FINAL REPORT

Prepared For:

IPART

Level 8, 1 Market Street

Sydney NSW 2000

Value of CityRail externalities and optimal Government subsidy

Final report

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1. EXECUTIVE SUMMARY

CityRail provides benefit to the NSW community in two main ways. Rail passengers derive consumer surplus by purchasing rail journeys at prices that are less than their private valuation of those journeys. Non-rail passengers derive benefits from the fact that others purchase rail journeys and therefore consume less private automobile and bus transport than they otherwise would.

This second effect, externality, represents a type of market failure that justifies Government intervention in the form of subsidisation, although Government subsidies could also be justified in the absence of externalities if there are scale economies. This report sets out an empirical analysis of the value of both the consumer surplus and the external benefits created by CityRail. The analysis has been conducted in such a way that it is possible to consider what level of consumer surplus and external benefit would be achieved at various different levels of average fare, rail patronage, and Government subsidy.

Our approach to the question of what level of Government financial support for CityRail is optimal has been to optimise net welfare, defined as the sum of consumer surplus, producer surplus, and external benefit less the deadweight loss to the community arising from distortions to consumption decisions of the taxation needed to support the CityRail subsidy. With an empirically grounded understanding of the relationship between net welfare and CityRail patronage, we have been able to calculate optimal levels of net welfare, and the policy settings (average fare and Government subsidy) needed to obtain those optima.

1.1. EXTERNALITY

In the present setting, an externality is a cost or a benefit to a party other than the purchaser or provider of passenger rail services that is caused by the provision or consumption of rail service. Traffic congestion is a good example of an external cost. One more car joining a crowded highway will experience delays itself, but the fact that it joined will increase the delays suffered by other motorists. It is the delays suffered by the other motorists as a result of the first motorist's decision that represent the external cost—it is felt externally to the parties making the decision that caused the cost.

If there were a system of road use pricing in force in Sydney that matched the motorist's payment to the full marginal costs, including the marginal external cost imposed by that usage, then it would not be necessary to take these externalities into account in deciding on the optimal CityRail fare and subsidy levels. That would be a preferable solution to the transport efficiency problem. Removing the distortions from road pricing would make it possible to price rail usage in a manner that took account only of the internal benefits.

However, recognising that an effective road pricing system is some way off, the terms of reference for the externality study note,

> "*The purpose of this consultancy is to assist IPART in developing a framework to estimate the social costs and benefits (also known as externalities) arising from CityRail's passenger services, and to use this framework to derive the appropriate contribution by the Government to CityRail's costs*."

While the term "appropriate" is not synonymous with the word "optimal," it would nevertheless be useful to view the process of establishing an appropriate Government contribution as an optimisation problem. Arguably, the optimal Government contribution (or optimal range) would be an appropriate contribution.

1.2. EMPIRICAL WORK UNDERTAKEN IN THIS STUDY

We have conducted this study subject to very severe data limitations, especially on the cost side. These limitations, which also affect CityRail we understand, have implications for the ability of CityRail to manage the efficiency of its operations. We note that IPART has commissioned a separate consulting study to consider CityRail's actual and potential future cost structures. Unfortunately, the information being generated by that other study does not provide the estimates of marginal cost that would be most useful for this study.

With that caveat in mind, the following main pieces of work have been undertaken to provide empirical substance to the conceptual analysis summarised above.

- Estimation of the demand schedule for CityRail;
- Estimation of the marginal cost function for CityRail;
- Estimation of the displacement of automobile and bus traffic by commuter rail service;
- Estimation of the marginal external benefit function for CityRail based on its ability to displace road traffic;
- Estimation of the effect on Sydney residential property prices of proximity to train stations.

This empirical work fed into a mathematical optimisation process through which optimal levels of Government support were estimated under a range of scenarios and compared to current levels of support.

1.3. DEMAND

The first quantitative link that must be established is that between the CityRail fare and CityRail patronage. We chose to estimate this relationship through an econometric investigation of annual historic CityRail revenue and patronage data over a 30 year period (1977/78 – 2006/07). This approach is quite different to the empirical methods employed to date to estimate the own-price elasticity of CityRail demand, which have generally focused on stated preference interviews.

After examining a range of possible explanators of patronage, we found that a simple linear model provided a good fit to the historic data, in which the key coefficients had the expected sign and were significant at or near the 1% level.

CRA's econometric demand model taking account of these variables generated an estimated short-run rail fare own-price elasticity of 24% and a long-run fare elasticity of 35%. These elasticity estimates corresponds well with those obtained by some prior studies, notably Hensher and Raimond. They are consistent with the elasticity estimates recently provided to IPART by Booz Allen and Hamilton.

1.4. MARGINAL COSTS

An accounting-based approach has been employed to estimate the marginal cost function for CityRail in its current organisational form. The marginal cost is expressed in units of dollars per passenger journey. The cost estimation method is to itemise cost areas and then make a judgement based on experience as to the extent each cost item would vary with a change to the annual number of passenger journeys.

Cost variability judgements are made in two steps. The main output-related drivers of cost are:

- Number of train kilometres travelled per annum;
- Number of track kilometres of infrastructure provided; and
- Number of stations in the CityRail service area.

The relationship between each of these drivers and particular cost categories can be surmised with some confidence. For example, rolling stock maintenance, consumption of traction electricity (to propel trains), and access charges would be proportional to train kilometres travelled. Infrastructure costs would be proportional to the quantum of infrastructure provided. Station costs would be proportional to the number of stations.

The relationship between patronage and each of these drivers depends, to a significant extent, on current levels of utilisation of the relevant assets and current capacity. This assessment is far from straightforward if, as is the case, asset utilisation and capacity is not well known to us. Lacking this detailed information, we make the following heuristic arguments.

1. We assume that the number of stations does not change with patronage.
2. In the long-run, we assume that the number of train kilometres travelled varies proportionally to patronage.
3. We assume that when patronage approaches the Olympic level of approximately 300mPJ/yr a 1% increase in patronage would involve a 2% increase in infrastructure costs.

These particular assumptions concerning variability of certain cost categories result in an estimated variable cost rate of $2.57/passenger journey when patronage = 200mPJ/yr and $5.88/passenger journey when patronage = 300mPJ/yr. Both of these figures are lower than CityRail's average costs of $6.50/PJ.

While plausible, the selected cost variability rates are somewhat arbitrary, as is the assignment of particular infrastructure cost variability rates to particular patronage levels. Sensitivity testing was applied to explore the effect on results of different choices for these parameters.

1.5. DISPLACEMENT OF ROAD TRAFFIC

The third empirical relationship that must be established is that between CityRail patronage and automobile use in Sydney. We have chosen to estimate this relationship through a series of runs of the Sydney Strategic Travel Model, which is operated by the Transport Data Centre of the NSW Ministry of Transport. The effect of changes in CityRail patronage is not necessarily one-for-one with changes in passenger journeys by car or bus. The Transport Data Centre's Sydney Strategic Travel Model is well suited to estimate the modal shift effects given its comprehensive data on characteristics of each transport mode in Sydney and its recursive method of converging to a solution. The recursive method allows for trip generation and other subtle effects on modal share by determining an equilibrium position between modes after price shocks have altered the prior balance.

There were two types of model runs required: an incremental rail fare change scenario, and a more extreme no-rail scenario. For each model run, the comparison was made between a set of model outputs in the specified case and in a business as usual case. These model runs enabled quantification of the link between CityRail patronage and such drivers of external benefit as passenger hours of travel time and fuel consumption.

Several aspects of the traffic displacement results may be counterintuitive. First, and perhaps most unexpectedly, the complete elimination of Sydney's commuter rail network does not have a drastic impact on either the total quantum of automobile travel or on the average speed of cars. The reason for this modest effect is that in the status quo case rail journeys represent only 4.5% of total journeys. Rail's share of person kilometres travelled is somewhat higher, 11%, but still relatively low.

The elimination of rail would induce considerable congestion on the main road arteries into the CBD during commuter hours, but this effect is somewhat masked in the total figures by the large number of automobile journeys that do not enter the CBD, and by the significant amount of off-peak travel on the road network. The modelling work does capture this effect, nevertheless, through the breakdown of automobile vehicle kilometres travelled by speed band, from which the congestion information was derived.

The second important observation is that waiting and walking time for public transport represents a very significant proportion of the time spent travelling for rail and bus. For rail, waiting and walking time represents 39% of the total travel time. The value of time calculations performed here do include waiting and walking times for public transport.

The third observation is that there is a significant shift from rail to bus when the rail option is eliminated. The effect is to approximately double the number of person kilometres travelled by bus, and to increase the average journey length of bus commuters. This change takes place because rail commuters travel longer distances on average than bus commuters. Once they are displaced from rail they need to travel further than the pre-existing bus travellers.

The fourth observation is that in the no-rail scenarios, the total quantum of travel increases somewhat compared to the status quo. This result is unexpected. We understand that it is an artefact of some of the SSTM modelling assumptions.

1.6. CONGESTION EXTERNALITIES

Road congestion occurs when the volume of traffic exceeds the maximum level at which traffic can flow at the normal speed limit. It is caused by the interference between vehicles. Congestion imposes both internal and external costs on motorists.

It is important to distinguish between the internal and external costs of road congestion. Under congested conditions, when one new motorist decides to join the traffic system, the cost of fuel to that motorist is a private cost. It includes the cost of the fuel that would have been consumed undertaking that journey under free-flow (uncongested) traffic conditions and the cost of the additional fuel that is consumed waiting in queues.

That motorist's decision to join the traffic system also increases the delays experienced by the other motorists who were already using it. As a consequence, the other motorists consume additional fuel waiting in queues. The cost to these existing road users of the additional fuel consumed because of the first motorist's decision to drive is an externality.

Exactly the same argument applies to the cost to motorists and their passengers of their own commuting time. The mode-switching motorist (the marginal driver) presumably knows and accepts the personal cost of the decision to drive in terms of her own travelling time. Therefore the marginal motorist's own travel time is an internal cost which is already taken into account in establishing the demand schedule for rail travel.

The pre-existing motorists (inframarginal drivers) suffer a new increment of cost as a result of the marginal driver's decision to join. The inframarginal motorists take longer to make the same journey as a direct result of the marginal motorist's decision. The personal cost of the inframarginal motorists' own additional commuting time and fuel consumption is an external cost that is not reflected in the demand or supply schedules for rail travel.

Relationships between CityRail patronage and these external costs to motorists were able to be established with some confidence through the Sydney Strategic Travel Model runs, using a range of values of travel time from \$9.23/hr to \$22.60/hr.

1.7. EMISSIONS EXTERNALITIES

Automobile and bus emissions contribute to two recognised types of social cost: increased health risk from conventional pollutants and increased risk of environmental harm from greenhouse gases. The quantity of each pollutant dispersed into the atmosphere varies directly with the quantity of fuel consumed. Therefore fuel consumption is the metric best suited to link the quantum of commuter transport in Sydney with the air pollution it causes.

It is important to note that every litre of fuel consumed creates some external effect via air pollution. The effect is external because the sufferers of air pollution (persons inhaling it and becoming unwell, or persons affected by global warming) are, in the overwhelming majority, different people to the car drivers whose modal choice caused the pollution. Put another way, every gram of carbon monoxide and every tonne of carbon dioxide has an effect on a great many people.

The core steps in the analytical approach are:

1. Estimate the fuel savings per passenger-kilometre associated with a mode shift from private vehicle 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.

Fuel consumption was calculated for each CityRail patronage scenario in a manner that reflected the higher fuel consumption rates per vehicle kilometre when congestion slows traffic.

We applied a carbon price of \$25/tonne CO2 and published values of United Kingdom marginal external health cost per litre of unleaded petrol of 9 pence sterling in 1993. The marginal external health cost per litre of diesel was 84 pence sterling in the same year. We converted these values to Australian dollars.

1.8. TRAFFIC ACCIDENT EXTERNALITIES

The accident externality phenomenon involves two complications that must be considered. First, some of the costs of accidents are borne by the accident victims. If the accident victim is a marginal motorist then the probability-weighted cost to that victim of the accident is an internal cost, not an externality. The fact of automobile accident insurance tends, if anything, to internalise more of the accident-related costs. Nevertheless, there remain some types of accident-related costs that are borne by the community at large, rather than the marginal motorists, even when insurance premiums are taken into account. The standby capacity at public hospitals for accident victims, police and emergency services, traffic congestion caused by accidents, and the uninsured detriment to the quality of life of third parties are examples of these external costs of traffic accidents.

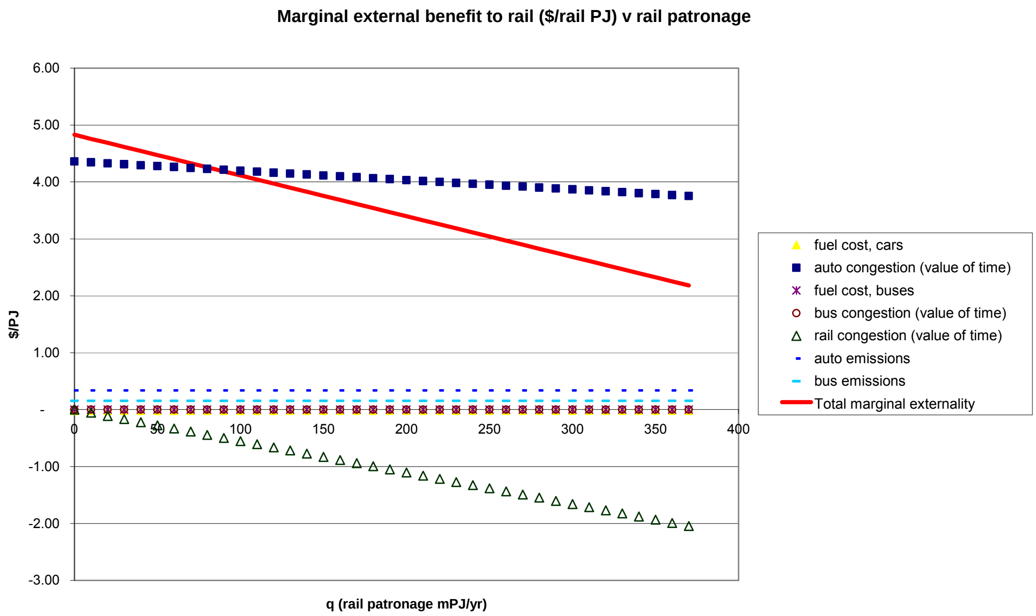
The second complication is that one must establish a quantitative relationship between the incidence of traffic accidents and the number of automobile (and bus) passenger kilometres travelled. In the absence of detailed information on this relationship, the most plausible simplifying assumption is that the incidence of accidents is proportional to automobile passenger kilometres or bus passenger kilometres. If this assumption is made, then the complication arises because inframarginal motorists do not experience any increase at all in their accident risk as auto passenger-kilometres rise. In other words, there is no external accident cost.

Note that this counterintuitive conclusion is dependent on the assumption that the accident rate per automobile passenger kilometre is constant. There may be grounds to believe that the accident cost per automobile passenger kilometre falls as automobile passenger kilometre increases: congestion slows the traffic, making it easier to avoid accidents and lessening the severity of those accidents that do occur. It is not clear from the available material that the traffic accident externality is necessarily a point in favour of increasing CityRail patronage.

1.9. MARGINAL EXTERNAL BENEFIT FUNCTION

It has been possible to combine the relationships between each type of external benefit and rail patronage into a single marginal external benefit function. The most important individual contributor to overall marginal external benefit is the congestion cost experienced by motorists (experienced as the value of time spent driving or being a passenger in a car), which is counteracted increasingly at high rail patronage levels by the value of time spent by rail commuters on the train, waiting for the train, or walking to and from the train station.

Using a value of travel time of $13.15/hr and a carbon cost of $25/tonne of CO2, the results of the foregoing estimations can be translated to linear marginal external benefit functions of patronage, meb(q), for each component of the external benefit of rail, shown graphically below.



This chart plots marginal external benefit expressed in dollars per passenger journey (vertical axis), against total rail patronage expressed in millions of passenger journeys per annum (horizontal axis). The total marginal external benefit to rail, meb(q), is the solid line. It begins at the maximum value of $4.83/PJ and decreases as rail patronage increases. The marginal external benefit per passenger journey declines as more passengers choose to travel by rail because of two effects. As roads become less congested, the additional saving in automobile travel time per rail passenger becomes less important. As the rail system becomes more heavily used, rail passengers spend more time waiting to board increasingly crowded trains.

The principal contributor to meb(q) is the marginal external cost of congestion for automobiles, which is the top row of square symbols. Rail travel time counteracts the automobile travel time effect. The other components of the marginal externality calculation make only a second-order contribution to the overall result.

It may seem counterintuitive that the automobile congestion externality declines slowly with rail patronage while the rail congestion (negative) externality changes rapidly. There are several reasons for this difference. First, the total population of automobile commuters declines by a relatively small proportion (only 8%) when rail patronage increases from zero to 275 million passenger journeys per annum. Such a small proportional change would not be expected to have a large effect on average road congestion. On the other hand, the same range of rail patronage represents a 100% change (from none at all to the present crowded conditions during peak hour).

