the given mode in units of dollars per passenger kilometre travelling on that mode.

The terms dX_c/dX_r, etc. refer to the change in passenger kilometres travelling by car (or other modes for other subscripts) for a given change in passenger kilometres travelling by rail. They represent the marginal rate of technical substitution between modes predicted by the STM runs. These values are given in Table 5.1 below.

Table 5.1 Modal substitution factors for all journey purposes combined

	dXi/dXr
car	-0.32
bus	-0.09
ferry	-0.03

Other inputs were presented in Tables 4.1 and 4.2 above. The results of this calculation are shown in Table 5.2 below.

Table 5.2 Calculation of total external benefit to rail service

Total external benefits	congest	air pol	GHG	road pricing		Total
Total external benefit $/wd	7,460,075	132,078	37,692	-	160,227	7,469,618
Total ext $m weekdays	1,857.56	32.89	9.39	-	39.90	1,859.93
Total ext $m weekends	-	4.81	1.37	-	0.13	6.06
Total ext $m public holidays	-	0.48	0.14	-	0.01	0.60
Total ext $m/year	1,857.56	38.18	10.89	-	40.04	1,866.59

Annual figures were derived from workday figures by multiplying by the number of work days in a year (249) and adding relevant figures for weekends and public holidays.

The second last column in Table 5.2 illustrates the fact that car users do in fact make a modest financial contribution toward the external costs that they impose. This contribution is made through road pricing, which is calculated in detail in chapter 7 below. It is netted off the external cost of car use (which is an external benefit of rail use to the extent that rail helps to avoid it). On a per automobile passenger-kilometre basis, road pricing represents 2.1% of the external cost of motoring.

The total external benefits presented in Table 5.2 are overstated to a small extent because of one further issue. In order to achieve the congestion and emission externalities quantified here, the Government must provide significant subsidies to CityRail. Taxation is required to fund these subsidies, and taxation leads to distortions to the consumption decisions of individuals and firms. These distortions represent a negative externality that is caused by subsidised public transport. Section 8.2 below includes an explanation of this effect, called the marginal excess burden of taxation. A value of 0.1 is adopted for the marginal excess burden rate for NSW tax revenue. This value implies that the external cost of taxation is 10% of the amount of tax revenue raised.

The total external benefit of CityRail for 2011 net of the marginal excess burden of taxation is $1.68b. This figure is 90% (benefit net of excess burden; 100% - 10%) of $1.867b.

5.2 Comparison to prior externality estimates

The estimated total external benefits of rail shown in Table 5.2 can be compared directly to those estimated in the 2008 rail externality study. This comparison is done in Table 5.3 below.

Table 5.3 Comparison of past and current estimates, total external rail benefits

	Rail 2008	Rail 2012
	$2008	$2011
Total ext rail $m/yr	1,528.2	1,866.6
congestion	1,390.8	1,857.6
air pollution	111.6	38.2
GHG	25.9	10.9
(less road pricing)	N.C. -	40.0

Since the 2008 study, the estimated congestion benefit of rail has increased substantially, while the estimated emission benefits have decreased. Table 5.4 provides more detail on where the two sets of estimates differed. Calculated values are highlighted in light blue in this table. The remaining figures are input values derived from other sources.

Table 5.4 Detailed comparison of externality inputs 2008 and 2012 studies

	Rail 2008	Rail 2012
	$2008	$2011
VOT $/hr	15.80	16.87
auto fuel consumption l/apk	0.078	0.101
airpol cost/litre unleaded	0.191	0.200
car airpol cost $/apk	0.015	0.020
carbon price $/tonne CO2	25.00	22.15
kg CO2/litre unleaded	2.64	2.34
car GHG cost $/apk	0.0052	0.0052
bus fuel consumption l/bpk	0.0120	0.0107
airpol cost/litre diesel	1.7872	0.7246
bus airpol cost $/bpk	0.0214	0.0078
kg CO2/litre diesel	3.00	2.68
bus GHG cost $/bpk	0.0009	0.0006
Base case		
rail mPJ/yr	281.30	294.49
rail pk/workday	18,199,243	19,052,531
auto pk/workday	151,767,908	105,568,300
dXauto/dXrail	- 0.89	- 0.32
dXbus/dXrail	- 0.36	- 0.09
dXferry/dXrail		- 0.03
emissions comparison		
car airpol saved by rail	66.62	35.58
car GHG saved by rail	22.96	9.22
bus airpol saved by rail	38.99	3.87
bus GHG saved by rail	1.63	0.32
car+bus airpol saved	105.61	39.45
car+bus GHG saved	24.60	9.53
congestion comparison		
A (ph_d/pk_d)/pk_d	1.15E-10	7.73E-10
A (aaph/aapk)/aapk	4.38E-07	
mec congestion $/apk	0.28	1.38
mec congestion $/rail PJ	4.65	8.26

Salient differences include:

- A marked reduction in the estimated air pollution cost per litre of diesel consumed by buses. This change arose because of an improved understanding of the emission performance of the Sydney Buses fleet, which includes many natural gas fuelled vehicles and generally better performing engines than was assumed in 2008.
- A more accurate, and lower, estimate of the total number of non-work purpose automobile journeys. This change arose through the use of the improved version 2 STM in the traffic modelling for 2012.
- A more accurate estimate of the mode-switching patterns. This change also arose through the use of the version 2 STM for 2012.
- A higher estimate of the congestion parameter A. This change also arose through the use of the version 2 STM for 2012.