Second, if rail patronage were to be drastically reduced, it would not necessarily follow that congestion-related delays to rail travellers would disappear entirely. A large drop in rail patronage would necessitate reductions in timetable frequencies, with the result that passengers would need to wait longer for a scheduled train, and may still face crowding issues when that train arrives.

Our results are compared to previously published results for CityRail in the table below. In order to facilitate comparability, the format of the published CityRail table has been adopted in this table. Two different demand schedules are considered in this table—both are consistent with the demand estimations performed in this study.

Comparison of external benefits			linear demand	exponential demand
		elasticity	-0.24	-0.35
assumed carbon price $/t CO2:			25	25
assumed value of time ($/hr):			13.15	13.15
Description	2006-07 ($m)	Average 1997-98 to 2006-07 ($m)	($m)	($m)
Shortfall [(b)]	- 1,650.5	- 1,139.0	-1363.9	- 1,363.9
Rail user benefits ©	2,055.7	2,364.6	1,031.3	1,414.3
Road user benefits [(d)]	740.5	726.4	923.1	923.1
Air pollution	71.0	69.6	109.1	109.1
Greenhouse gas emission	52.1	51.1	25.3	25.3
Noise pollution	20.4	20.0		
Accidents	114.6	112.4	too small to measure	
Road damage	3.7	3.6		
Fleet externality cost	- 18.0	- 18.0	- 18.0	- 18.0
Total rail benefit	3,039.9	3,329.8	2,070.7	2,453.8
Net benefit to community	1,389.4	2,190.8	706.8	1,089.9
	CityRail results		*CRA results*	
sum of externalities	1,002.3	983.1	1,057.5	1,057.5

The two columns to the left represent the results of the earlier study published by RailCorp staff members Karpouzis et. al. The two rightmost columns represent the results of the study presented in this report.

Overall, taking either of the two demand schedule considered in this study, the total benefit of CityRail derived by Karpouzis et. al. is higher than the values produced by our study. RailCorp estimates of consumer surplus are significantly higher than ours. RailCorp estimates of total external benefits is similar in magnitude to ours, although the contribution of different types of externalities differs: our estimate of congestion and air pollution costs are higher, but our estimate of the greenhouse gas and road accident externalities are lower, substantially so in the latter case. Additionally there is a question as to whether the noise pollution externality works in rail's favour (trains are not quieter than cars). Arguably, road damage costs are not external to motorists' modal choice decision.

1.10. Optimisation

We set out to develop a framework to estimate the social costs and benefits arising from CityRail's passenger services, and to use this framework to derive the appropriate contribution by Government to CityRail's costs. It is apparent that the social benefits depend on the extent to which passengers use CityRail, and that the fare is an important determinant of passenger use. There is, in fact, a tradeoff: higher fares mean CityRail is less unprofitable and a lower Government subsidy is needed, but they also mean lower ridership and lower external benefit. There is likely to be a preferred fare setting at which total welfare is maximised, and this study has developed a framework through which that preferred point can be determined.

Welfare is formally defined as the sum of what are known as consumer surplus, producer surplus, and externalities less the welfare costs of taxation. It depends on CityRail patronage in a subtle way that reflects the tradeoff between producer surplus on one hand, and the combination of consumer surplus and externalities on the other. Low fares mean highly negative producer surplus and significant tax distortions, but high patronage, consumer suplus, and external benefit. High fares mean lower patronage, consumer surplus and external benefit, but less negative producer surplus and less tax distortion. At some intermediate point, any increase in fares would lead to a greater loss of consumer surplus and external benefit than the gain in producer surplus and reduction in tax distortion, and at the same point, any decrease in fares would lead to a greater loss of producer surplus and increase in tax distortion than the gain in consumer surplus and external benefit. That point is the optimum. There will be a unique level of Government support that corresponds to it.

In order to find this optimum point, it has been necessary to understand, in a quantitative way, the relationship between fares and patronage, between patronage and consumer surplus, between patronage and producer surplus, and between patronage and external benefit. The bulk of the analytical work presented in this report has been directed to obtaining the quantitative understanding of these relationships.

Based on our sensitivity analysis, there are five main uncertainties that determine the optimal levels of fare, patronage and Government subsidy:

a) The point fare-elasticity of demand (-0.24 or -0.35);

b) The functional form of the demand schedule (e.g., linear or negative exponential);

c) The value of passenger time (ranging from $9.23/hr or $22.60/hr, with a central value of $13.15/hr), which influences the slope and y-intercept of the marginal external benefit function;

d) The slope and y-intercept of the CityRail marginal cost function; and

e) The marginal excess burden of taxation, “d” (0.1 or zero, corresponding to the case where the deadweight loss of taxation is excluded from the analysis).

We developed a central or most likely case and report the results for that case. Sensitivity analysis takes this central case as its point of departure. The central case involves the following choices for uncertain parameters:

- Point fare-elasticity of demand = -0.35 with a negative exponential shape to the demand schedule
- Marginal cost function = \$0.0331/(PJ^2) q – \$4.05/PJ (corresponding to marginal cost of \$2.57/PJ at q=200mPJ/yr and \$5.88/PJ at q=300mPJ/yr)
- Marginal external benefit function = -\$0.007157/(PJ^2) q + \$4.83/PJ (corresponding to a value of passenger time of \$13.15/hr)
- Marginal excess burden of taxation, “d” = 0.1

Adopting these central case settings, the optimum welfare is achieved with an average fare of $2.17/PJ, which is a 21% increase over the $1.80/PJ average fare level that prevailed in 2005/06. The optimal level of Government Contribution to CityRail of $1,214m/yr is approximately $150m/yr lower than the level that prevailed in 2005/06 (an 11% reduction in Government funding). Significantly, the optimal level of patronage of 256.03m passenger journeys per annum is 7% lower than 2005/06 patronage.

Given that increased patronage is an explicit policy goal, it might seem counterintuitive that optimal patronage is lower than actual patronage. The explanation is that (subject, of course, to the accuracy of the measurements presented in this report) increases in patronage from the 2005/06 point would lead to an increase in CityRail’s operating deficit and in tax distortions that is greater than the increase in consumer surplus and external benefit that it would create. Previous studies have tended to ignore the distortionary effect of taxation and to overestimate both the consumer surplus derived by rail users and the additional external benefit from additional patronage.

The conventional wisdom appears to be that higher levels of CityRail patronage would be preferable to current patronage on welfare and public interest grounds, and that a study of externalities would support the argument for greater ridership, along with the higher levels of Government subsidy it would entail. This study contradicts that conventional wisdom.

The following intuitive explanation may assist in understanding how entrenched public views could be incorrect on this important issue. First, the relationship between CityRail patronage and road congestion appears to be misunderstood. The majority of automobile journeys do not enter the CBD, and those that do not are largely unaffected by the existence or usage of CityRail.

Second, the capacity of CityRail to shoulder a larger part of the commuting burden appears to be greatly overestimated. CityRail is not well placed spatially to serve commuting journeys to employment centres other than the CBD, Parramatta, North Sydney, and a handful of other destinations. These destinations no longer represent the majority of all commuting trips.

CityRail's ability to accept a large increase in ridership is severely limited by capacity constraints. These constraints would be extremely costly to alleviate, and this cost must be taken into account in any reckoning of a socially optimal solution to Sydney's future transport challenges.

Third, the significant cost to rail commuters of their own time spent walking to the train station and waiting for a train appears to be overlooked. If unproductive time spent queueing in traffic is the prime external cost of automobile travel, then the corresponding unproductive waiting time associated with train travel must be included in any valid comparison.

Fourth, the ability of buses to substitute for rail appears to be greatly underestimated. Like rail, buses contribute to an alleviation of road congestion and to a reduction in emissions per passenger journey.

That said, it is worth noting, however, that the optimal welfare is only $11m/yr higher than the welfare achieved with the 2005/06 fare and patronage settings. In other words, 99.6% of the optimum welfare level could be achieved with no change to the 2005/06 fare, patronage and Government contribution levels.

If the distorting effect of taxation is ignored, then the optimum patronage is very close to the actual 2005/06 patronage. The optimum average fare in that case would be between 7% and 9% higher than actual 2005/06 average fares, and the actual 2005/06 welfare outcome would be within $1m/yr of the optimal welfare outcome.

This finding gives some hope that, while current CityRail policy settings may not be optimal, they could achieve a near-optimal result without drastic changes to fare, patronage or Government support levels.

Sensitivity analysis revealed the following points. The optimal government contribution level is most sensitive to changes in the marginal cost function and the assumed marginal excess burden rate for taxation. It is quite insensitive to the changes in the price elasticity of demand, and relatively insensitive to changes in the marginal external benefit function within the ranges established by the empirical work reported here.

The importance of knowing the marginal cost function is highlighted by these sensitivity test results. It strongly suggests that CityRail should strive to measure this important metric for its future operations, particularly as there are large-scale infrastructure investments contemplated that could conceivably have a marked effect on marginal costs.

1.11. Conclusions

Previous published estimates of external benefit and consumer surplus have tended to overestimate the social benefits flowing from CityRail's ongoing operations. While these benefits are significant and important, the point of indifference for further capital expenditure on CityRail is somewhat closer than prior studies have indicated—to the extent these other studies provided a means of determining that point. The unthinkable scenario, in which CityRail did not exist at all, would lead to profound changes in the way traffic into the CBD is orchestrated, but these changes would not be so drastic as to prevent Sydney from functioning. The majority of commuter journeys are not to or from the CBD, and rail's share of total passenger kilometres is only 11%.

This study has proposed a new method of calculating the optimal settings for CityRail average fare per passenger journey, CityRail patronage, and the total level of Government subsidisation for CityRail's operating loss. This calculation is subject to a number of important uncertainties, which should be narrowed before concrete steps are taken in pursuit of these optimal settings. The most likely case values of the uncertain parameters lead to the conclusion that average fares should be higher, optimal patronage should be somewhat lower than at present, as should optimal Government subsidies.

These conclusions may appear surprising, given the policy intent to increase rail patronage. Nevertheless, they follow from the quantitative comparison of costs, passenger demand, and external benefits that are presented in this report. To the extent that external benefits of rail may have been overstated, the rationale for current levels of public subsidy of rail is weakened. Given the low price elasticity of rail commuters, the case for fare increases is strengthened.

Two caveats should be borne in mind when interpreting the optima derived from this study. First, the empirical work has been unable to finally resolve several important uncertainties: namely the precise marginal external benefit rate per passenger journey, and the marginal cost of CityRail service. Sensitivity analysis has revealed, however, that the results are not particularly sensitive to the functional form of the demand schedule.

Second, the net welfare function exhibits very broad and flat peaks. This finding is significant because it means that the selection of a precisely optimal value of fare, Government subsidy and patronage is not necessary to achieve a nearly optimal outcome in net welfare terms. In other words, the net welfare function is relatively forgiving of policy miscalculations.

It appears to be well accepted that CityRail's system is facing profound capacity constraints during peak hour that are able to be remedied only with extremely large capital investment in new trackwork and stations in and near the CBD of Sydney. Any significant expansion in patronage would require such investments. Properly speaking, the true long-run marginal cost of a CityRail passenger journey should include these capital costs of expansion (expressed in DCF terms and amortised over the lifetime numbers of passenger journeys that they would support). It was not within our scope to conduct such a long-run marginal cost estimate, but the high-patronage marginal cost value employed in this study ($5.88/PJ) was derived on a basis that treated all train operating costs as fully variable (constant returns to scale), and rail infrastructure costs as exhibiting diseconomies of scale at patronage levels nearing those experienced during the Sydney 2000 Olympics.

If the lower value of the marginal external benefit rate (corresponding to a value of time of $9.23/hr) were applied instead of the central case settings, the optimal level of government support would not change drastically, but the optimal fare levels would change significantly.

Importantly, in the high marginal cost sensitivity case the optimal level of Government support was most different from present levels. These calculations reveal that the optimal level of Government support is highly dependent on the extent of long-run marginal costs, which are dependent on the Government's intended capital works programme. New capital investment (as opposed to renewal work) that does not contribute to the removal of pertinent capacity constraints or the attraction of new patronage will involve heavy Government expenditure that has a negligible positive impact on either consumer surplus or external benefits, both of which are dependent upon actual ridership of CityRail.

2. INTRODUCTION

2.1. THE TASK

IPART commissioned CRAI to develop a framework to estimate the social costs and benefits (capturing externalities) arising from CityRail's passenger services, and to use this framework to derive a range of empirical estimates of the appropriate contributions by the Government to CityRail's costs (i.e., the optimal apportionment between farebox and subsidy of total costs).

Specifically, CRAI was asked to perform the following tasks:

1. Identify the social costs and benefits of public transport, especially passenger rail. This task would include a review of previous studies of the social costs and benefits of public transport.

2. Review empirical estimates of the social costs and benefits of rail transport, noting whether they are likely to be applicable to CityRail.

3. Weigh the options for taking into account the social costs and benefits of public transport in developing the regulatory framework for CityRail, and an assessment of the appropriate mix of cash contributions or other instruments (such as road pricing) to take account of these externalities in the NSW context. In doing so it would be important to consider the appropriate stage/s in public policy, regulatory, pricing or other forms of economic decision-making where externalities should be considered (eg, in investment decisions between transport options, in road pricing or in public transport fares).

4. Develop a framework for assessing the optimal level of government cash contributions to CityRail in light of the social costs and benefits of its services.

5. Outline the methodologies that could be used to make quantitative estimates of the various social costs and benefits, recommend the preferred methodology (or methodologies), and the basis for this recommendation. In particular consider and discuss with the Tribunal whether the total external costs and benefits of CityRail's services or the marginal costs and benefits of a change in these services or both of these should be estimated.

6. Develop a model or models that provide quantitative estimates of the relevant social costs and benefits arising from rail transport. Where appropriate these estimates should rely on existing information and data sources. An integral output of this model will be an empirical estimate of the appropriate level of the Government's cash contribution to CityRail in relation to passenger services.

7. Provide IPART with a breakdown of these benefits and costs into different market segments where appropriate. These segments will be refined in discussions between the consultant and IPART but could include, for example, peak/off-peak times, or metropolitan/non-metropolitan travel.

8. The framework, analysis and modelling developed by the consultant should be adaptable to other forms of transport (such as buses and ferries) at a later stage if required.

2.2. NATURE OF EXTERNALITIES

In the present setting, an externality is a cost or a benefit to a party other than the purchaser or provider of passenger rail services that is caused by the provision or consumption of rail service. Traffic congestion is a good example of an external cost. One more car joining a crowded highway will experience delays itself, but the fact that it joined will increase the delays suffered by other motorists. It is the delays suffered by the other motorists as a result of the first motorist's decision that represent the external cost—it is felt externally to the parties making the decision that caused the cost.

In some cases, an external benefit may lie in the avoidance of a cost that would have been imposed in the absence of the provision or consumption of rail service. For example, many of the external benefits ascribed to rail in this report are really external costs imposed by private automobile usage (such as traffic congestion, pollution, and accident costs). The more individual travellers choose the rail mode instead of road, the more these external costs are avoided. The existence of a rail alternative makes it possible to avoid some of these external costs. The actual usage of rail is what generates the external benefit. A rail network that no one used would generate negligible external benefits.

Externalities are relevant to the assessment of the benefits generated by CityRail. A simple assessment of rail's benefits would look at the consumer surplus it generates to users, but rail has two important characteristics that require extensions to the analysis. First, rail is heavily subsidised by the government because fares are set below marginal costs, which in turn are below average costs. Second, because rail competes with auto and bus in the urban transportation environment it generates positive externalities by reducing congestion and emissions and by enhancing vehicle safety. Thus, a complete assessment must account for benefits to users, government subsidies, and externalities.

Studies such as the 2001 CIE report "*Subsidies and the social costs and benefits of public transport*" elaborate a useful theoretical framework for considering the question of the optimal balance between funding of urban passenger rail by its users as against Government subsidy.

That study and others make the point that, compared to the second-best solution of subsidising public transport in order to increase the production of external benefits, road use pricing may represent a superior method of internalising the external costs associated with automobile usage.

While a review of literature in this vein is an important starting point for the present consultancy, we have undertaken analysis with a distinctly empirical emphasis that is firmly grounded in the particular circumstances facing CityRail in Sydney. We have examined the issues from the standpoint that, if the first-best solution involving road pricing is not available, what level of subsidy (and therefore, implicitly what level of user charges) for CityRail would be welfare-optimal?

The external costs and benefits associated with urban passenger rail in Sydney are a key focus of this consultancy. Many of the most often cited external benefits—the mitigation of congestion on urban roads, of vehicular emissions, of noise, and of costs associated with motor vehicle accidents—depend on a modal shift from automobile use to urban rail. However it is impractical to study this modal shift in a meaningful way without taking into account the specific spatial characteristics of the Sydney rail network and of passenger flows through Sydney. In simple terms, price incentives won't induce a commuter to use rail if the train stations are in the wrong locations.

Other than road congestion relief, emission minimisation, and passenger safety, the following types of external benefits are also associated with rail:

- Resource contention and congestion related to parking in the metropolitan area. Care needs to be taken to distinguish between the purely private costs associated with parking (which are presumably internalised in drivers' modal choice decisions already) and external effects.

- Benefits to the community arising from the additional mobility options afforded by the existence of a rail network and scheduled services.