The last row in Table 5.4 indicates that the estimated marginal external cost of congestion per rail passenger journey has nearly doubled, in nominal terms, between the 2008 and 2012 studies. This outcome is driven by the improvements to the STM modelling of congestion effects, coupled with the fact that road congestion has worsened in fact between the 2006 and 2011 Household Travel Surveys, upon which the two externality studies are based.

The second-last row in Table 5.4 suggests that the estimated marginal external cost of congestion has increased by a factor of five, when expressed on a per automobile passenger kilometre basis. This ratio differs from the ratio in the last row because the estimated total number of automobile passenger kilometres travelled for non-work purposes has decreased significantly between the 2012 and 2008 studies as the STM has been improved. The declining denominator in congestion cost per apk is responsible for this higher ratio. For this measure, the 2008 starting point was unrealistically low.

5.3 Forecasting / back-casting to different years

Because IPART fare determinations need to take a medium-term perspective, it is useful to be able to translate marginal and total external cost estimates that were done for the 2011 year to other years.

Taking marginal external congestion cost first, the value is determine by the product of three quantities: the value of travel time, the total number of automobile passenger kilometres travelled, and the coefficient A which expresses the relationship between automobile traffic and congestion effects.

The average value of travel time to users of the Sydney transport system (including motorists) is usually taken to be some set portion of the average hourly wage. If the portion is relatively stable over time, then the value of travel time would be expected to move in line with a wage index.

Movements in the automobile passenger kilometre total and in the congestion parameter A are more difficult to predict. While increasing population would be expected to gradually exacerbate the congestion effect overall (the product of Q and A), major road construction projects would work in the opposite direction and these would be triggered to some extent by any perceptions of a worsening congestion problem. On balance, and over a relatively short forecasting horizon, the changes to the product of Q and A might be small. If that is the case, then marginal external congestion costs would be primarily driven by wage indexation.

Taking marginal external emissions costs next, the value is determined by the product of fuel consumption per vehicle kilometre, vehicle occupancy, combustion rates for emitted substances, and the rate of health or climate-related costs per quantum of emission. Of these factors, only the rate of health or climate-related costs per quantum of emission would change over the medium term. The changes to these cost rates would be expected to track a relevant price index. Therefore, marginal external emissions costs would also be primarily driven by price indexation.

Turning to total external benefits of rail transport, they are determined by the marginal external costs of the transport modes displaced by rail and by the quantum of rail travel. Consequently, total external benefits of rail transport would be expected to be roughly proportional both to the total quantum of rail passenger kilometres travelled and to a relevant price index that could capture medium-term movements in wages, health cost rates and climate-related cost rates.

Put another way, to a first approximation in the medium term, total external benefits of rail transport expressed in real terms should be proportional to the total rail passenger kilometres travelled. Marginal external benefits of rail would be approximately constant in real terms.

6 Marginal costs and fares

This section summarises work done previously on the estimation of average public transport fare yields and marginal costs for each mode.

6.1 Public transport fares

Annual Report and related data is used to derive average public transport fare yields for each mode. It is important that this figure represent the out-of-pocket cost to the traveller of taking public transport. The total fare revenue (from passengers, as

opposed to Government service payments) is divided by the total number of annual passenger journeys to obtain the average fare. Results are shown in Table 6.1 below.

Table 6.1 Average public transport fare yields 2011 (units $/passenger journey)

bus avg fare/pj FY2011	1.59
ferry avg fare/pj FY2011	3.37
rail avg fare/pj FY2011	2.37

Sources:
- *Bus: STA 2011 Annual Report and IPART services report 2011.*
- *Ferries: Sydney Ferries 2011 Annual Report. Fare revenue including pensioners and other beneficiaries, divided by passenger journeys for 2009/10 year.*
- *Rail: RailCorp 2011 Annual Report.*

Note that average journey lengths tend to differ significantly between modes, so the prices per passenger-kilometre on rail are actually somewhat lower than on bus, owing to the longer average rail journey length. Ferry prices remain the highest on a per passenger-kilometre basis.

6.2 Summary of previous SRMC estimates

Short-Run Marginal Costs (SRMC) were previously estimated for the public transport modes. Smart (2008) determined CityRail SRMC values based on regression analysis of several decades' worth of Annual Report data. Smart (2009) determined average Sydney Buses SRMC values based on regression analysis of confidential monthly bus contract data. Smart (2012) determined average Sydney Ferries SRMC values based on a bottom-up cost model of Sydney Ferries employing public data and some accounting data provided by Sydney Ferries. The results are summarised in Table 6.2 below.

Table 6.2 Summary of prior SRMC estimates for public transport in Sydney

bus MC ($/pj)	3.49
ferry MC ($/person-km)	1.17
rail SRMC ($/person-km)	0.33

Note that the units in which bus SRMC is expressed ($/passenger journey) differ from the units in which the ferry and rail SRMC are expressed ($/passenger-kilometre). Differences in these units arise from differences in the estimation methods employed. For purposes of comparison it should be noted that, across all

journey purposes, the average bus journey length is 8.46 km, which implies the average bus SRMC is $0.41 / passenger-kilometre.