While these external benefits (other than reductions in road congestion, automobile emissions, and accident risk) may be of some importance, measurement difficulties have made it impractical to include them in the quantitative analysis presented below.

3. OVERALL METHODOLOGY

3.1. ROAD PRICING AS THE FIRST-BEST SOLUTION

The external benefits created by CityRail are largely the avoided external costs associated with private automobile use during peak travel periods of the day. There is a widespread perception that automobiles are overused in Sydney as a result of the underpricing of road use. While there are some toll roads, the majority of roads are unpriced. Motorway tolls are not set so as to reflect the marginal external costs imposed by road usage. If they were, then tolls would be time-of-day variable.

Fuel prices contain a Commonwealth excise tax that is partly used to fund road investments nationwide. This arrangement does not make the fuel excise a road use charge, however. The fuel excise revenue is not hypothecated to road funding. The relationship, if any, between the amount of excise paid by a motorist and the external cost imposed by that motorist's road usage is extremely indirect.

If there were a system of road use pricing in force in Sydney that matched the motorist's payment to the full marginal costs, including the marginal external cost imposed by that usage, then it would not be necessary to take these externalities into account in deciding on the optimal CityRail fare and subsidy levels. That would be a preferable solution to the transport efficiency problem. Removing the distortions from road pricing would make it possible to price rail usage in a manner that took account only of the internal benefits.

Unfortunately, road pricing of the ideal type is some way off being achieved. In the immediate future there appears to be no prospect of its introduction. Consequently, CityRail finds itself in a second-best world wherein Government subsidies are required to achieve the internal and external welfare benefits that might othewise have been achieved with road pricing and a fully commercial rail network. Some form of congestion pricing for roads may be feasible in the medium term, and should not be dismissed, however. The second-best world may involve some mixture of road pricing and subsidised rail. The remainder of this report proceeds on the presumption that CityRail inhabits this second-best world.

3.2. SUBSIDY AS AN OPTIMISATION PROBLEM IN A 2ND BEST WORLD

The terms of reference for the externality study note,

> "*The purpose of this consultancy is to assist IPART in developing a framework to estimate the social costs and benefits (also known as externalities) arising from CityRail's passenger services, and to use this framework to derive the appropriate contribution by the Government to CityRail's costs*."

While the term "appropriate" is not synonymous with the word "optimal," it would nevertheless be useful to view the process of establishing an appropriate Government contribution as an optimisation problem. Arguably, the optimal Government contribution (or optimal range) would be an appropriate contribution.

In order to construct the optimisation problem it is necessary to identify the control variables, the uncertain variables representing the state of nature, the logical linkages between these variables and the objective function. The main control variables are fares and levels of service such as vehicle frequency, vehicle capacity, and travel times. Service quality is difficult to measure and hard to adjust on a consistent basis over the long period considered in our demand analysis, so our analysis focuses on fares. Given a known cost function for CityRail and the assumption that total receipts equal total cost in each year, specifying the fare is tantamount to specifying the total amount of Government contribution.

The fare, together with service quality, environmental variables relating to the cost of automobile usage, unemployment and population, among others determines the patronage on CityRail. As noted earlier, however, service quality is difficult to measure on a consistent historic basis. It is possible that capacity constraints on CityRail at peak hour also influence the patronage, tending to reduce it relative to the unconstrained level.

In keeping with a long tradition of public sector economics, the objective function would be a measure of welfare, including consumer surplus, producer surplus, external benefits and costs. Each of these elements of the welfare calculation are functions of CityRail patronage, so there is a fairly direct causal chain between the policy decision to set the fare and the welfare outcome via patronage. There may be at least one fare setting, for any given values of the environmental variables and capacity constraints, that will produce a local maximum in the welfare function.[1] IPART's task could be construed as to identify that optimal fare setting (assuming it exists) and to consider how best to transition to it from the current fare setting.

1 Theoretically, it is also possible that welfare would be maximised by shutting down the system. Work presented later in this report suggests that is not the case for CityRail.

3.2.1. Optimal subsidy may not equal external benefit

The optimal subsidy should seek to maximize net benefits, which are composed of consumer surplus, producer surplus which, if negative, involves government subsidy, and external effects. Intuitively, the greater the total external benefits of CityRail, the greater the subsidy level the Government should consider appropriate. This does not mean, however, that the dollar value of the Government subsidy should equal the dollar value of the external benefit generated by CityRail, for two reasons.

First, as just discussed, the optimal Government subsidy will be determined through a process of mathematical optimisation, in which there is no particular reason to believe it will precisely equal the external benefit at the optimum patronage level. Indeed, the central case and sensitivity cases presented later in this paper do not support the notion of equality between subsidy and externality.

Second, while the change in external benefit as one moves from one specific situation to another may be quantifiable in dollar terms, the absolute dollar value of externalities in any specific situation is not well defined. External benefit is intrinsically a relative concept, unlike producer surplus or consumer surplus. Parties to a transaction have a natural zero level of private benefit defined by the benefit obtained by not transacting. The parties experiencing external benefits have no such reference point—they cannot opt out of a transaction to which they are not a party.

3.2.2. Discussion of welfare effects of externalities

In the absence of externalities and ignoring the welfare costs associated with taxation, the socially optimal level of CityRail patronage would be the amount at which price equals marginal cost,[2] as the deadweight loss is minimised at that point. In the present case, however, CityRail generates external benefits which depend most directly on the amount of usage of CityRail's services. The implications of this fact for the socially optimal level of CityRail output is set out below in conceptual terms.

The diagram below illustrates the conventional welfare analysis for a service that does not create external costs or benefits, and how that analysis is modified to take account of externalities. Note that the figures presented in these charts are purely hypothetical and are presented for purposes of illustrating the method only.

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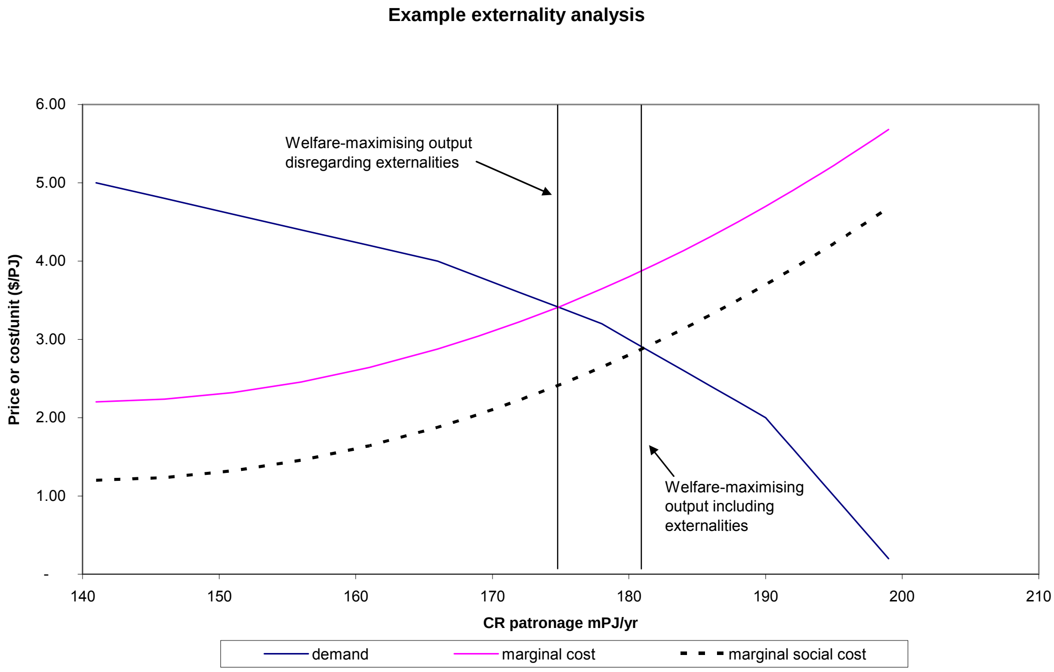
2 This statement ignores the welfare costs of imposing taxation to fund the subsidy required to meet the fixed costs of CityRail's operation. If users of CityRail service were the only beneficiaries, then some form of Ramsey Pricing to raise the funding for fixed costs may be preferable to general taxation (because only users would pay). However, the working hypothesis that external benefits of CityRail are significant in total and widely dispersed motivates the use of subsidy funding from taxation receipts.

The intersection of the two solid lines is the conventional competitive market equilibrium point where demand and marginal cost curves meet. The dotted line is the social marginal cost curve, which lies to the right of the marginal cost curve because the additional use of rail generates external benefits (reduced road congestion, etc) that reduce the net costs of the additional patronage. The new equilibrium point, where demand and social marginal cost curves meet, yields higher patronage and lower price compared to the conventional equilibrium point.



Note that the numbers in the illustrative diagrams below are not intended to be realistic. The actual optima have been estimated through the empirical work that is described in this report.

3.2.3. Welfare costs of taxation

One often reads in economic textbooks that socially optimal pricing involves setting price equal to marginal cost, but this prescription is problematic when fixed costs are significant, as they are for CityRail. Someone must pay for the fixed costs. If only users of the service benefit from it, then a form of Ramsey pricing is optimal—the fixed costs are recovered through a markup on marginal costs designed to minimally distort consumption decisions. Where external benefits are widespread, Ramsey pricing overtaxes the users and undertaxes the third-party beneficiaries. Here, Government subsidy can assist in achieving an efficient mix of funding sources.

However, one cannot overlook the fact that taxation itself will distort consumption decisions (even when one overlooks the cost of collecting taxes). Income taxes reduce the utility of working, so the balance between work and liesure is distorted toward the latter. Commodity taxes reduce the income of consumers and change the relative prices of different goods, invariably affecting consumption patterns. Like monopoly pricing, taxation imposes a deadweight loss on society. This loss should be part of the marginal welfare analysis used in the optimisation of Government subsidy to CityRail. In subsequent analysis we assume that the deadweight loss associated with taxation raised to fund CityRail's operating deficit, is 0.1 times the amount of tax revenue raised,[3] and we test the sensitivity of the results to this choice.

3.2.4. Objectives of Government

As the foregoing discussion has noted, there are several possible alternative objective functions that a government might conceivably wish to apply to its determination of an optimal CityRail fare structure. CRAI's role in this process is to prepare valid empirical estimates of the relevant relationships and to construct some modelling tools that will permit the optimisation process to be undertaken in a flexible manner by IPART. It is neither appropriate nor necessary for us to select the objective function that IPART would apply. Instead, the modelling tools developed as described in this report are constructed in a flexible manner so that any of the potential objective functions discussed below may be applied.

Potentially, one objective might be to minimise the subsidy paid to CityRail. This objective might conceivably be achieved by attempting to set average fares equal to the average cost per passenger journey of running CityRail. It is not certain, however, that average cost pricing would be practically achievable. Depending upon the actual shape of the demand schedule, there may be no patronage level greater than zero at which prices would equal average costs.

A more achievable objective may be to set fares so that the marginal revenue equals marginal cost. That prescription, monopoly pricing in effect, would minimise the subsidy, but that minimum subsidy may still be a significantly positive amount. It would be somewhat unusual for a government to adopt what is in essence a profit-maximising strategy in respect of a service which is undertaken essentially for social welfare reasons.

A more likely objective would be to maximise welfare, defined as the sum of producer and consumer surplus. This objective would be achieved by setting price equal to marginal cost.

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3 A range of figures for the marginal excess burden for a number of key state taxes is provided in Gabbitas, O. and D. Eldridge, "Reforming State Taxation", Policy, Autumn 1999, p. 22. Apart from the franchise fees on petrol, tobacco and alcohol, which are no longer levied by State Governments, the marginal excess burden rates fall within the range 0 – 12 cents per dollar of taxation revenue, supporting a range of deadweight loss factors for the present externality study from 1.0 – 1.12.

A further potential objective, and one canvassed in the terms of reference for this study, would be to maximise welfare including externalities. This objective would be achieved by setting price equal to the marginal social cost, where positive externalities associated with rail patronage would act to make the marginal social cost lower than the marginal cost at a given patronage level.

The objectives mentioned so far have overlooked the costs associated with raising tax revenue to meet the fixed costs of the rail system, which are substantial. If a primary driver of rail subsidisation is the desire to capture external benefits generated by rail, then it would be illogical to charge taxpayers, say, the equivalent of $10/passenger journey in additional tax in order to achieve external benefits worth only $3/passenger journey. There must be some nexus between the costs of taxation and the magnitude of external benefits which that taxation is intended to deliver.

With this principle in mind, one further possible Governmental objective should be considered. This possible objective is to maximise welfare including externalities, less the deadweight loss associated with taxation. The optimum point under this objective would correspond to a somewhat lower patronage level relative to the objective of maximising welfare including externalities, and a somewhat higher fare level. This is the objective adopted in this study.

3.3. Conduct of the study

Turning now to CRAI's research program, the following steps have been undertaken:

1. Determine the socially optimal level of CityRail patronage (under each of several possible objective functions), given current or expected future settings of the key environmental variables;

2. Determine what average CityRail fare level, given current fare structures and relativities between different fare categories, would encourage that optimal level of CityRail patronage; and

3. Determine what level of Government subsidy would be necessary to support CityRail financially, at current or expected future levels of productivity and cost-effectiveness, given those optimal fare and patronage levels.

3.3.1. Main empirical pieces of work

We have conducted this study subject to very severe data limitations, especially on the cost side. These limitations, which also affect CityRail we understand, have implications for the ability of CityRail to manage the efficiency of its operations. We note that IPART has commissioned a separate consulting study to consider CityRail's actual and potential future cost structures. Unfortunately, the information being generated by that other study does not provide the estimates of marginal cost that would be most useful for this study.

With that caveat in mind, the following main pieces of work have been undertaken to provide empirical substance to the conceptual analysis summarised above.

1. Econometric estimation of the own-price elasticity of CityRail demand to provide a partial view of the demand schedule, which is complemented with house price analysis[4] in order to select between possible alternative functional forms for the demand schedule.

2. Analysis of CityRail financial data was used to estimate marginal cost as a function of patronage.[5] It has proven not to be practical to reach reliable conclusions from econometric work on historic cost levels because CityRail's production function has been shifting systematically over the past 35 years. This financial data does not treat capital-related costs in a manner that is consistent with conventional economic analysis (for example, some capital costs for major periodic maintenance are expensed, while others do not appear in the profit and loss statement at all.) For this reason, the cost analysis must be treated with some caution.

3. External modelling conducted to our specifications by the Transport Data Centre using its Sydney Strategic Travel Model was used to establish the relationship between CityRail patronage and the various characteristics of automobile and bus usage that drive the most readily quantifiable externalities.

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4 This house price analysis, described fully in Appendix 2, quantifies the value of convenient access to the railway system that is embedded in Sydney property prices. This value represents an amalgam of consumer surplus and suburb-specific externalities. It is useful in establishing an upper bound to the level of total consumer surplus for rail commuters at current levels of patronage.

5 There are reasons to believe that CityRail may be nearing some binding capacity constraints for peak hour on the City Circle: peak hour trains are already operating at minimum headway and maximum load factors, and occupancy on some train platforms (such as Town Hall in particular) is already nearing the practical limit. If it is true that the City Circle is nearing capacity, then marginal costs should start to rise steeply at patronage levels slightly above those currently being experienced. We have attempted to quantify that effect, and our senstivity analysis will consider what impact our heuristic cost arguments may have on our results.

4. As a reality check on the estimated quantum of consumer surplus and local external benefits,[6] a separate type of analysis has been undertaken based on published econometric relationships between Sydney house prices and proximity to train stations (among a great many other factors). Using these published relationships, and holding all else constant, we estimated the consequences for house prices of removal of the rail network.

3.3.2. Externality calculation process

The steps in our estimation of the empirical relationship between CityRail fares and the external benefits associated with rail are as follows. First, it is necessary to empirically derive the demand-side relationship between CityRail average fares and patronage. Second, it is necessary to estimate the marginal cost of operating CityRail services. Both parts of this examination of CityRail are necessary to make any statement about the relationship between patronage and welfare.

Third, it is necessary to establish the relationship between CityRail patronage and usage of other passenger transport modes in Sydney, particularly private automobile travel. It is automobile displacement that generates the greatest external benefits attributable to CityRail.

Fourth, with a knowledge of the quantitative extent of automobile displacement by CityRail under different fare and patronage scenarios, it is possible to calculate the specific drivers of the external benefits:

- Changes in the amount of passenger time spent travelling provide one of the most direct measures of the costs of urban road congestion. More congestion means more time spent travelling. The traveller's valuation of that extra time gives rise to a dollar value for the congestion externality, when compared to alternative scenarios.

- Changes in the amount of fuel consumed (which depends on the number of vehicle kilometres travelled, but also on the average travel speed—slower travel means more litres of fuel consumed per kilometre travelled) lead directly to changes in the amount of CO2 and other pollutants released to the atmosphere.

6 Local external costs would be suburb-specific. They may include some localised noise impacts, and potentially some traffic congestion impacts. They would not include greenhouse gas emissions, which are experienced equally by all suburbs, or traffic congestion in the CBD or on major transport arteries.

- Changes in the number of vehicle kilometres travelled lead to changes in the expected number of traffic accidents. The full relationship is subtle because average vehicle speeds influence the risk and severity of accidents. Under low rail patronage scenarios there are more automobile kilometres travelled each day, but the average speed may decrease as congestion becomes more severe.[7] Accidents generate both internal and external costs. Published unit cost data do not always clearly specify which cost types are included, adding to the difficulty of reliable estimation of this externality.

These stages in our analysis are set out in chapters 3 – 9 below. Following that presentation, chapter 10 presents a discussion of the optimisation of fares, patronage and, implicitly, Government subsidy that focuses on the governmental objective of maximising welfare including externalities, less the total direct and indirect costs of taxation. Chapter 11 presents the conclusions.

4. PRICE ELASTICITY OF DEMAND FOR CITYRAIL SERVICES

The first quantitative link that must be established is that between the CityRail fare and CityRail patronage. We chose to estimate this relationship through an econometric investigation of annual historic CityRail revenue and patronage data over a 30 year period (1977/78 – 2006/07). This approach is quite different to the empirical methods employed to date to estimate the own-price elasticity of CityRail demand, which have generally focused on stated preference interviews.

One reason that long-term historic fare and patronage data has not been used previously for this purpose is that the fare data is not readily available. Indeed, our initial inquiries revealed that RailCorp does not maintain historic farebox or ticket price data. These data limitations have proven problematic in the present study. It is also concerning that CityRail places such an apparently low priority on the capture and use of commercial data of this type for its own decision-making.

Another likely reason that long-term time series data has not been used is that over a 30 year period many determinants of patronage, including demographic, technological, and quality factors have changed profoundly. In recognition of this fact it was necessary to select a range of explanatory variables that goes well beyond the factors that would normally be considered in a short-term analysis of modal choice.

7 In this report we have not modified the accident incidence or severity parameters to take account of slower vehicle speeds under congested conditions.

After examining a range of possible explanators of patronage, we found that a simple linear model provided a good fit to the historic data, in which the key coefficients had the expected sign and were significant at or near the 1% level.

CRA's econometric demand model taking account of these variables generated an estimated short-run rail fare own-price elasticity of 24% and a long-run fare elasticity of 35%. These elasticity estimates corresponds well with those obtained by some prior studies, notably Hensher and Raimond. They are consistent with the elasticity estimates recently provided to IPART by Booz Allen and Hamilton.

We investigated the possibility that the long-run elasticity might be significantly different from the short-run elasticity, employing the Voith methodology. Long-run elasticity reflects long-run adjustments through investments in relocation and transportation assets, whereas short-run elasticity reflects only current-period changes in location or investment in public transportation which affect ridership. For example, in the long-run automobile commuters may respond to a permanent shift in fuel, parking or car prices by changing jobs, moving house, or telecommuting. Changes of this magnitude would not be part of the short-run response. We concluded that the long-run effect was significant in the case of CityRail, but even in the long-run patronage was relatively price-inelastic.

Two alternative functional forms for the demand schedule were investigated:

- Linear demand; and
- Elasticity proportional to price.

The latter functional form was employed in RailCorp's own externality analysis.[8] The house price analysis referred to in the appendix permitted us to narrow down the plausible range of demand schedules, as discussed in more detail later in this chapter.

4.1. DEMAND MODEL

The dependent variable selected was annual CityRail passenger journeys.

The independent variables were:

- The real average fare per passenger journey in dollars of the 2006/07 year (CityRail passenger revenue excluding subsidies divided by the number of passenger journeys);
- The real value of a composite Sydney motoring cost index, including fuel, maintenance and ownership costs;

8 Karpouzis, G., A. Rahman, K.Tandy, and C. Taylor, "The value of CityRail to the NSW community 1997-98 to 2006-07", 30th Australasian Transport Research Forum, June 2007, Appendix B.

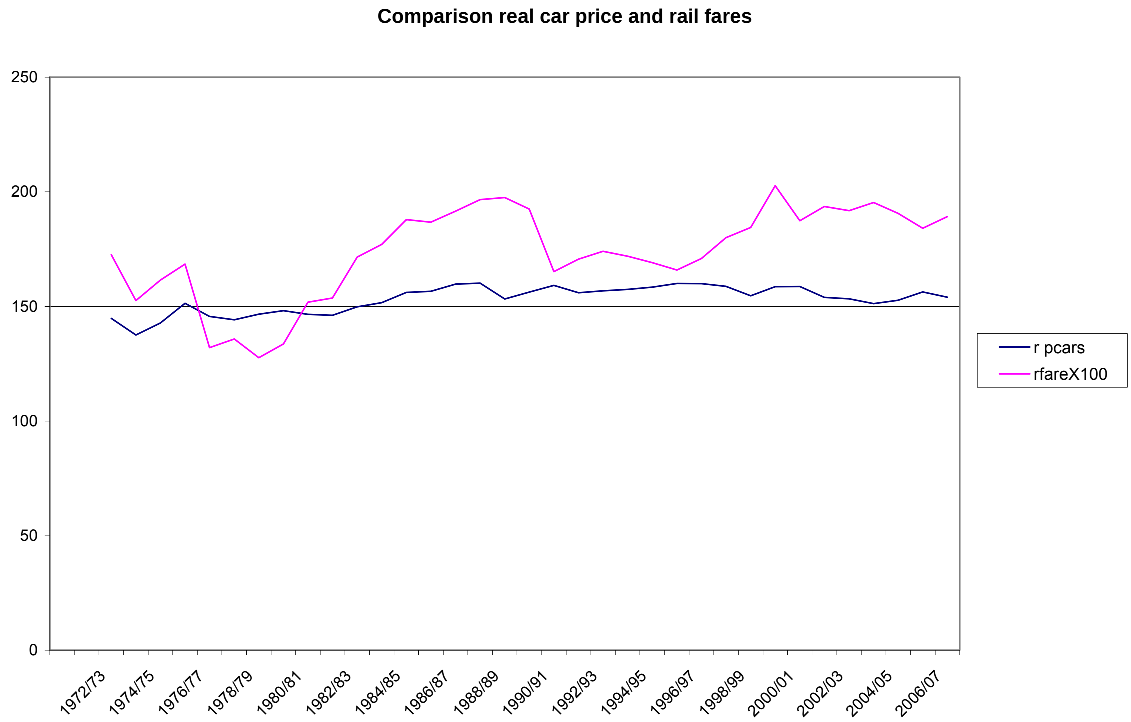
- The dependent variable lagged by one year;
- The Sydney unemployment rate multiplied by the population of Sydney;
- The number of new CityRail stations built since 1932;
- The incidence of strikes affecting railway workers (thousands of hours of time lost due to NSW railway industrial stoppages divided by the number of employees of the NSW Railways);
- The population of Sydney;
- Time (1971/72 = 1, 1972/73 = 2, etc.);
- A dummy variable for the 1977 Granville rail disaster involving a 5 year time lag effect;
- A dummy variable for the 2000 Sydney Olympics (which occurred in the 2000/01 financial year.

4.2. MOTIVATION FOR CHOICE OF REGRESSION VARIABLES

Passenger journeys, rather than passenger kilometres, were chosen as the dependent variable simply because of the unavailability of passenger kilometre data on a consistent basis over the time period. The comparative data that is available suggests that the average distance travelled per CityRail passenger journey has remained relatively constant at 18 – 19 km.

The real average fare was selected as the principal own-price variable of interest. Adjusting nominal fares by the CPI reflects the tradeoff made by households between outlays on rail travel and outlays on other consumer purchases. It is necessary to establish that fares are determined exogenously to patronage. Given the institutional basis for the fare-determination process in Sydney, it seems likely that fares are exogenously determined. Since 1992 (half the period used in the demand estimation) IPART has been responsible for determining CityRail fares. IPART follows an exhaustive and time-consuming process to arrive at annual fare determinations, involving public hearings and submissions. Section 15 of the IPART Act sets out a range of matters to be considered by IPART in making fare determinations. These matters include, inter alia, the cost of providing the services, protection of consumers, the effect on general price inflation, the need for ecologically sustainable development, the need for greater efficiency, and standards of quality, reliability and safety. The multiplicity of these objectives, the timing of the process, and the complexity of the required analysis makes it extremely unlikely that there is any steady causal link between patronage and prices.

The real private motoring cost index was selected as the principle alternative mode-price variable of interest. We obtained a time series from the Australian Bureau of Statistics representing a composite private motoring cost index that includes fuel, maintenance, registration, and ownership costs. This index closely tracked the CPI over the period, as shown in the chart below (i.e., when the index was CPI-adjusted it was nearly constant over 35 years). Real CityRail fares and the real private motoring price index are both plotted. The latter is relatively constant, while the former exhibits considerable variation over the period.



An alternative motoring cost index, consisting of the real Sydney fuel price index, was considered, but ultimately not used. The coefficient for this variable was not statistically different from zero. Further, the sign of the coefficient was negative, indicating a drop in patronage when the price of fuel increases. This converse relationship is understandable in terms of the impact on the economy (hence employment, hence rail patronage) of higher fuel prices, but it means that the fuel price term does not provide useful insight into the importance of the price of alternative transport modes.

The lagged dependent variable was included as a regressor in order to estimate the difference between long-run and short-run values for all coefficients. This method is discussed in a paper by Richard Voith.[9]

Two quality of service indicators were included in the demand model: number of stations opened since 1932, and incidence of strikes. The coefficient for number of stations was positive and highly significant. The coefficient for incidence of strikes was negative, as would be expected, and also highly significant.

It is necessary to establish that the number of stations was determined exogenously to patronage. To do so, we note that the number of stations increased three times during the sample period: the Eastern Suburbs line opening in 1979/80, the East Hills line extension in 1987/88, and the Airport Rail line opening in1999/2000. In each case, the new stations were constructed as part of an entirely new line serving an area that was previously not served by rail. The direction of causality was clearly that patronage increased because new stations were built in previously unserved areas.

Other quality of service variables that would have been useful include on-time running, frequency of service, passenger safety, train cleanliness and crowding. Unfortunately no consistent and reliable data were available on these measures over the period. Furthermore, the basis for measurement of on-time running statistics has changed several times over the period.

Demographic factors included in the model were unemployment in Sydney, and the population of Sydney. Unemployment is relevant because the principal use of CityRail during peak hours is the journey to and from work. The pool of potential CityRail passengers would be expected to grow with Sydney's population, although the geographic location of that growth is also important.

The inclusion of a time variable reveals that there is a statistically significant trend away from the use of rail over time when usage is expressed in terms of passenger journeys per head of Sydney population. One possible explanation of this phenomenon is that Sydney's population and employment growth since 1977/78 has occurred predominately in areas not served by the rail network.

9 Voith, R. (1991), "The Long-Run Elasticity of Demand for Commuter Rail Transportation," Journal of Urban Economics 30, 360-372.

Dummy variables were employed to account for the patronage impacts of two unique events in Sydney's history: the Olympic games in September 2000, and the Granville rail disaster in January 1977. During the Olympic games, rail was heavily promoted by the NSW Government as a means of accessing Olympic events and car usage was heavily discouraged. As a direct result of these events and policies, CityRail achieved an all-time yearly high in patronage during the 2000/01 financial year in which the Olympics took place. The dummy variable represents an instantaneous effect in that year only.

The Granville rail disaster occurred in January 1977. A morning commuter train derailed around a bend and subsequently collided with the central support of a road bridge crossing the railway line at Granville. The bridge collapsed onto the train, flattening the 3rd and 4th carriages, killing more than 80 people and seriously injuring many more. It was the worst rail disaster in Australia's history. The subsequent inquiry found that the accident was caused as a direct result of inadequate infrastructure maintenance, which was endemic to the entire NSW railway system at that time.

This event shattered public confidence in the rail system, particularly because the cause was systemic. Despite the fact that CityRail fares were at an all-time low (in both nominal and real terms), patronage was also at an all-time low. The approach taken to construction of a dummy variable for this event was as follows. The Granville effect for 1976/77 was set at 0.5 to reflect the fact that the accident occurred roughly halfway through that financial year. For the following two years, the Granville effect was set at 1.0. For 1979/80 the Granville effect was set at 0.66 and for 1980/81 it was set at 0.33. The Granville effect was set at zero for all subsequent years.

Admittedly, there is an element of judgement in selecting this particular profile over time for the Granville effect. The reason for phasing it out across 1979/80 and 1980/81 is that the June 1979 opening of the new Eastern Suburbs Line is generally credited with heralding a new sense of public confidence in the suburban rail system. This effect is observable in the historic patronage data, which showed a 14% increase in passenger journeys in the first full year of the Eastern Suburbs Line's operation despite a 15% increase in nominal average fares. Some of that increase would be attributable to users of the new line.

Given that the immediate post-Granville period saw the coincidence of historical low fares and patronage, demand models that do not include the Granville dummy fail to produce a statistically significant relationship between fares and patronage.

4.3. DATA SOURCES FOR DEMAND FUNCTION

We relied on annual reports for the State Rail Authority, its predecessors and Rail Corp for these data. Our analysis of annual report data was complemented by analysis conducted in 1997 by Dr Ian DeMellow as part of his PhD thesis.[10] The data employed in our analysis is summarised in the table below.

	dep var	independent variables									
	PJ	REALFARE	REAL Pcars	PJ(t-1)	UNEMP persons	Stations	STRIKE	POP	TIME	Granville dummy 5 yr effect	Olympics
1977/78	180.0	1.36	144.20	179.58	13,757	2	0.002715	2,413	7	1	0
1978/79	179.1	1.28	146.60	180.02	13,164	2	0.01055	2,445	8	1	0
1979/80	205.0	1.34	148.14	179.08	12,575	6	0.002677	2,478	9	0.666	0
1980/81	207.9	1.52	146.55	204.96	11,736	6	0.002505	2,501	10	0.333	0
1981/82	215.5	1.54	146.08	207.86	16,717	6	0.003814	2,539	11	0	0
1982/83	203.0	1.72	149.80	215.53	25,940	6	0.005274	2,577	12	0	0
1983/84	198.1	1.77	151.68	203.03	22,495	6	0.009673	2,603	13	0	0
1984/85	197.0	1.88	156.17	198.07	20,245	6	0.019415	2,646	14	0	0
1985/86	214.9	1.87	156.55	196.98	19,701	6	0.000935	2,699	15	0	0
1986/87	220.6	1.92	159.71	214.88	20,376	6	0.000562	2,760	16	0	0
1987/88	242.6	1.97	160.20	220.61	18,017	13	0.00043	2,811	17	0	0
1988/89	246.1	1.98	153.23	242.59	14,967	13	0.002649	2,842	18	0	0
1989/90	248.4	1.92	156.23	246.09	16,066	13	0.001113	2,873	19	0	0
1990/91	251.6	1.65	159.24	248.40	23,709	13	0.000924	2,906	20	0	0
1991/92	243.8	1.71	156.01	251.55	28,086	13	0.004859	2,938	21	0	0
1992/93	229.8	1.74	156.84	243.80	29,297	13	0.000917	2,964	22	0	0
1993/94	234.8	1.72	157.44	229.80	25,753	13	0.000127	2,992	23	0	0
1994/95	249.6	1.69	158.40	234.80	21,906	13	0.000173	3,035	24	0	0
1995/96	256.4	1.66	160.01	249.60	21,247	13	4.51E-05	3,087	25	0	0
1996/97	264.7	1.71	159.92	256.40	20,399	13	0	3,134	26	0	0
1997/98	266.5	1.80	158.79	264.70	18,405	13	8.59E-06	3,178	27	0	0
1998/99	270.5	1.84	154.63	266.50	15,524	13	0	3,212	28	0	0
1999/2000	278.7	2.03	158.59	270.50	14,446	18	0.001673	3,252	29	0	0
2000/01	302.6	1.87	158.72	278.70	16,893	18	1.11E-07	3,301	30	0	1
2001/02	276.4	1.94	153.95	302.64	17,021	18	8.22E-08	3,343	31	0	0
2002/03	273.4	1.92	153.29	276.37	17,007	18	2E-06	3,379	32	0	0
2003/04	273.3	1.95	151.21	273.40	15,996	18	0	3,415	33	0	0
2004/05	270.3	1.91	152.68	273.30	15,224	18	0	3,447	34	0	0
2005/06	273.7	1.84	156.35	270.30	15,744	18	0	3,479	35	0	0
2006/07	281.3	1.89	154.05	273.70	15,971	18	0	3,521	36	0	0

Passenger journeys and nominal fares were obtained from the annual reports and Dr DeMellows' thesis. The number of stations opened since 1932 was taken from historical records. Data on unemployment, and population in Sydney were obtained from the Australian Bureau of Statistics.

10 DeMellow, Ian T. M. 1997, *Cost efficiency of NSW rail passenger services 1951/52-1991/92: a case study in corporate strategic modelling*, Thesis (Ph. D.), University of Sydney.

Prior to 1972, the annual reports amalgamated CityRail patronage and revenue with country train data, rendering it unsuitable for our analysis. Of the 35 years for which stand-alone CityRail data is available, only the latter 30 years, from 1977/78 – 2006/07 were used because the population and unemployment data was not available on a consistent basis prior to 1978.[11] Within the 30 years included in the econometric demand analysis, patronage ranged from 179mPJ/yr to 303mPJ/yr. If the Granville and Olympic effects are not included, the patronage ranged between 197mPJ/yr and 279mPJ/yr over the period.