6.3 LRMC estimates for CityRail

Anyone who has caught a peak-hour train in Sydney recently will be aware that crush loading is endemic. As Smart (2008) noted, alleviating peak hour capacity constraints on CityRail is a genuinely hard problem. The City Circle underground infrastructure is the system-wide bottleneck, as it prevents any increase to the number or passenger-holding capacity of peak hour trains.

There appears to be a growing consensus among transport planners that the only viable long-term solution is to construct a new underground heavy-rail line through the Sydney CBD, continuing to the North Shore via a second harbour rail crossing, which would most likely be a tunnel.

Authoritative costings for such a construction project are not publicly available. However, reference to some similar past construction projects gives some idea of the likely order of magnitude. Table 6.3 presents this precedent information.

Table 6.3 Construction costs for existing underground transport links in Sydney

Project	Route length	# stations	cost	dates
Epping-Chatswood Rail Line	12.5 km double track	5	$2.3b	2002-2009
Airport Line	10 km double track	4	approx. $1.7b	Completed 2000
Sydney Harbour Tunnel	Approx. 1 km dual carriageway (road only)	none	$554m	Completed 1992

Ballpark estimates mentioned in the press for a double track second harbour heavy rail crossing and new CBD underground rail line and associated stations are around $10b. The complexity of working under the CBD and constructing a new harbour tunnel would make this project substantially more costly than the Epping-Chatswood Rail Line, which was built under greenfields conditions and on land.

Notwithstanding this capital cost, the benefits of such a project would be extremely large. The capacity of the system bottleneck would be increased from the current 6

tracks (2 crossing the Harbour Bridge, 2 passing through the City Circle via Wynyard and Circular Quay, and 2 Eastern Suburbs Line tracks) to 8. This 33% capacity increase would eventually permit CityRail's system to carry an additional 93m passenger journeys per annum (representing 33% of 2008 CityRail patronage).

A very crude estimate of the long-run incremental cost of a project like this can be made if the assumed $10b capital cost is annuitized. Using a 50 year term and a 5% interest rate, this annuity would equate roughly to an additional marginal cost of $0.32/passenger kilometre (making various assumptions about rapid takeup of new capacity, relatively constant rail journey lengths, etc.) The total LRMC for rail, taking into account this method of capacity expansion, would then be on the order of $0.65/passenger kilometre (SRMC of $0.33 + $0.32).

While the crudeness of this calculation and its assumption-dependence is acknowledged, it seems preferable to explore the long-term future on the basis of some reasonable guesses, rather than ignore the crush-loading problem entirely. Failing to acknowledge these steep future capital costs of expansion could itself lead to misguided policy choices. If the true LRMC is underestimated, then the logic for fare optimisation might mistakenly recommend rail fare reductions, leading to worsening overcrowding with no means of funding the necessary investments and public disappointment with public transport.

7 Current extent of road pricing

Given the dependency of optimal public transport fares on road pricing, it is important to estimate the difference between marginal social cost and price for private car use in Sydney. As noted earlier, the marginal social cost of a transport service is the sum of the marginal cost and the marginal external cost for that service.

The price of private car use can be itemised under the following headings:

- marginal cost of vehicle operation;

- fixed costs of car ownership;

- accident insurance premiums;

- risk-weighted human cost of death or injury in an automobile accident, including pain and suffering of family and friends.

- tolls;

- fuel excise tax; and

- Government parking space levy.

The first two dot points can be combined into a single long-run marginal cost of car ownership and use.[6] The competitive nature of most markets for automobile inputs tends to make these prices converge to cost. It is assumed, therefore, that the price of private car use at least covers these long-run marginal costs.

Accident insurance premiums serve to internalise a significant proportion of the risk-weighted cost of accidents. It is important, when calculating the external accident costs, not to include these insured costs. The risk-weighted human costs associated with accidents are assumed to form part of the car driver (and passenger) decision to travel by that mode. In other words, while this cost is not monetised, it is assumed to be included in the private traveller's reckoning of the full private costs of automobile travel. For this reason, these human costs are also excluded from the calculation of external accident costs—they are assumed to be internalised.

Tolls on the Sydney Harbour Bridge and Harbour Tunnel apply only to Southbound journeys. The toll rate depends on the time of day. For the AM and PM peak periods, the toll is $4 per car. For the Inter Peak period it is $3, and for the Evening period it is $2.50.

The Federal Government applies a fuel excise tax of 38.143 cents per litre to unleaded petrol and diesel, from which $5.892 billion in tax revenue was raised Australia-wide in 2010-11. Of this sum, only $2.980 billion was spent on roads nationally by the Commonwealth.[7] Assuming that the national proportions are valid for Sydney, these facts imply that 18.851 cents per litre of the excise tax (i.e., the fuel excise less the avoidable cost of road usage) could be considered a user contribution toward the marginal external costs of private car usage. This particular road price does not differ between peak and off-peak use.

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[6]   Included are costs of vehicle ownership or lease, repairs and component replacements, and the non-tax component of the fuel price. Road infrastructure pricing is not included under this head.

[7]   Australian Government, 2012-13 Federal Budget, Budget Paper 1, Statement 5 Revenue, Table 11 2010-11 Actual Petrol only, and Statement 6 Expenses and Net Capital Investment, Table A1, Road and Transport 2010-11 actual expenditure.

For several years the NSW Government has levied a tax on parking spaces in the CBD and several other concentrated commercial precincts.[8] In 2010-11 this levy is $2,040 per car space in the CBD and North Sydney.[9]

These price points are summarised in table 7.1 below.

Table 7.1 Summary of government taxes on car users

Excise tax on unleaded petrol (cpl)	38.143
excise revenue ($m) in 2010-11	5892
Cwlth road funding ($m) in 2010-11	2980
SHB SHT toll AM/PM Southbound ($/crossing)	4.00
SHB SHT toll IP Southbound ($/crossing)	3.00
SHB SHT toll EV Southbound ($/crossing)	2.50
PSL 2010-11 CBD, North Sydney ($/space/yr)	2040
PSL 2010-11 Bondi J, Chats, Parra, St Leo ($/space/yr)	720

Under the following assumptions, table 7.2 summarises the calculation of each of these elements of the road price in units of average price per person-kilometre. The assumptions are that:

1. Tolls are a pure tax, as the SRMC is approximately zero for a harbour crossing; and
2. Parking prices equal the sum of the parking space levy plus the LRMC of providing a parking space. Therefore the parking space levy is the only component of price that is in excess of cost.

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[8] The parking levy applies to Sydney CBD, North Sydney and Milson's Point. At a somewhat lower rate, it also applies to Chatswood, St Leonards, Parramatta, and Bondi Junction.

[9] Source: www.transport.nsw.gov.au/aboutus/psl.html Note that the levy rate will approximately double from 1 July 2009.

Table 7.2 Calculation of road price components in units of $/p-km for journeys to which they apply

p - c for car journeys	
avg litres/veh km	0.144
occupancy	1.43
avg litres/person-km	0.10
pure fuel tax $/p-km	**0.019**
avg car distance 1 way	10.11
occupancy	1.43
RT person km	28.96
Toll AM/PM $/p-km RT	**0.14**
Toll IP $/p-km RT	**0.10**
Toll EV $/p-km RT	**0.09**
CBD PSL/commuting day	8.19
RT person km per commute	28.96
PSL $/p-km	**0.28**

Finally, table 7.3 summarises the overall road price as a weighted-average across various types of car journeys, using the Business as usual scenario (base case).

Table 7.3 Weighted average road price across journey types

scenario	2011_Base
avg weekday VKT (all journey purposes)	77,214,470
VKT with CBD as destination	1,396,920
VKT Southbound SHB or SHT	1,881,750
AM or PM	1,237,900
IP	382,870
EV	260,980
% VKT paying PSL	1.8%
%VKT paying AM/PM toll	1.6%
%VKT paying IP toll	0.5%
%VKT paying EV toll	0.3%
average p-mc for cars	**0.027**

The units for the average p-mc are $/automobile passenger kilometre. These are significantly lower than the figures shown in Table 7.2 because, while all car journeys incur the fuel excise tax, only a small proportion of journeys incur either the parking space levy or the toll on a harbour crossing.

Any significant change to road pricing, either in the form of an amended rate of petroleum products excise, cordon pricing, increased parking space levy, or more extensive tolling arrangements, would have implications for optimal public transport prices.

8 Optimisation of fares

This chapter explains the method for calculating optimal rail fares, and presents the results of the calculation.

8.1 Specification of optimisation problem

The optimal rail price, p^{r*}, is the marginal social cost of rail service less an adjustment factor that depends on the optimality of prices for other transport modes. The marginal social cost is simply the sum of marginal cost and marginal external cost.

In a first-best world, all transport services would be priced at their own marginal social costs, implying zero adjustment factor. Otherwise, the adjustment factor is the weighted sum of the quantity (marginal cost + marginal external cost – price) for all transport modes other than rail. That is, car, ferry and bus. Marginal external costs were calculated for each of these three modes in prior studies completed for IPART (Smart 2008, Smart 2009, and Smart 2012). Marginal costs were also calculated for train, ferry and bus services in these studies.

Strictly speaking, neither the marginal cost nor the price for car use is known with any certainty. Nonetheless, it is reasonable to suppose that as most inputs to motoring are supplied in competitive marketplaces, their prices would closely approximate long-run marginal costs plus any government taxes that apply. For this reason, the difference between price and marginal cost for motoring would simply be the sum of government taxes that vary with car use. This difference can be determined with a high degree of certainty, and that calculation was the subject of chapter 7.

The weightings used in the adjustment factor are the marginal rate of technical substitution between rail and each of the other transport modes. This substitution rate is the answer to the following question. If 100 rail passengers choose to travel by a mode other than rail (either because the rail price has risen or because rail

service is now unavailable), what percentage travel instead by car, train, and bus? The STM runs provide answers to that question for rail services overall, and for rail service on each of the routes.