4.4. RESULTS OF FARE OWN-PRICE ELASTICITY ESTIMATION

The results are presented in two parts. First, the local elasticity estimate is presented. Then the likely functional form of the overall demand schedule is discussed.

4.4.1. Elasticity in neighbourhood of current demand

The main regression results are summarised below. First patronage was regressed on contemporaneous values of the explanatory variables. The results are presented below.

11 We did investigate the use of a proxy for Sydney population based on NSW population and for Sydney unemployment based on national unemployment for the earlier years. However, the results of the longer time series regression were inconclusive, probably as a result of the crudeness of the unemployment proxy.

Dependent Variable: PJ
Method: Least Squares
Date: 04/07/08 Time: 14:21
Sample: 7 36
Included observations: 30
Newey-West HAC Standard Errors & Covariance (lag truncation=3)

	Coefficient	Std. Error	t-Statistic	Prob.
C	-650.87	236.29	-2.8	1.22%
REALFARE	-46.37	9.73	-4.8	0.01%
REAL_PCARS	0.86	0.31	2.8	1.12%
UNEMP	-0.0013	0.0003	-4.1	0.06%
STATIONS	2.33	0.54	4.3	0.03%
STRIKE	-431.88	221.70	-1.9	6.56%
POP	0.38	0.12	3.3	0.39%
TIME	-13.29	4.49	-3.0	0.78%
GRANVILLE	-45.61	6.86	-6.6	0.00%
OLYMPICS	22.85	2.66	8.6	0.00%

R-squared	0.98	Mean dependent var	241.85
Adjusted R-squared	0.98	S.D. dependent var	33.10
S.E. of regression	5.05	Akaike info criterion	6.34
Sum squared resid	510.51	Schwarz criterion	6.81
Log likelihood	-85.08	Hannan-Quinn criter.	6.49
F-statistic	136.10	Durbin-Watson stat	1.18
Prob(F-statistic)	0		

While the correlation coefficient and t-values are high, the low value of the Durbin-Watson statistic indicates the presence of serial correlation among residuals, meaning that the standard tests of significance may be misleading. The serial correlation problem arises because there is a lagged response by patronage to changes in the explanatory variables, including fare. Putting this another way, the full long-term effects of a change in fare are not reflected in the same year's patronage. It was this tendency of long-run price elasticity to exceed short-run price elasticity that motivated Voith to employ a more sophisticated estimation method. The application of Voith's method to the CityRail data is presented in the next section.

4.4.2. Long-run versus short-run elasticity

The regression results presented above employ an unusually long time series (compared to other elasticity studies) to derive what is in effect a short-run value of the elasticity of demand for CityRail services. The distinction between long-run and short-run elasticity values is potentially important. A temporary change in ticket prices or in the price of fuel might induce a temporary modal shift, but a permanent change in the relative attractiveness in modes may lead to more far-reaching decisions by commuters. For example, faced with the prospect of ever-increasing fuel prices, a road commuter may move to a different home located closer to work, change jobs, buy a more fuel-efficient car, telecommute or retire early. A long-run elasticity would reflect an individual's freedom to make a wider range of decisions than would be available in the short-run. For this reason, long-run elasticities are likely to be higher than short-run values.

Richard Voith published an econometric method to estimate the differences between short-run and long-run price elasticities for commuter rail transportation, and applied it to the SEPTA system in Philadelphia.[12] At the heart of his method was a regression model in which demand for rail trips was expressed as a function of the prices and attributes of the rail mode and competing modes, as well as the lagged demand variable. The coefficient for the lagged demand variable, estimated using an instrumental variable approach, determines the multiplicative factor to be applied to the short-run elasticity to obtain the long-run elasticity.

In order to apply Voith's method, we modified the above regression model so as to include the lagged dependent variable as one of the explanatory variables. A lag of one year is used. The Voith approach assumes that changes to the independent variables, including fare, have an influence that persists over time with an effect that declines in a geometric series. Exploiting the mathematical properties of geometric series, Voith was able to estimate the ratio of consecutive terms by including the dependent variable with a one-period lag only. The results of this alternative demand model are presented below.

12 Voith, R. (1991), "The Long-Run Elasticity of Demand for Commuter Rail Transportation," Journal of Urban Economics 30, 360-372.

Dependent Variable: PJ
Method: Least Squares
Date: 04/07/08 Time: 14:08
Sample: 7 36
Included observations: 30
Newey-West HAC Standard Errors & Covariance (lag truncation=3)

	Coefficient	Std. Error	t-Statistic	Prob.
C	-350.56	231.58	-1.5	14.66%
REALFARE	-36.36	8.22	-4.4	0.03%
REAL_PCARS	1.16	0.24	4.9	0.01%
PJ(-1)	0.30	0.11	2.8	1.03%
UNEMP	-0.0015	0.0003	-5.2	0.01%
STATIONS	1.69	0.46	3.7	0.14%
STRIKE	-555.73	211.54	-2.6	1.66%
POP	0.19	0.13	1.5	16.04%
TIME	-6.49	4.77	-1.4	19.01%
GRANVILLE	-32.65	6.83	-4.8	0.01%
OLYMPICS	21.42	1.71	12.5	0.00%

R-squared	0.99	Mean dependent var	241.85
Adjusted R-squared	0.98	S.D. dependent var	33.10
S.E. of regression	4.12	Akaike info criterion	5.94
Sum squared resid	321.83	Schwarz criterion	6.46
Log likelihood	-78.16	Hannan-Quinn criter.	6.11
F-statistic	185.70	Durbin-Watson stat	2.03
Prob(F-statistic)	0		

Voith notes the possibility that error terms will be serially correlated for such a demand model. If serial correlation is present, an ordinary least squares estimation of our demand function would yield inconsistent estimates of the coefficients. The Durbin-Watson statistic does not provide a meaningful indication of the presence or absence of serial correlation when one of the regressors is the lagged dependent variable. For this reason, we have performed the Breusch-Godfrey test for serial correlation. The results of this test are tabulated below.

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.066533	Prob. F(1,18)	0.7994
Obs*R-squared	0.11048	Prob. Chi-Square(1)	0.7396

Test Equation:
Dependent Variable: RESID
Method: Least Squares
Date: 04/07/08 Time: 14:03
Sample: 7 36
Included observations: 30
Presample missing value lagged residuals set to zero.

	Coefficient	Std. Error	t-Statistic	Prob.
C	29.48	242.15	0.12	90%
REALFARE	1.52	12.07	0.13	90%
REAL_PCARS	0.03	0.30	0.10	92%
PJ(-1)	0.02	0.12	0.16	88%
UNEMP	0.00	0.00	-0.02	98%
STATIONS	-0.03	0.57	-0.05	96%
STRIKE	-15.58	274.74	-0.06	96%
POP	-0.02	0.13	-0.14	89%
TIME	0.67	4.94	0.14	89%
GRANVILLE	1.54	10.55	0.15	89%
OLYMPICS	0.51	4.97	0.10	92%
RESID(-1)	-0.09	0.35	-0.26	80%

R-squared	0.003683	Mean dependent var	-7.76E-14
Adjusted R-squared	-0.605178	S.D. dependent var	3.331325
S.E. of regression	4.220643	Akaike info criterion	6.007026
Sum squared resid	320.6489	Schwarz criterion	6.567505
Log likelihood	-78.1054	Hannan-Quinn criter.	6.186328
F-statistic	0.006048	Durbin-Watson stat	1.988245
Prob(F-statistic)	1		

This test suggests that the error term is not serially correlated with a lag of 1, and that none of the regressors is correlated with the error term. In light of this finding, we did not proceed to an instrumented variable approach, as would normally be done in the event of serial correlation.

The long-run demand model provides an extremely good explanation of the variation in the dependent variable. The t-values are all above 2 except for the constant, population, and the time trend variable. They key variables of interest are all significant at or near the 1% level.

The point estimate of the long-run elasticity for patronage levels observed in 2005/06 and 2006/07 derived from this regression (-0.35) is significantly different from the short-run elasticity estimate derived from this model (-0.24). A sensitivity run omitting the time trend variable yielded a long run elasticity point value of (-0.29) and a short run elasticity value of (-0.18).

Given these results, the sensitivity testing performed later in this report will examine a range of point elasticity estimates between -0.24 and -0.35 for the patronage levels observed in 2005/06.

Some commentary is warranted on the fact that CityRail demand is so price inelastic. Voith's own results showed that for the SEPTA system in Philadelphia, long run elasticities had an absolute value of greater than 1, despite the fact that short run elasticities had an absolute value lower than 1.

For Sydney, CityRail's share of passenger kilometres on a normal working day in 2006 was only about 11%.[13] Nevertheless, the vast majority of commuter rail journeys have the Sydney Central Business District (CBD) as their origin or destination. CityRail's modal share for peak hour trips to the CBD is greater than 50%. The congestion on major arteries into the CBD, together with the cost and scarcity of CBD parking (supported in part by active Government policies to discourage it) contribute to this high rail modal share in Sydney. These factors, as well as the similarity to previous CityRail price elasticity estimates, support the low elasticity figures reported here.

4.4.3. Functional form of demand schedule

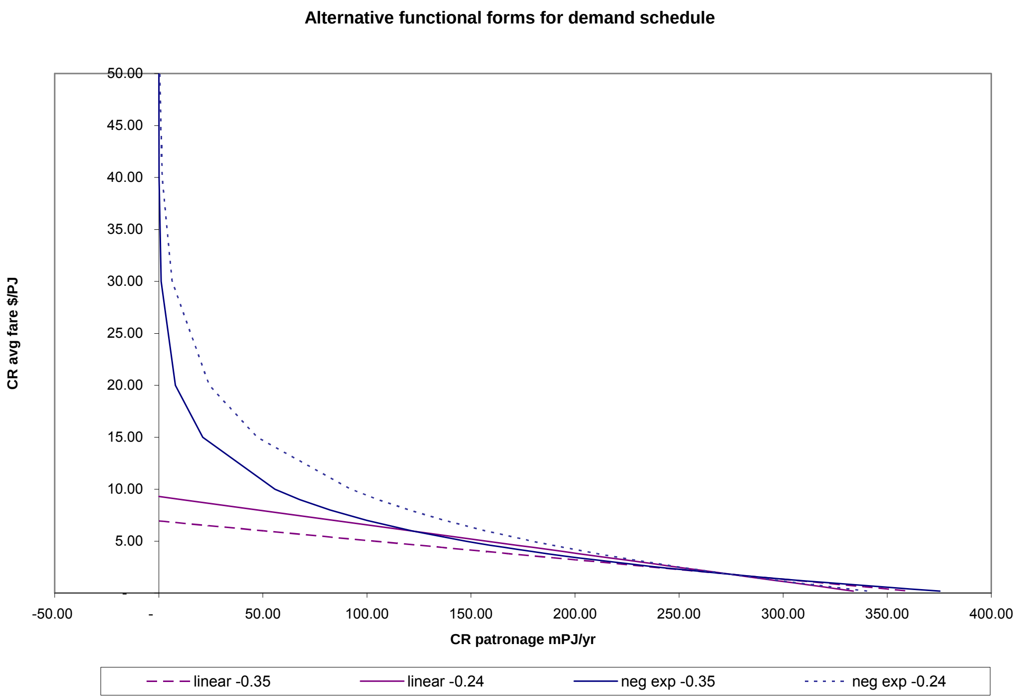
As the price elasticity of demand for CityRail services was estimated over a relatively narrow range of historical patronage (between 179mPJ/yr and 303mPJ/yr), it is not straightforward to extrapolate the demand schedule for much lower patronage values. Unfortunately, the demand schedule at these low patronage values is relevant to estimates of the consumer surplus created by CityRail.

The demand schedule could conceivably conform to any one of a number of possible functional forms including, among others:

- Linear demand;
- Elasticity is proportional to fare (referred to by RailCorp as "negative exponential demand"; and
- Constant elasticity.

13 See the BAU column (business as usual) for the Transport Data Centre's SSTM model run in s6.4 below.

While a constant elasticity demand schedule can probably be ruled out on the grounds of implausibility,[14] both the linear and negative exponential functional forms are consistent with observed patronage and fare data. The sensitivity range for fare elasticity considered in this study is between -0.24 and -0.35. There are four possible permutations of fare elasticity and functional form, excluding the constant elasticity demand schedule. These are shown graphically in the chart below.



Casual inspection of the areas beneath the four demand schedules shows that the consumer surplus at current patronage levels (of approximately 275mPJ/yr) would be very different, depending on the particular demand schedule selected from this group of four. Clearly the choice of functional form is important to the quantitative result of this analysis.

14 Constant elasticity across all patronage levels is implausible because it is inconsistent with the widely observed phenomenon of increasing elasticity at extreme high prices, reflecting the greater range of substitution possibilities at higher prices.

The property price analysis described in Appendix 2 derived an annuity value of $1.4b. This figure represents the sum of consumer surplus and those external benefits that are suburb-specific. Some external benefits, such as reduced greenhouse gas emissions, are not suburb-specific and for that reason would not lead to any price differential between houses in different suburbs. While other external benefits of rail, such as reduced road congestion and risk of automobile accidents, may be suburb-specific to some degree, the suburb-specific component of even these externalities may be a small part of the total external benefit.

If the negative exponential functional form for the demand schedule were calibrated to the low elasticity value of -0.24, the total consumer surplus at the 2006 level of CityRail patronage would be $2.1b/yr—a figure that far exceeds the annuity calculated based on the property price analysis. This finding suggests that the negative exponential functional form with point elasticity of -0.24 is not consistent with the property price analysis.

On the other hand, if the linear demand schedule is calibrated to the high elasticity value of -0.35, the total consumer surplus at the 2006 level of CityRail patronage would be only 707m/yr—less than half the figure estimated from the property price analysis. Noting that the externality component of the $1.4b estimate from the property price analysis is likely to be relatively small (only the suburb-specific externalities), this finding suggests that the linear functional form with point elasticity of -0.35 is not consistent with the property price analysis.

That leaves the two intermediate demand schedules (shown in solid lines in the chart above): a linear functional form with point elasticity of -0.24 and a negative exponential functional form with point elasticity of -0.35. The former yields a total consumer surplus at 2006 patronage levels of $1.0b/yr—a figure that is consistent with the annuity value derived from the property price analysis, when one recognises that the annuity also includes some element of suburb-specific external benefit for rail. The latter yields a total consumer surplus at 2006 patronage levels of $1.4b/yr—a figure that is also broadly consistent with the annuity derived from the property price analysis.

These findings suggest that either a linear functional form with point elasticity of -0.24 or a negative exponential functional form with point elasticity of -0.35 should be used for the consumer surplus analysis and the other welfare analysis relied upon in the optimisation stage of this study.

4.5. COMPARISON TO OTHER PRICE ELASTICITY RESULTS

The econometric estimates described in this chapter fall within the range -0.24 (for short-run elasticity) to -0.35 (for long-run elasticity). Rough estimates of the short-run rail own price elasticity can be made using the Transport Data Centre's runs of the SSTM performed to our specification (as described in chapter 5 below). These elasticity estimates range from -0.17 to -0.23 depending on whether the price change was positive or negative, 10% or 20%.

The January 2008 Booz Allen Hamilton (BAH) Draft Final Report "City Rail Fare Elasticities" commissioned by IPART sets out the own-price elasticity estimates derived from the authors' stated preference survey, and compares these to previously published values. The BAH elasticity estimates were -0.36 for CityRail overall, -0.38 for commuter ticket types and -0.33 for non-commuter ticket types. BAH also cites results from Hensher and Raimond's 1996 study: -0.29 for CityRail overall, -0.24 for commuter ticket types, and -0.33 for non-commuter ticket types.[15]

Our short-run elasticity estimates are similar to but somewhat higher than those implicit in the SSTM. Our short-run elasticity estimate is similar in magnitude to the Hensher and Raimond estimates. Our short-run price elasticities are lower than those generated by BAH's stated preference work commissioned by IPART, but our long-run elasticities are similar in magnitude.

It is possible that one reason for differences between our results and other published stated preference work is that the latter does not take into account the effect of capacity constraints on CityRail patronage at the peak hour. When a respondent answers a survey question, that individual may not be in a position to anticipate the potentially crowded conditions on a peak-hour train that might arise as a result of a favourable movement in rail fares.

Further, it is not clear to what extent respondents to a stated preference survey take into account the long-term possibilities of moving house, buying a more fuel-efficient car, changing job, etc., when weighing the modal options currently offered.

5. ESTIMATION OF CITYRAIL SHORT-RUN COSTS

5.1. METHODOLOGY

Historical cost regression has proven unsuccessful in estimating marginal cost rates prevailing in the present day, for the reason that the CityRail cost function has been steadily undergoing transformation over the past 30 years or more. Successive waves of institutional reform at CityRail and its predecessor organisations have led to drastic changes in organisational structure, staffing levels, and outsourcing policies. Even in very recent times, since the 2004 formation of CityRail's parent organisation, RailCorp has undergone significant reform. The number of RailCorp employees has changed significantly every year between 2004 and 2006. These changes make intertemporal comparisons of cost relationships impractical.