Under the assumption that the marginal excess burden of taxation is near zero, and that there is no change to bus or ferry fares or to the rate of taxation of motoring, the formula for the optimal rail price is given by equation (9) below. This equation is developed in Appendix 1.

$$p^r * = c^r + \sum_h mec^r_h + \sum_{i<>r} [c^i - p^i + \sum_h mec^i_h] \; (\partial X^i / \partial X^r) \qquad\qquad (9)$$

The straightforward interpretation of equation (9) is that optimal prices should equal the sum of marginal costs, marginal external costs, and an adjustment factor that compensates for any departures from optimal pricing that occur in competing transport modes. Evidently, if the price is equal to marginal cost plus marginal external cost for all of the other modes, then the adjustment factor is equal to zero.

Where one or more of these other modes requires significant subsidy, as in ferry for example, it will have a downward influence on the optimal rail price, all else being equal. This point can be seen by recognising that the need for subsidy implies that $c^i > p^i$. The modal substitution factor, $(\partial X^i / \partial X^r)$, is always negative. Therefore, the larger the bus or ferry subsidy, the lower the optimal rail price will be.

Prices, marginal costs and marginal external costs as calculated in chapters 4, 6 and 7, and previous studies are summarised in table 8.1 below.

Table 8.1 Summary of p, c, mec by mode

$/person-km	journey purpose
	All
bus fare	0.19
ferry fare	0.38
rail fare	0.13
bus mc	0.41
ferry mc	1.17
rail mc (SRMC+ΔLRMC)	0.65
p-mc	
bus	- 0.22
ferry	- 0.79
rail	- 0.52

Only averages across all journey purposes and all times of day are shown here. The extent of road pricing (price – marginal cost for cars) for an individual journey depends on whether the car journey involves CBD parking (in which case it bears the NSW Government parking space levy tax) and whether it involves the use of the Sydney Harbour Bridge or Harbour Tunnel (in which case it incurs the toll.)

The marginal rate of technical substitution for trains can be calculated from the STM runs. Table 5.1 above showed the STM substitution data for all journey purposes combined.

8.2 Results and analysis

The results of the optimal rail fare calculation for commuter trips are shown in table 8.2 below, under the assumption of no marginal excess burden of taxation.

Table 8.2 Optimal rail fare calculation for all journey purposes combined (other prices fixed, λ=0)

Units of $/person-km		journey purpose
		All
car	price - marginal cost	0.03
	mec	1.40
	dXi/dXr	-0.32
	Zi = dXi/dXr*(mec+c-p)i	-0.44
bus	price - marginal cost	-0.22
	mec	0.02
	dXi/dXr	-0.09
	Zi = dXi/dXr*(mec+c-p)i	-0.02
ferry	price - marginal cost	-0.79
	mec	0.11
	dXi/dXr	-0.03
	Zi = dXi/dXr*(mec+c-p)i	-0.03
rail	current price	0.13
	marginal cost	0.65
	curr price - marg cost	-0.52
	mec	0.01
ideal rail fare	p* = c + mec + Σ Zi	0.16
ideal - current price	p* - p	0.04
% price increase	(p* - p)/p	29%
ideal rail fare ($/pj)	p* x avg journey km	3.07

Table 8.2 indicates that the ideal rail fare would be 29% higher than the current average rail fare. Note that this calculation takes account of the long run marginal cost of expanding infrastructure capacity in the CBD bottleneck.

8.2.1 Marginal excess burden of taxation

As noted previously, all modes of public transport in NSW receive government subsidies, raised via state taxation. The imposition of government taxes generally results in three categories of costs: the direct cost (value) of the tax revenue raised; the administrative and compliance costs of imposing the tax; and the costs arising from changes (or distortions) to behaviour.

The value of the tax revenue raised is a simple transfer from taxpayer to Government, which has no direct welfare consequences. The administrative and compliance costs of taxation are relatively small, and are ignored here. The cost associated with behavioural changes as a result of taxation, reflected in changed resource consumption decisions, is known as the marginal excess burden of taxation.

For the purposes of the optimal rail fare calculation, it is assumed that the revenue required to fund the relevant subsidies is a result of an additional tax that creates some distortions which are themselves negative externalities arising from (the need to subsidise) public transport. By this assumption, the subsidy revenue requires a new tax. Therefore it is the marginal excess burden of taxation, rather than the average excess burden across all State taxes, that is relevant.

Incorporating the impacts of the marginal excess burden of taxation into the optimal rail fare calculation requires estimating the value of the marginal excess burden of taxation. There is a body of quantitative studies which estimate rates of marginal excess burden for various types of tax. However, relatively little work has been done looking at the marginal excess burden of NSW state taxation specifically, or state taxation in Australia more generally.

Gabbitas and Eldridge (1998) undertook an assessment of the efficiency of various state taxes. Their analysis estimated, for the majority of taxes assessed (stamp duties being an exception), a marginal excess burden of taxation of between zero and 20 cents per dollar of revenue collected (i.e. $\lambda=0$ to 0.2).[10] More recent estimates of the marginal excess burden of state taxation are provided by KPMG Econtech (2010). KPMG Econtech analysis suggest state taxes range from very efficient ($\lambda<0.1$) to very inefficient ($\lambda>0.65$).[11]

Noting the assumed premise underpinning the CityRail subsidies, an estimate of $\lambda=0.1$, reflecting a tax that is more efficient than not, has been adopted for the purposes of calculating the optimal rail fare where the marginal excess burden of taxation is not zero. This value is consistent with estimates for the marginal excess burden of the GST, which is a principal source of state tax revenues even though it is levied by the Commonwealth.

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[10] Gabbitas, O & Eldridge, D, 1998, *Directions for State Tax Reform – staff research paper*, p. 53, table 4.10

[11] KPMG Econtech, 2010, *The Excess Burden of Australian Taxes – Report prepared for the Department of the Treasury*, p. 44, table 5.1

It is important to recognise that the negative externalities created by taxation are derived from the fact that public transport operates at a loss: average revenue per ticket is less than the marginal cost of providing service. Taxation, and the excess burden that comes with it, would be required even if the long run marginal costs related to a second harbour crossing could somehow be avoided.

8.2.2   Optimal fare when marginal excess burden is not zero

When the marginal excess burden of taxation is not zero, the taxation needed to fund subsidies induces distortions to consumption decisions that harm welfare. In this case, equation (12) is needed to derive the optimal rail fare.

$$p^r* = \{(c^r\,(1+\lambda) + \Sigma_h\,mec^r_h + \Sigma_{i<>r}\,[(c^i - p^i)\,(1+\lambda)\ + \Sigma_h\,mec^i_h]\ (\partial X^i/\partial X^r)\}$$

$$/\,(1+\lambda+\lambda/e^{rr})\quad(12)$$

Equation (12) is derived in Appendix 1. In order to evaluate equation (12) it is necessary to know the rail own-price elasticity. Hensher and Raimond (1996) provide a range of own-price elasticities for ferries of approximately -0.2 to -0.44 (see table on p. 32). Price elasticity is lower for single tickets, higher for travel ten tickets, lower for commuters and higher for non-commuters.

Adopting a mid-range value of -0.35 for the own price elasticity and $\lambda = 0.1$, optimal prices are as shown in table 8.3 below.

Table 8.3 Optimal rail fare calculation for all journey purposes combined (other prices fixed, λ=0.1)

Units of $/person-km		journey purpose
		All
car	price - marginal cost	0.03
	mec	1.40
	dXi/dXr	-0.32
	Zi = dXi/dXr*(mec+(c-p)(1+λ))i	-0.44
bus	price - marginal cost	-0.22
	mec	0.02
	dXi/dXr	-0.09
	Zi = dXi/dXr*(mec+(c-p)(1+λ))i	-0.02
ferry	price - marginal cost	-0.79
	mec	0.11
	dXi/dXr	-0.03
	Zi = dXi/dXr*(mec+(c-p)(1+λ))i	-0.03
rail	current price	0.13
	marginal cost	0.65
	curr price - marg cost	-0.52
	mec	0.01
ideal rail fare	p* = (c(1+λ)+mec+Σ Zi)(1+λ+λ/e rr)	0.19
ideal - current	p* - p	0.06
% price increa	(p* - p)/p	49%
ideal rail fare (	p* x avg journey km	3.52

Table 8.3 indicates that a 49% fare increase would be optimal, taking into account a marginal excess burden of State taxation of 0.1 and the need to meet the long run marginal costs of expanding CBD rail infrastructure capacity. It shows that the inclusion of the marginal excess burden of taxation has a significant upward influence on optimal rail prices. This change reflects the fact that of all the public transport modes, rail requires the highest Government subsidy per passenger kilometre.

9 Conclusions

The 2008 estimation of CityRail external benefits has been revisited using 2011 data and with the benefit of improvements to the method that have been achieved in the intervening time. Notably, a newer version of the Strategic Travel Model of the NSW Bureau of Transport Statistics has enabled improved estimates of traffic flow patterns.

The comparison between total external benefits estimated in 2008 and now was presented in Table 5.3 above, which is repeated here.

	Rail 2008	Rail 2012
	$2008	$2011
Total ext rail $m/yr	1,528.2	1,866.6
congestion	1,390.8	1,857.6
air pollution	111.6	38.2
GHG	25.9	10.9
(less road pricing)	N.C.	- 40.0

It is possible to disentangle the separate patronage and inflation effects by presenting this comparison on a per-passenger journey basis and CPI-adjusting the 2008 figures. This comparison is presented in the table below.

	Rail 2008	Rail 2008	Rail 2012
	$2008	$2011	$2011
Total ext $/PJ	5.43	5.88	6.34
congestion	4.94	5.35	6.31
air pollution	0.40	0.43	0.13
GHG	0.09	0.10	0.04
(less road pricing)	N.C.	N.C.	- 0.14

This table shows that present estimates of the total congestion benefit are substantially higher than in 2008, even when changes in patronage and inflation are taken into account. This real per-journey change is driven, in part, by changes in traffic flow patterns since the 2006 Household Travel Survey on which the earlier version of the STM was based. However part of this change is also likely to be caused by improvements to the way the STM handles non-work purpose travel by car.