15 Data points presented in Table 11, p. 27, Booz Allen Hamilton Draft Final Report.

Instead, an accounting-based approach has been employed to estimate the marginal cost function for CityRail in its current organisational form. The marginal cost is expressed in units of dollars per passenger journey. The cost estimation method is to itemise cost areas and then make a judgement based on experience as to the extent each cost item would vary with a change to the annual number of passenger journeys.

Cost variability judgements are made in two steps. The main output-related drivers of cost are:

- Number of train kilometres travelled per annum;
- Number of track kilometres of infrastructure provided; and
- Number of stations in the CityRail service area.

The relationship between each of these drivers and particular cost categories can be surmised with some confidence. For example, rolling stock maintenance, consumption of traction electricity (to propel trains), and access charges would be proportional to train kilometres travelled. Infrastructure costs would be proportional to the quantum of infrastructure provided. Station costs would be proportional to the number of stations.

The relationship between patronage and each of these drivers depends, to a significant extent, on current levels of utilisation of the relevant assets and current capacity. For example, if load factors on trains were presently 40% on average, then a 50% increase in patronage may be able to be accommodated without any increase in train kilometres travelled by increasing load factors to 60%. On the other hand, if average load factors were presently 90%, then even relatively small increases in patronage would require an increase in train kilometres travelled.

This assessment is far from straightforward if, as is the case, asset utilisation and capacity is not well known to us.[16] Lacking this detailed information, we make the following heuristic arguments.

1. We assume that the number of stations does not change with patronage. Station openings are a relatively infrequent event (only 18 stations have opened since 1932 and three of the five groups of station openings were associated with the opening of completely new lines). As discussed in section 4.2 above, it does not appear to be the case that stations are opened in response to changes in patronage. The number of stations is exogenously determined.

16 Even if average load factors are known, information about the distribution of load factors across trains is also important. A 40% average load factor may disguise the fact that some trains are at 100% and a greater number of trains is at only 10% load factor. In that case, it might be necessary to increase frequencies at the peak, and therefore increase train kilometres travelled, in order to achieve a 50% increase in average load factors.

2. In the long-run view with which we are concerned, we assume that the number of train kilometres travelled varies proportionally to patronage. Notwithstanding the point made earlier about changing load factors on trains, in the longer term the fleet, the timetable, and train crews will be adjusted to maintain a steady, comfortable, but relatively high average load factor. Persistently low load factors would lead to a rationalisation of service costs, meaning a reduction in train kilometres. Persistently and uncomfortably high load factors would lead to an increase in train kilometres in order to ameliorate overcrowding.

3. The current track configuration is adequate to meet current levels of patronage. The level of patronage experienced during the 2000 Sydney Olympics most likely would have exceeded the current infrastructure capacity were it not for the fact that much of the Olympic travel occurred off-peak and citizens of Sydney were actively encouraged to take vacation during that period. It is well recognised that the CityCircle is the most significant traffic bottleneck on the system at peak hours and that all projects considered to date to augment CBD rail infrastructure capacity involve unprecedented levels of capital expenditure. This being the case, we assume that when patronage approaches the Olympic level of approximately 300mPJ/yr a 1% increase in patronage would involve a 2% increase in infrastructure costs.

5.2. DATA SOURCES FOR COST FUNCTION

Data was obtained from RailCorp's management accounts for the 2006/07 financial year,[17] and summary cost figures produced by LEK for the current IPART review of the CityRail regulatory framework. We performed a reconciliation between the two sets of figures, and ultimately decided to rely on the LEK figures. Where judgements needed to be made about the likely variability of certain cost items with patronage, these judgements were made on the basis of CRAI's experience with rail systems, and subjected to sensitivity testing.

5.3. RESULTS FOR COST FUNCTION ESTIMATION

The results of this exercise are tabulated below.

17 CityRail cost centres only. These figures are not comparable to the RailCorp-wide figures presented in s10.2 below and sourced from Karpouzis et. al. The later figures include as revenue Countrylink farebox, access charge and other revenue from other rail entities, and concession revenue from the Government in addition to the CityRail farebox. The total cost figure presented in s9.2 is RailCorp's total cost, not merely the cost of providing CityRail services.

ASSUMPTIONS		@ PJ=200mPJ/yr		@ PJ=300mPJ/yr	
Δ train km for 100% ΔPJ		100%		100%	
Δ infrastructure for 100% ΔPJ		10%		200%	
Δ overheads for 100% ΔPJ		5%		5%	
Δ train control for 100% Δ train km		10%		10%	
RESULTS	LEK 2006/07 RailCorp actual	%var	var$		var$
Corporate Overhead	263,030,638	5%	13,151,532	5%	13,151,532
Marketing	13,866,474	5%	693,324	5%	693,324
Revenue Collection	56,499,765	5%	2,824,988	5%	2,824,988
Train Drivers	138,878,692	100%	138,878,692	100%	138,878,692
Train Guards	98,519,356	100%	98,519,356	100%	98,519,356
Other Crewing	29,606,317	100%	29,606,317	100%	29,606,317
Train Control	73,278,260	10%	7,327,826	10%	7,327,826
Electricity	39,900,112	100%	39,900,112	100%	39,900,112
Access Charge	188,677	100%	188,677	100%	188,677
Rolling Stock Maintenance	253,375,862	100%	253,375,862	100%	253,375,862
Total Infrastructure Cost	490,039,063	10%	49,003,906	200%	980,078,125
Stations	227,632,153	5%	11,381,608	5%	11,381,608
Bussing	31,988,344	100%	31,988,344	100%	31,988,344
Presentation	42,086,179	100%	42,086,179	100%	42,086,179
Security	48,441,741	5%	2,422,087	5%	2,422,087
Safety	21,020,439	5%	1,051,022	5%	1,051,022
Total cost	1,828,352,071	VC	722,399,831	VC	1,653,474,050
		FC	1,105,952,240	FC	174,878,021
Implied cost rates			$/PJ		$/PJ
		MC	2.57	MC	5.88
		AC	6.50	AC	6.50

These particular assumptions concerning variability of certain cost categories result in an estimated variable cost rate of $2.57/passenger journey when patronage = 200mPJ/yr and $5.88/passenger journey when patronage = 300mPJ/yr. Both of these figures are lower than CityRail's average costs of $6.50/PJ.

While plausible, the selected cost variability rates are somewhat arbitrary, as is the assignment of particular infrastructure cost variability rates to particular patronage levels. Sensitivity testing will be applied to explore the effect on results of different choices for these parameters.

6. DISPLACEMENT OF AUTOMOBILE USE BY CITYRAIL

The third empirical relationship that must be established is that between CityRail patronage and automobile use in Sydney. We have chosen to estimate this relationship through a series of runs of the Sydney Strategic Travel Model, which is operated by the Transport Data Centre of the NSW Ministry of Transport.

CRA formed the view that the Transport Data Centre's Sydney Strategic Travel Model represented the best available tool to analyse the interaction between price-induced shifts towards or away from rail patronage on one hand and changed patterns of automobile and bus usage on the other, for the following reasons. The effect of changes in CityRail patronage is not necessarily one-for-one with changes in passenger journeys by car or bus. The Transport Data Centre's Sydney Strategic Travel Model is well suited to estimate the modal shift effects given its comprehensive data on characteristics of each transport mode in Sydney and its recursive method of converging to a solution. The recursive method allows for trip generation and other subtle effects on modal share by determining an equilibrium position between modes after price shocks have altered the prior balance.

6.1. Our brief to the Transport Data Centre

There were two types of model runs required: an incremental rail fare change scenario, and a more extreme no-rail scenario. For each model run, the comparison was made between a set of model outputs (listed below) in the specified case and in a business as usual case.

MODEL OUTPUTS REQUIRED for each model run

1) passenger kilometres and passenger hours per annum by mode (rail, bus, and car)

2) bus kilometres and bus hours per annum

3) train kilometres and train hours per annum

4) vehicle kilometres (annually) by speed band, in increments of 5 km/hr

5) road volume to capacity ratio expressed as the number of lane kilometres of roadway by volume/capacity bands in increments of 0.1 from 0 to the highest band

6) lane kilometres of roadway by speed band, in increments of 5 km/hr

We understand that the road network included in the model extends outward from Sydney to: Newcastle, Mount Victoria, Penrose, and Bomaderry. That geographic footprint is suitable for our purpose as it overlaps the CityRail electrified network reasonably closely.

6.1.1. SPECIFICATION OF INCREMENTAL RAIL FARE CHANGE SCENARIOS

Scenarios involving an incremental change to current CityRail fares were considered in order to investigate the behaviour of the Sydney transport system at different fares within the neighbourhood of current patronage settings. This set of scenarios sheds light on marginal external benefits. The extreme no-rail scenarios considered later are also relevant to estimating marginal external benefit as a function of rail patronage. Further, they can also assist in deriving an absolute value of external benefits if the question concerns the existence, rather than just the pricing of CityRail. For practical intents, the future existence of CityRail is not a policy variable, but pricing may be.

To explore the incremental cases, four model runs were undertaken. Each involved a uniform percentage change to all rail fare categories. We used the price elasticities built into the SSTM for these runs, but our focus was on the patronage changes, rather than the fare changes applied in the model to induce them.

The model runs were:
A) 10% increase in all rail fares with no change to any other public transport fares
B) 20% increase in all rail fares with no change to any other public transport fares
C) 10% decrease in all rail fares with no change to any other public transport fares
D) 20% decrease in all rail fares with no change to any other public transport fares

6.1.2. SPECIFICATION OF EXTREME NO RAIL SCENARIO

For the “no rail” scenarios, the rail fare was set infinitely high, so that all rail passengers ceased to use that mode.

The prospect of no rail service in Sydney whatsoever would involve some drastic changes, and it is not straightforward to say how Sydney would respond demographically, economically, or politically to such a shock. In selecting the specification noted below, we have tried to find a least-cost response to this shock which can be specified reasonably simply without the need for excessive iteration or speculation.

The modelling choices were:

(I) There would be no passenger train service whatsoever in Sydney.

(II) The existing rail corridor would be sterilised--that is, unavailable for any other use.

(III) No new road infrastructure would be built in response to this shock, and no new dedicated busways.

(IV) There would be no change to current bus lanes on existing roads. Cars would continue to be free to go wherever they go now.

(V) The bus fleet and bus timetable frequencies would be increased as much as necessary to meet the increased demand.

(VI) Bus speeds were varied by assumption, one set of scenarios for each bus speed setting:

(a) current speeds

(b) 50% of current speeds

(c) 25% of current speeds.

(V) The price of parking in the CBD was varied by assumption, one set of scenarios for each parking price setting:

(d) current price

(e) 50% increase in current parking price

(f) 100% increase in current parking price.

Each of the 9 possible permutations of bus speed and parking price was the subject of one “no rail” scenario run.

TDC accepted the modelling assignment with the following caveat:

- TDC produced average working day results. CRAI converted these to annual estimates using a factor of 265 working day equivalents per annum.
- The estimated road speeds and volume over capacity ratios should be used with considerable caution.

6.2. METHODOLOGY FOR QUANTIFYING DISPLACEMENT OF AUTOMOBILES

The methodological basis of the SSTM is explained in detail in a range of documents available on the Transport Data Centre’s web site:
http://www.transport.nsw.gov.au/tdc/

In general terms, SSTM is a transportation simulation model that analyses traffic flows in Sydney. Speeds are determined by the volume/capacity ratios on various thoroughfares. The model also includes rail service for these thoroughfares. It can be used to address the following question: suppose the price of rail increased by an arbitrary amount, what impact would this change have on highway traffic, travel speeds and delays?

The model accounts for trip generation and modal substitution. It is assumed that all rail users either switch to or from auto or bus, or do not travel. More auto users will reduce traffic speeds and increase delay according to a standard speed flow curve. Note the model does not allow changes in land use.

6.3. AUTOMOBILE DISPLACEMENT CONVERTED TO EXTERNAL BENEFITS

Some of the most important externalities associated with CityRail services involve the avoidance of congestion, emissions, and traffic accidents. The quantum of these external costs depends on the amount and spatial incidence of automobile and bus usage. The TDC modelling effort provided this information.

Taking the TDC model outputs, we applied published relationships between:

- Changes in travel time resulting from congestion and congestion costs;
- Vehicle-km, speed and fuel consumption;
- Fuel consumption and emissions;
- Emissions and related costs (such as accepted ranges of carbon prices, for example);
- Traffic levels and the risk and severity of accidents;
- Risk, severity of accidents and related costs;

to quantify the additional external costs associated with changed rail patronage.

6.4. RESULTS FOR AUTOMOBILE DISPLACEMENT ANALYSIS

The SSTM model results are summarised in the tables below.

IPART Externalities Study
Results from the Sydney Strategic Travel Model

Scenario:	BAU	Fare1	Fare2	Fare3	Fare4	NoRail1	NoRail2	NoRail3
Description								
Year	2006	2006	2006	2006	2006	2006	2006	2006
Road network	Current	Current	Current	Current	Current	Current	Current	Current
Rail services	Current	Current	Current	Current	Current	***None***	***None***	***None***
Bus services	Current	Current	Current	Current	Current	Current	Current	Current
Bus fares	Current	***+10%***	***+20%***	***-10%***	***-20%***	Current	Current	Current
Bus speeds	Current	Current	Current	Current	Current	Current	Current	Current
CBD parking costs	Current	Current	Current	Current	Current	Current	***+50%***	***+100%***
Results								
Passenger km by mode (average weekday) (Million PKT)								
Rail	19.8	19.4	19.1	20.2	20.7	0.1	0.1	0.1
Bus	7.6	7.7	7.7	7.5	7.4	14.6	14.8	14.9
Car	151.8	152.0	152.2	151.5	151.2	169.5	169.3	169.2
~~Ferry~~	~~N/A~~	~~N/A~~	~~N/A~~	~~N/A~~	~~N/A~~	~~N/A~~	~~N/A~~	~~N/A~~
Public transport services (1-hour AM peak)								
Bus km	36,230	36,230	36,230	36,230	36,230	36,230	36,230	36,230
Bus hours	1,672	1,672	1,672	1,672	1,672	1,672	1,672	1,672
Train km	7,501	7,501	7,501	7,501	7,501	0	0	0
Train hours	179	179	179	179	179	0	0	0
Vehicle kilometres travelled (average weekday) (Million VKT)								
0-5 kph	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
5-10 kph	0.6	0.6	0.6	0.6	0.6	1.2	1.2	1.2
10-15 kph	1.7	1.7	1.7	1.7	1.7	2.7	2.8	2.7
15-20 kph	3.8	3.8	3.9	3.8	3.8	5.3	5.3	5.3
20-25 kph	6.9	6.9	6.9	6.8	6.7	9.2	9.1	9.1
25-30 kph	11.2	11.3	11.3	11.3	11.1	13.3	13.3	13.4
30-35 kph	14.3	14.2	14.3	14.2	14.3	16.0	16.0	15.9
35-40 kph	13.9	13.9	13.9	13.8	13.8	14.2	14.2	14.2
40-45 kph	11.3	11.3	11.3	11.3	11.3	11.9	11.8	11.9
45-50 kph	11.3	11.3	11.3	11.4	11.4	12.6	12.7	12.7
50-55 kph	10.6	10.6	10.7	10.6	10.5	10.9	10.9	10.9
55-60 kph	11.3	11.3	11.4	11.3	11.4	11.5	11.5	11.6
60-65 kph	5.2	5.1	5.1	5.2	5.2	5.2	5.2	5.1
65-70 kph	8.5	8.5	8.5	8.4	8.4	8.3	8.4	8.4
70-75 kph	1.8	1.8	1.8	1.8	1.8	2.2	2.1	2.2
75-80 kph	1.8	1.8	1.8	1.8	1.8	1.3	1.3	1.3
80-85 kph	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
85-90 kph	1.6	1.7	1.7	1.7	1.7	1.6	1.6	1.6
90-95 kph	0.2	0.2	0.2	0.2	0.2	0.5	0.5	0.5
95-100 kph	3.2	3.3	3.3	3.2	3.2	3.3	3.3	3.3
Total	120.1	120.3	120.4	120.0	119.8	132.4	132.3	132.2

Global Stats									
	Description	BAU	Fare1	Fare2	Fare3	Fare4	NoRail1	NoRail2	NoRail3
Person Travel									
Person Trips - Linked Trips									
	Car Driver	10,509,000	10,527,000	10,543,000	10,486,000	10,462,000	11,358,000	11,330,000	11,310,000
	Car Passenger	4,414,000	4,421,000	4,428,000	4,404,000	4,394,000	4,770,000	4,759,000	4,750,000
	Train	743,000	726,000	711,000	763,000	785,000	13,000	13,000	14,000
	Bus	770,000	779,000	786,000	762,000	752,000	1,256,000	1,276,000	1,290,000
	Total Trips	16,436,000	16,453,000	16,468,000	16,415,000	16,393,000	17,398,000	17,378,000	17,364,000
Person Kms - Linked Trips									
	Car Driver	112,421,000	112,601,000	112,729,000	112,237,000	112,000,000	125,528,000	125,424,000	125,361,000
	Car Passenger	39,347,000	39,410,000	39,455,000	39,283,000	39,200,000	43,935,000	43,898,000	43,876,000
	Train	19,773,000	19,400,000	19,083,000	20,201,000	20,674,000	137,000	138,000	139,000
	Bus	7,570,000	7,664,000	7,748,000	7,475,000	7,359,000	14,558,000	14,777,000	14,937,000
	Total Kms	179,112,000	179,075,000	179,015,000	179,196,000	179,232,000	184,158,000	184,238,000	184,313,000
Person Hours - Linked Trips									
	Car Driver	3,342,000	3,351,000	3,356,000	3,331,000	3,321,000	3,957,000	3,949,000	3,944,000
	Car Passenger	1,170,000	1,173,000	1,174,000	1,166,000	1,162,000	1,385,000	1,382,000	1,380,000
	Train	545,000	534,000	525,000	558,000	572,000	8,000	8,000	8,000
	Bus	339,000	343,000	347,000	334,000	329,000	641,000	651,000	659,000
	Total Hours	5,396,000	5,402,000	5,402,000	5,390,000	5,384,000	5,992,000	5,991,000	5,992,000
PT Out of Vehicle Hours - Linked Trips									
	Train Waiting	126,000	123,000	120,000	129,000	133,000	2,000	2,000	2,000
	Train Walking	218,000	213,000	209,000	224,000	231,000	3,000	3,000	3,000
	Bus Waiting	103,000	105,000	105,000	102,000	101,000	174,000	176,000	177,000
	Bus Walking	205,000	207,000	208,000	203,000	201,000	313,000	317,000	320,000
Train In Vehicle Hours									
	Train	411,000	403,000	397,000	419,000	429,000	0	0	0
	Light Rail	1,000	1,000	1,000	1,000	1,000	2,000	2,000	2,000
	Ferry	1,000	1,000	1,000	1,000	2,000	0	0	0
	Bus or Car	131,000	127,000	125,000	134,000	139,000	5,000	5,000	5,000
	Total Train In-vehicle	544,000	533,000	524,000	557,000	570,000	7,000	7,000	7,000
Commercial Vehicles (Passenger Car Equivalents)									
	Trips	713,000	713,000	713,000	713,000	713,000	713,000	713,000	713,000
	Distance	18,081,000	18,080,000	18,079,000	18,081,000	18,078,000	18,107,000	18,111,000	18,110,000

Results are not shown above for the runs NoRail4 – NoRail9. Investigation of the average automobile travel speeds in the No Rail scenarios as compared with those in the five less extreme scenarios showed that the reduction was on the order of 10%. Scenarios NoRail4 – NoRail6 presume a 50% reduction in average bus speed, and scenarios NoRail7 – NoRail9 presume a 75% reduction. In light of NoRail automobile speeds, none of these last six NoRail scenarios appears plausible as a description of the characteristics of bus travel.