Relative to 2008, the emission externality benefits of rail are reduced. This change is driven mainly by an improved understanding of the emission performance of Sydney's bus fleet, which is relatively good and has been improving in recent years. There was also, in 2008, an overestimate of the amount of non-work purpose automobile travel that has since been corrected.

Calculations of optimal rail fares were also updated for the new data set and improvements to the optimisation method. The largest change to this calculation since 2008 is the explicit inclusion of a rough estimate of the long run marginal cost of expanding CityRail's CBD rail infrastructure capacity (which is the systemic bottleneck.) Broad-brush figures of a $10b capital cost annuitized over 50 years with a 5% discount rate, and an assumed resulting 33% lift in system capacity lead to an incremental long run cost of approximately $0.32/rail passenger-kilometre. This figure leads to a LRMC that is roughly double prior estimates of the SRMC. Taking account of this LRMC, the optimal rail fare ignoring the marginal excess burden of taxation would be 29% higher than 2011 levels. If a plausible value of 0.1 is assumed for the marginal excess burden of State taxation generally, then the optimal rail fare would be 49% higher than 2011 levels.

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Appendix 1: Technical formulation of fare optimisation problem

Important foundations for the estimation of socially optimal public transport fares were established by Glaister and Lewis (1978), Small (1983) and Viton (1980, 1983). More recently, De Borger et. al. (1996), building on these foundations, set out optimal public transport pricing rules in a partial equilibrium model of the transport sector. Following De Borger et. al., I adopt a Bergson-Samuelson type consumer surplus function W, which depends only on the indirect utility functions of individuals comprising the society.

The indirect utility of an individual V_h is a function of that individual's full[12] income Y_h, the out-of-pocket price for each of n transport services p^i, the average speed for each transport service, the level of environmental pollution by transport services in total, and the number of transport accidents for each transport service.

Normally one would think of travel by car, train, bus and ferry as separate transport services. This could be taken further. Peak and off-peak travel by each of these modes could be treated as separate transport services. Subscripts h refer to individuals. Superscripts i and j refer to different transport services.

The optimisation problem is to select a set of prices for all transport services that maximises the sum of consumer and producer surplus. Where a public subsidy is needed to fund the public transport deficit, the producer surplus is negative. For each set of transport prices, I assume that individuals will maximise their own utility. The overall welfare function that we wish to maximise is:

$$F = MAX \quad W(V_1, \dots V_h, \dots V_H) + (1 + \lambda) [\Sigma (p^i X^i - C^i) - FC] \quad (1)$$

The first term, MAX W, is consumer surplus maximised by the decisions of individuals, subject to the constraints posed by transport prices. The second term is the producer surplus for transport providers as a whole. For public transport services this is expected to be negative, reflecting a deficit that must be funded from taxation. λ represents the marginal excess burden of taxation (a measure of

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[12] Full income refers to the sum of monetary and non-monetary consumption ability of an individual.

the economic inefficiency of the state taxes used to raise the funds). X^i is the total number of passenger kilometres travelled by all individuals on transport service i. C^i is the total cost of transport service i at patronage level X^i. FC is the fixed cost of all transport services combined. The summation in the second term of equation (1) is over transport services i=1..n.

The partial derivatives of F with respect to each of the transport prices p^j will be zero at an interior optimum (the "first-order condition" for optimality). It remains to be seen whether these interior optimum points exist and whether they do indeed correspond to welfare maximising prices. I will examine that question later in this report, once the input values have been calculated. The first-order conditions can be written as follows:

$$\partial F/\partial p^j = 0$$

$$= \Sigma_h (\partial W/\partial V_h)(\partial V_h/\partial Y_h)(\partial Y_h/\partial p^j) + (1 + \lambda) [X^j + \Sigma_i (p^i - \partial C^i/\partial X^i) (\partial X^i/\partial p^j)] \qquad (2)$$

Equation (2) can be simplified by noting the following facts.

$(\partial W/\partial V_h)(\partial V_h/\partial Y_h)$ represents the marginal social utility of income to individual h. For simplicity, I assume that this quantity is equal to one for all individuals. In reality, lower-income individuals are likely to have a higher social utility of income than high-income individuals. However it would add unmanageable complexity to the fare calculation to attempt to take account of this effect here.

The elasticity of demand for transport service i with respect to the price of transport service j is $e^{ij} = (\partial X^i /X^i) / (\partial p^j /p^j)$. When i=j this quantity is the own-price elasticity. Otherwise it is a cross-price elasticity. Rearranging terms,

$$(\partial X^i/\partial p^j) = e^{ij} X^i /p^j$$

$\partial C^i/\partial X^i$ is the marginal cost of transport service I, which I shall call c^i.

Applying these simplifications to equation (2):

$$\Sigma_h (\partial Y_h/\partial p^j) + (1 + \lambda) [X^j + \Sigma_i (p^i - c^i) e^{ij} X^i /p^j] = 0 \qquad (3)$$

$(\partial Y_h/\partial p^j)$ is the change in an individual's full income with respect to a change in the price of transport service j. It has two elements: direct and indirect. The direct effect is on the individual's own travel costs: $p^j x^j_h$, where x^j_h is defined as the number of kilometres individual h travels on service j.

The indirect effect comes about because a change in the price of transport service j will affect X^j. In turn, a change in X^j will influence individual h's utility through its effect on transport speeds, environmental pollution, and transport accidents—the

externalities, in other words. Quantitatively, this influence on individual utility with a given income is equivalent to the influence on the same individual's full income with a given utility level, as a result of the duality between Marshallian and Hicksian demand.[13] Given these observations,

$$(\partial Y_h / \partial p^j) = -x_h^j - \Sigma_i \, mec_h^i \, (\partial X^i / \partial p^j) \tag{4}$$

where "mec" refers to the marginal external cost imposed on individual h by transport service i.

Combining equations (3) and (4), rearranging to group like terms and simplifying:

$$\Sigma_i \, e^{ij} \, X^i [(1 + \lambda)(c^i - p^i) + \Sigma_h \, mec_h^i] = \lambda \, p^j X^j \tag{5}$$

Note that equation (5) is actually a system of simultaneous equations. There is one equation for each of the n possible values of j. Each one must be satisfied for the price set to be optimal (unless there is a corner solution).

In the case where the marginal excess burden of taxation (λ) is zero, equation (5) can be reduced to a more intuitive form:

$$\Sigma_i \, e^{ij} \, X^i [c^i - p^i + \Sigma_h \, mec_h^i] = 0 \tag{6}$$

This version of equation (5) implies that when all prices are equal to the sum of marginal costs and marginal external costs for their respective transport services, prices are optimal. It is important to recognise, however, that if price does not equal the sum of marginal cost and marginal external cost for any one of the transport services (for example cars), then it is not optimal for the remaining prices (i.e., public transport fares in this example) to equal the sum of their own marginal costs and marginal external benefits. Rather, the imbalance in car prices (the lack of sufficient road pricing) implies that public transport fares would need to be subsidised to achieve a welfare-optimal modal split.

Equation (6) can be rearranged to solve for optimal rail prices, on the assumption that prices for other transport services are fixed at their current values. Let the superscript i = r for rail.

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[13] Marshallian demand is the consumption bundle that maximises individual utility given prices and an income constraint. Hicksian demand is the consumption bundle that minimises individual expenditure, given prices and a minimum utility constraint. These two demands must be equal.

$$p^r * = c^r + \Sigma_h\ mec^r_h + \Sigma_{i<>r}\ [c^i - p^i + \Sigma_h\ mec^i_h]\ (e^{ij}\ X^i\ /\ e^{rj}\ X^r) \qquad (7)$$

Recalling that $e^{ij} = (\partial X^i\ /X^i) \Big/ (\partial p^j\ /p^j)$, the expression $e^{ij}\ X^i\ /\ e^{rj}\ X^r$ can be simplified further:

$$e^{ij}\ X^i\ /\ e^{rj}\ X^r = (\partial X^i\ /\ (\partial p^j\ /p^j))\ *((\partial p^j\ /p^j)/\ \partial X^r)) = \partial X^i\ /\ \partial X^r \qquad (8)$$

Therefore, the optimal rail price when $\lambda = 0$ and other prices are fixed is:

$$p^r * = c^r + \Sigma_h\ mec^r_h + \Sigma_{i<>r}\ [c^i - p^i + \Sigma_h\ mec^i_h]\ (\partial X^i\ /\ \partial X^r) \qquad (9)$$

The intuition behind equation (9) is that when the marginal excess burden of taxation is zero, the optimal rail price is the sum of marginal cost and marginal external costs of rail service plus the weighted sum of the difference between price and marginal social costs for each of the other transport modes. The weights are the marginal rate of technical substitution between rail and each of these other modes. To the extent that other modes are under-priced relative to their own social costs, optimal prices would be reduced below marginal social costs for ferries.

In the case where the marginal excess burden of taxation (λ) is not zero, equation (5) can be reduced to a somewhat more complicated form:

$$(c^r - p^r *)\ (1+\lambda) + \Sigma_h\ mec^r_h + \Sigma_{i<>r}\ [(c^i - p^i)\ (1+\lambda)\ + \Sigma_h\ mec^i_h]\ (\partial X^i\ /\ \partial X^r)$$

$$= (\lambda\ p^j X^j /\ e^{rj}\ X^r) \qquad (10)$$

Equation (10) must be valid for all values of j, including r. Where j=r, equation (10) can be reduced to:

$$(c^r - p^r *)\ (1+\lambda) + \Sigma_h\ mec^r_h + \Sigma_{i<>r}\ [(c^i - p^i)\ (1+\lambda)\ + \Sigma_h\ mec^i_h]\ (\partial X^i\ /\ \partial X^r)$$

$$= \lambda\ p^r */e^{rr} \qquad (11)$$

Here, e^{rr} is the rail own-price elasticity. Gathering the p* terms, the optimal rail ticket price in the presence of non-zero marginal excess burden of taxation is:

$$p^r * = \{(c^r\ (1+\lambda) + \Sigma_h\ mec^r_h + \Sigma_{i<>r}\ [(c^i - p^i)\ (1+\lambda)\ + \Sigma_h\ mec^i_h]\ (\partial X^i\ /\ \partial X^r)\}$$

$$/\ (1+\lambda+ \lambda/e^{rr}) \qquad (12)$$