Several aspects of this result table may be counterintuitive, so a fuller explanation is warranted. First, and perhaps most unexpectedly, the complete elimination of Sydney's commuter rail network does not have a drastic impact on either the total quantum of automobile travel or on the average speed of cars. The reason for this modest effect is that in the status quo case rail journeys represent only 4.5% of total journeys. Rail's share of person kilometres travelled is somewhat higher, 11%, but still relatively low.

The elimination of rail would induce considerable congestion on the main road arteries into the CBD during commuter hours, but this effect is somewhat masked in the total figures by the large number of automobile journeys that do not enter the CBD, and by the significant amount of off-peak travel on the road network. The modelling work does capture this effect, nevertheless, through the breakdown of automobile vehicle kilometres travelled by speed band, from which the congestion information was derived.

The second important observation is that waiting and walking time for public transport represents a very significant proportion of the time spent travelling for rail and bus. For rail, waiting and walking time represents 39% of the total travel time. The value of time calculations performed here do include waiting and walking times for public transport.

The third observation is that there is a significant shift from rail to bus when the rail option is eliminated. The effect is to approximately double the number of person kilometres travelled by bus, and to increase the average journey length of bus commuters. This change takes place because rail commuters travel longer distances on average than bus commuters. Once they are displaced from rail they need to travel further than the pre-existing bus travellers.

The fourth observation is that in the no-rail scenarios, the total quantum of travel increases somewhat compared to the status quo. This result is unexpected. We understand that it is an artefact of some of the SSTM modelling assumptions that are in the process of being refined.[18]

18 A fixed ratio of non-commuter to commuter journeys by automobile is assumed within the SSTM at present. As the number of automobile commuter journeys increase in response to the elimination of the rail option, the number of non-commuter automobile journeys is also increased by this fixed ratio.

7. TRAFFIC CONGESTION EXTERNALITIES

Road congestion occurs when the volume of traffic exceeds the maximum level at which traffic can flow at the normal speed limit. It is caused by the interference between vehicles. Congestion imposes both internal and external costs on motorists.

In contrast, a timetabled passenger railway service does not experience congestion as there is no interference between trains. Train movements are coordinated at the time the timetable is established and centrally controlled in real time.

It is important to distinguish between the internal and external costs of road congestion. This distinction is perhaps most easily explained with reference to the cost of fuel consumed by private motorists. Under congested conditions, when one new motorist decides to join the traffic system, the cost of fuel to that motorist is a private cost. It includes the cost of the fuel that would have been consumed undertaking that journey under free-flow (uncongested) traffic conditions and the cost of the additional fuel that is consumed waiting in queues.

That motorist's decision to join the traffic system also increases the delays experienced by the other motorists who were already using it. As a consequence, the other motorists consume additional fuel waiting in queues. The cost to these existing road users of the additional fuel consumed because of the first motorist's decision to drive is an externality.

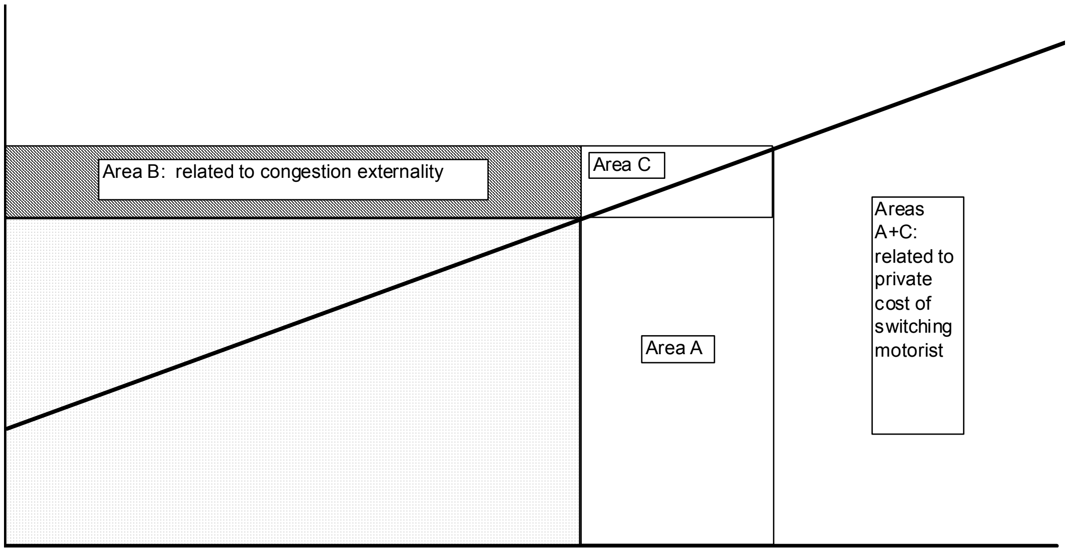
Exactly the same argument applies to the cost to motorists and their passengers of their own commuting time. The mode-switching motorist (the marginal driver) presumably knows and accepts the personal cost of the decision to drive in terms of her own travelling time. That cost is presumably taken into account when weighing the pros and cons of travelling by car or by train, along with the price of fuel and car ownership, the rail fare, the time penalty associated with rail travel (including time in the train, time waiting for the train, and time walking to and from the train stations at each end of the journey). In a sense, the marginal motorist's travel time is part of the general cost of automobile travel that is compared to the general cost of train travel in order to make the mode choice decision. Therefore the marginal motorist's own travel time is an internal cost which is already taken into account in establishing the demand schedule for rail travel.

The pre-existing motorists (inframarginal drivers) suffer a new increment of cost as a result of the marginal driver's decision to join. The inframarginal motorists take longer to make the same journey as a direct result of the marginal motorist's decision. The personal cost of the inframarginal motorists' own additional commuting time and fuel consumption is an external cost that is not reflected in the demand or supply schedules for rail travel. This aspect of the automobile travel time and cost of fuel consumed is the true congestion externality which is quantified in this chapter.

7.1. METHODOLOGY FOR QUANTIFYING CONGESTION EFFECTS

In order to develop the intuition behind the methodology, we focus first on the distinction between internal and external costs associated with automobile travel time. Let us suppose that the number of person-hours of automobile commuting time per person-kilometre travelled increases as the total number of automobile person-kilometres increases. Such an effect would be expected as a given fixed road network approached congested conditions.

The ratio (person-hours/person-kilometres) or (aph/apk) would be an increasing function of apk. The various costs can be interpreted as areas in the diagram below.



The horizontal axis represents automobile person-kilometres travelled (apk). The vertical axis represents automobile person-hours per apk. The sloping line represents the ratio (aph/apk), which increases as apk increases.[19] For any value of apk0, a rectangle with its lower left corner at the origin, its right-hand side at x = apk0, and its upper right corner lying on the sloping line has an area that is equal to the total number of automobile person hours of travel time corresponding to apk0 automobile person kilometres travelled. To see this, note:

$$\text{Area} = XY = (\text{apk0})(\text{aph}/\text{apk}) = \text{aph}_{\text{apk0}}$$

19 In this report we assume, in fact, that automobile person hours is a quadratic function of automobile person-kilometres travelled. We estimate the quadratic coefficients from empirical data derived from the SSTM later in this chapter.

Let the area of the rectangle with light shading represent aph_{apk0}. An increase in apk will increase the total automobile travel time by the sum of areas A, B, and C. Assume that the increase in apk takes place because more motorists join the road network. Areas A and C represent the travel time of these marginal motorists. As discussed, the cost of this travel time is internal.

Area B (shaded with diagonal lines) represents the additional travel time experienced by the inframarginal motorists as a result of the decision of the marginal motorists to join. The value of time multiplied by area B is the external cost associated with the marginal motorists' decision.

In order to quantify the effect of the Sydney rail system in reducing congestion costs incurred by motorists, we employed the SSTM to simulate traffic conditions resulting from different levels of rail fare and patronage. Of particular interest in quantifying congestion is the relationship between total automobile person travel time and total automobile person-kilometres travelled as reductions in rail patronage cause roads to become more crowded. Knowing the distribution of vehicle-kilometres by speed band in each SSTM scenario, congestion costs are obtained as the product of the increase in travel time, modelled vehicle occupancy, an assumed value of travel time, and vehicle-kilometres.

The distinction between internal and external travel time costs, noted above, can be made if the ratio (aph/apk) can be determined as a function of apk. The SSTM scenario runs permit this determination to be made.

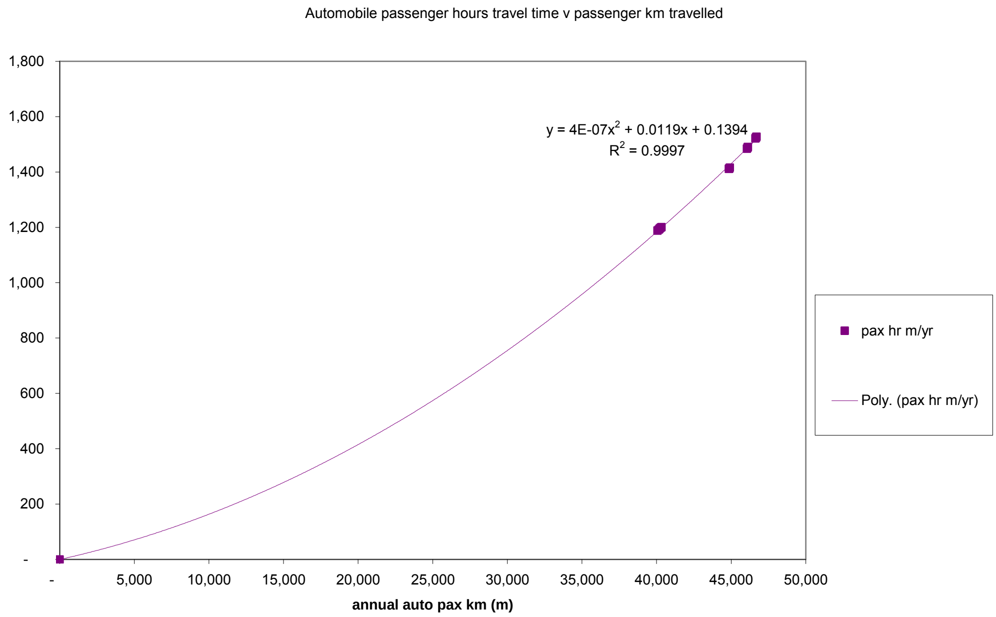
This approach is more specific to the Sydney road network in reference year 2006 than many other studies of road congestion externalities, which typically take published national total values and simply divide by the number of vehicle kilometres to obtain an average congestion cost per vehicle kilometre. Approaches of that type are less satisfactory for studies of particular cities because each urban transport network has its own unique geo-spatial features and commuting patterns—all of which are captured for Sydney in the SSTM.

7.2. DATA SOURCES AND ISSUES FOR CONGESTION EFFECT ESTIMATION

The data we rely on to estimate congestion effects is embedded in the Transport Data Centre's Sydney Strategic Travel Model. We do not propose to perform any independent review of the SSTM inputs. We take them to be widely accepted values.

7.2.1. Person hours per automobile person kilometre

The chart below plots an empirical relationship between automobile person hours and automobile person kilometres travelled. Each data point represents a single SSTM run. A point at the origin has been added to the data set. Presumably there will be zero person hours when there are zero person kilometres travelled. A quadratic curve of best fit is superimposed on the diagram.



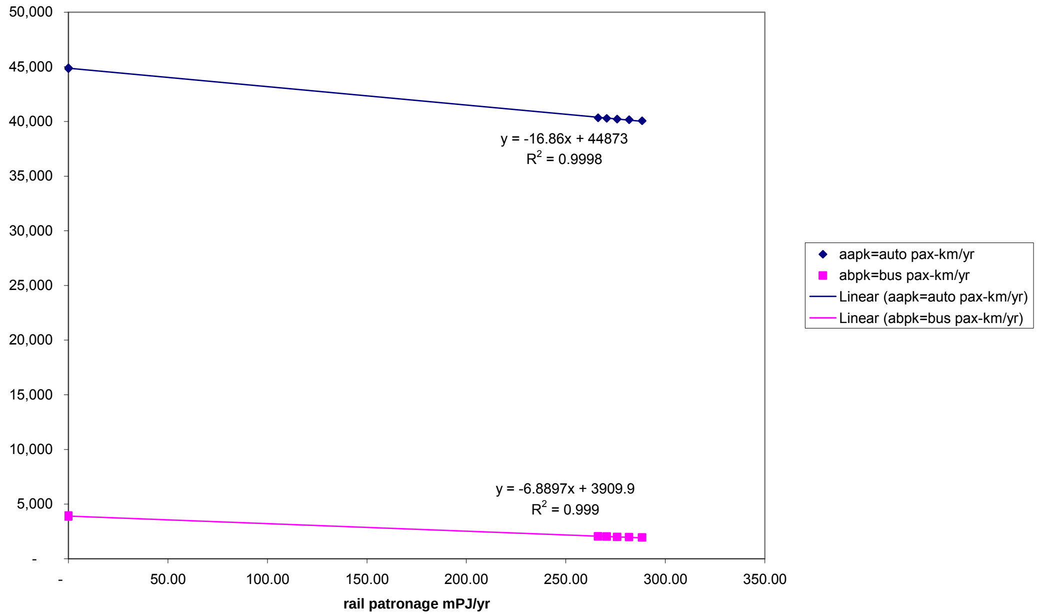
Noting that the constant term in the best quadratic fit is approximately zero, the ratio (aph/apk) is a linear function of apk, with slope = 4.38e-7 pax-hrs/(pax-km)^2 and y-intercept = 0.012 pax-hrs/pax-km.

Knowing this slope and y-intercept, it is possible to calculate the marginal external benefit associated with an incremental change in rail patronage, Δq. First, note that the SSTM runs established a linear relationship between a change in rail patronage, q, and automobile passenger kilometres travelled, apk.

apk = slope_apk * q + yint_apk

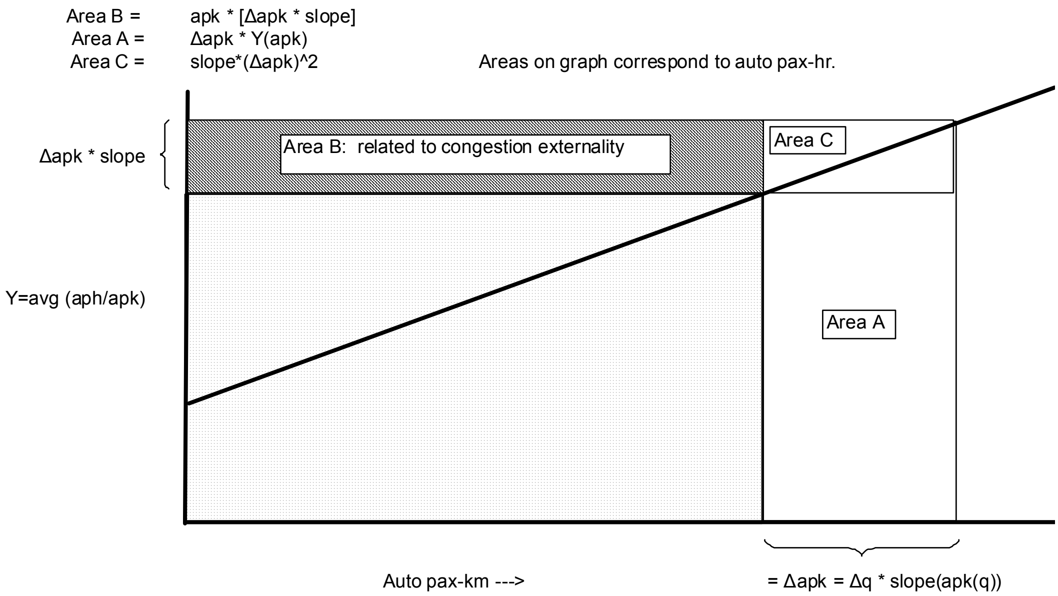
The relationship between rail and auto usage is depicted in the chart below. Each SSTM scenario is represented with a single point. The relationship of bus passenger kilometres (bpk) to rail patronage, which is linear as well, is also shown.

bpk = slope_bpk * q + yint_bpk



The slope of these lines is negative, reflecting the fact that both automobile and bus usage are substitutes for rail usage. As an aside, while it cannot be seen from this graph, which compares road passenger kilometres to rail passenger journeys, the relationship between rail and automobile passenger journeys is not one-to-one, reflecting the fact that the total number of passenger journeys across all modes combined changes when the cost and benefit profile of the modal options changes.

We adopt these best-fit lines to establish a linear relationship between Δq and Δapk. In the chart below, it is Area B that represents the additional hours of automobile travel time imposed on inframarginal motorists by the decision of marginal motorists to drive.



For small values of Δq, the passenger kilometres travelled by marginal motorists, Δapk, will also be small. Area B is calculated as follows:

$$\text{Area B} = \text{apk} * \Delta\text{apk} * \text{slope of line (aph/apk)}$$

$$= \text{apk} * \Delta\text{apk} * 4.38\text{e-}7 \text{ pax-hrs/(pax-km)}^2$$

$$= (\text{slope\_apk}*q+\text{yint\_apk})*(\Delta q*\text{slope\_apk})* 4.38\text{e-}7 \text{ pax-hrs/(pax-km)}^2$$

$$= \Delta q*(q*\text{slope\_apk}^2+\text{yint\_apk}*\text{slope\_apk}) * 4.38\text{e-}7 \text{ pax-hrs/(pax-km)}^2$$

The marginal external benefit ("meb(q)") associated with a small increment of additional rail patronage consists, inter alia, of the travel time savings to inframarginal motorists from the reduced congestion. The value of this component is:

$$\text{meb}(q)_{\text{auto travel time}} = \text{VOT} * \partial\,(\text{Area B})/\,\partial q$$

$$= \text{VOT} * (q*\text{slope\_apk}^2+\text{yint\_apk}*\text{slope\_apk}) * 4.38\text{e-}7$$

$$= \text{VOT} * ((-16.86)^2\, q - 16.86*44{,}873)*4.38\text{e-}7$$

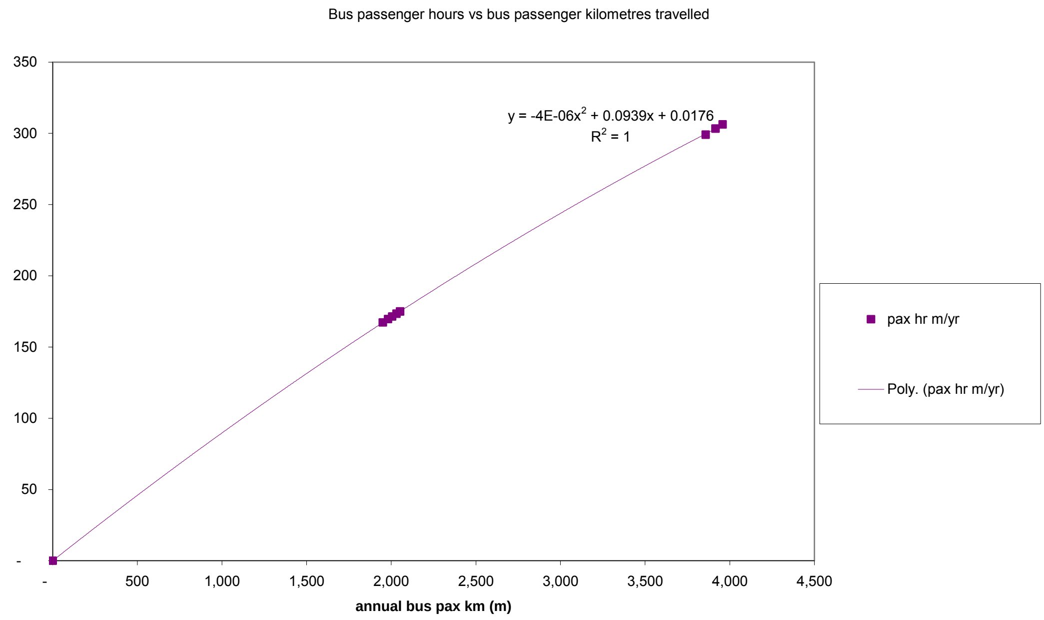
$$= \text{VOT} * (1.245\text{e-}4\, q - 0.33)$$

Where VOT is the value of time in \$/person-hr. Published values for that input are discussed later in this chapter.

7.2.2. Person hours per bus person kilometre

In theory, travel time savings to bus users constitute an additional component of meb(q), which could be estimated using the same procedure as just applied to automobile time savings. The chart below plots bus passenger hours versus bus passenger kilometres travelled. Again, a best-fit quadratic equation is superposed.

Perhaps surprisingly, the quadratic term of the best-fit equation has a negative sign, meaning that the average time per bus passenger kilometre decreases as the number of bus passenger kilometres increases. This result is not the expected consequence of increasing road congestion.



Close inspection of the SSTM scenarios reveals that a reduction in rail patronage leads to an increase in the number of bus passenger journeys, and also to an increase in the average distance travelled per bus journey—presumably because new bus passengers switching from rail travel longer distances to work.

The No Rail scenarios on which we focus here involve no change to average bus speeds relative to the business as usual scenario. This implies that the bus in-vehicle-time per kilometre travelled remains constant across scenarios.

For buses, part of the journey time is spent walking to and from bus stops and waiting for the bus. There is no counterpart to these time elements for private motoring as it is assumed that motorists park at home and near work, spending the entire commuting time in their cars.

As rail patronage decreases, bus passenger-kilometres travelled increase more than proportionally because of this increasing journey distance effect. While bus in-vehicle-time per kilometre travelled remains constant, the walking and waiting time decreases on a per kilometre basis. It is this latter effect which leads to the decline in bus passenger hours per passenger kilometre as bpk increases.

If one were to accept this logic, the bus travel time effect would work in the opposite direction to the automobile travel time effect of congestion. However, the apparent effect on average bus journey lengths appears to be the result of new bus passengers (who were previously rail passengers) taking longer journeys than the inframarginal bus passengers. It does not seem likely that inframarginal bus passengers would travel longer distances on the bus than they did previously simply because the roads have become more congested.

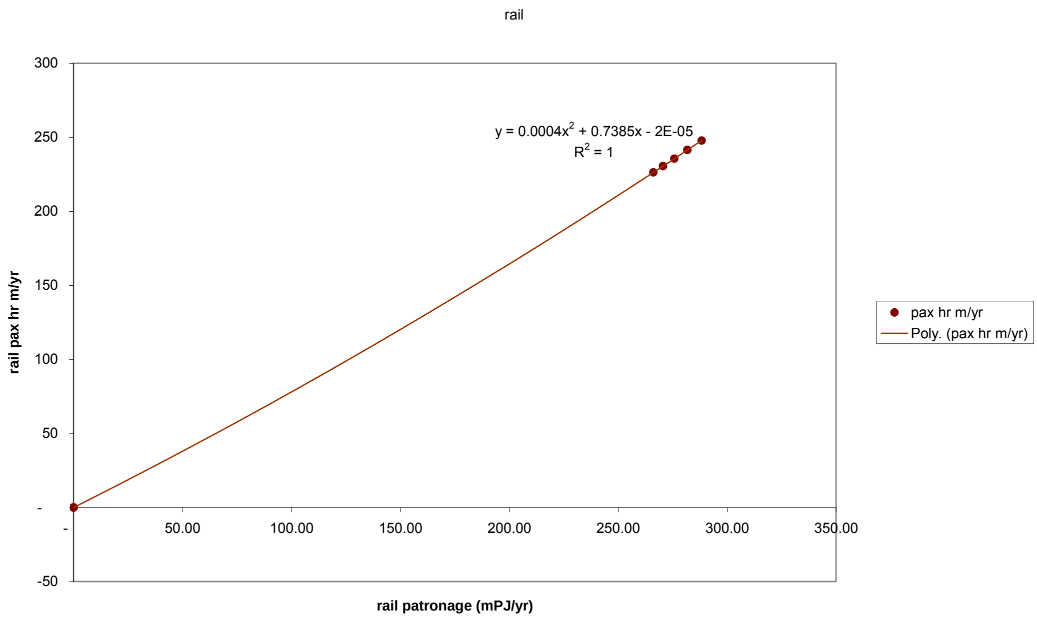
If that is the case, then the calculated decrease in bus passenger hours per passenger kilometre as bpk increases is not an external effect. Rather it is an effect experienced only by the marginal bus passengers. It is internal to the mode choice decision of these marginal commuters.

Therefore we assume that the observed relationship between bus passenger hours and bpk is neither an external benefit nor cost associated with rail patronage. We assume instead that the marginal external benefit associated with bus passenger VOT is zero. For the inframarginal bus passengers, as for the inframarginal automobile passengers, increasing congestion on the roads will mean longer travel times for the same journey. Unfortunately we are unable to quantify this effect, given our assumption that bus speeds do not change in the no-rail scenario. It is possible to say, nonetheless, that by omitting the bus travel time effect from the calculation of meb(q), the marginal external benefit of rail is, if anything, understated.

7.2.3. Person hours per rail passenger journey

So far the discussion has considered travel time effects on other modes of a change in rail patronage. Congestion per se does not affect trains because of the timetabled and centrally coordinated nature of train movements. Nevertheless, it does seem intuitively plausible that as increasing patronage makes trains and railway stations more crowded, rail travellers will experience increasing delays.

This rail travel time effect is an external cost of rail transport which must be balanced against the external benefits of a modal shift toward rail. It must be quantified so it can be netted off against the external benefits to rail from reduced road congestion. Travel time dissavings to rail users constitute an additional component of meb(q). They may be estimated using the same procedure as just applied to automobile and bus time savings. The chart below plots rail passenger hours versus rail passenger journeys. Again, a best-fit quadratic equation is superposed.



The component of meb(q) representing the rail travel time effect is given by:

$$meb(q)_{\text{rail travel time}} = VOT * \partial \text{ (Area B)} / \partial q$$

$$= VOT * q^* (- 4.20e\text{-}4)$$

7.2.4. Value of travel time

In order to convert the SSTM outputs into dollar values of marginal external benefit it is necessary to establish values of travel time, and then apply them to the passenger hours for inframarginal users calculated for each mode in each model run.

The range of values of travel time used in sensitivity analysis was:

- A low value of $9.23/hr, representing the value per occupant of travel time for private use of a car;[20] and
- A high value of $22.60/hr, representing a weighted average of business and private travel in passenger cars in urban areas.[21]

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20 Centre for International Economics (August 2006), "Business costs of traffic congestion," Prepared for Victorian Competition and Efficiency Commission, Table 4.1, p. 20.

Both reference sources cite a 2004 Austroads publication as the primary source.[22]

In order to compare these values with hourly rates of pay, we note that, according to the ABS catalogue number 6306.0, “Employee earnings and hours, Australia, May 2006,” the average hourly rate of pay across all full-time employees, for ordinary time was $26.00/hr. Ordinary time best matches the CityRail peak commuter travel profile. ABS catalogue number 6302001 indicates that average weekly earnings for persons in full-time work during ordinary hours increased by 7.7% between May 2006 and February 2008, suggesting that the February 2008 hourly rate of pay had increased to $28.01/hr. ABS catalogue number 63020011a permits an inference to be made of the NSW average weekly earnings compared to the Australian average weekly earnings in both May 2006 and February 2008. Putting this information together, a February 2008 NSW average hourly rate of pay for persons in full-time employment during ordinary hours of $28.80/hr is derived. The ABS does not routinely collect city-specific data on hourly wages or weekly earnings, so it is difficult to make this figure more geographically specific than NSW.

The low time valuation of $9.23/hr would be approximately 32% of this $28.80 hourly wage figure, and the high time valuation of $22.60/hr would be approximately 78% of the hourly wage. It is relatively common practice to link the value of travel time to the prevailing hourly wage, however the literature reveals considerable dispersion in the measured ratio of value of time to hourly wage. For example, BTE Occasional Paper 51 calculates and presents the ratio of value of travel time to average wage rate implicit in the travel time valuations contained in a range of studies.[23] Table 8.1 in that paper presents the ratio for business values of travel time. Of the 27 references cited there that are not assumed values, the mean ratio is 83.8%, the median ratio is 76%, and the standard deviation is 62.7%. Table 8.3 presents the ratio for commuter values of travel time. Of the 71 references cited there that are not assumed values, the mean ratio is 43.5%, the median ratio is 35%, and the standard deviation is 25.8%.

For business travel, the median ratio applied to the $28.80/hr wage would be $21.89/hr. For commuter travel, the median ratio applied to the hourly wage would be $10.08/hr. There is necessarily a degree of imprecision in these ratios. Rather than attempt to refine the estimates further, we adopt a central case value of time of $13.15/hr, which lies between the median ratios for business and commuter travel applied to the hourly rate, but somewhat closer to the commuter median. For sensitivity testing we retain the range mentioned above: low valuation of $9.23/hr and high valuation of $22.60/hr.

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21 Marschke, K., L. Ferreira, J. Bunker (2005), “How should we prioritise incident management deployment?,” Proceedings 28th Australasian Transport Research Forum, Sydney, Table 4, p. 7.

22 Austroads (2004). Guide to Project Evaluation Part 4: Project Evaluation Data. Sydney.

23 “The Value of Travel Time Savings in Public Sector Evaluation,” BTE Occasional Paper 51, AGPS, Canberra, 1982.

Separate values of time for motorists, bus passengers and rail passengers[24] have not been adopted, but the analytical framework set out here could easily be adapted to reflect mode-specific values of time.

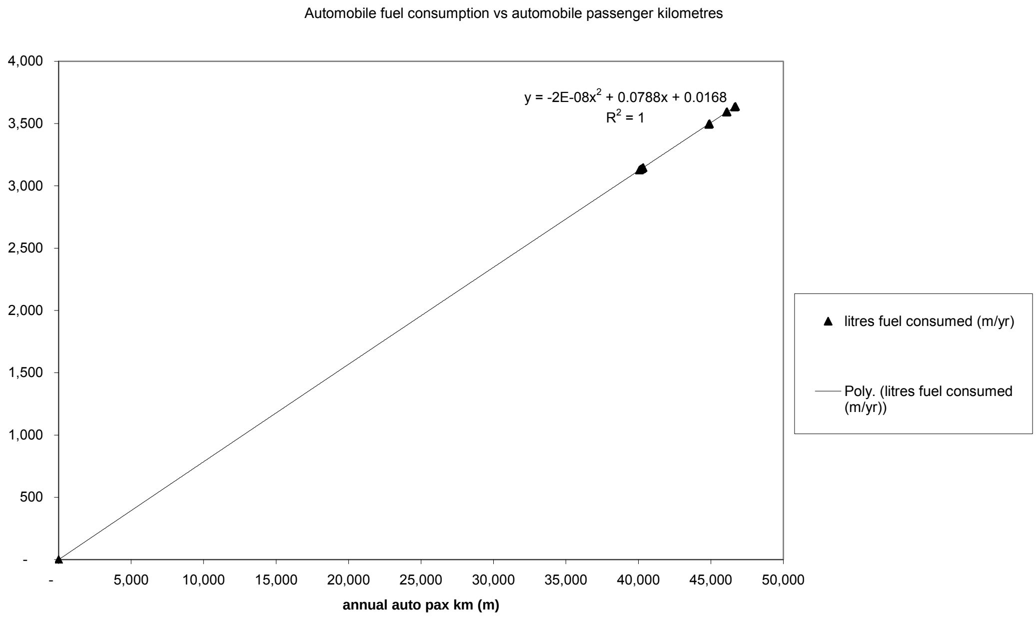
7.2.5. Fuel consumption per person kilometre

There are several distinct external costs associated with fuel consumption, including those involving air pollution. Here we consider only one of these: the cost to inframarginal motorists of purchasing the additional fuel that is consumed as a result of traffic congestion. Air pollution externalities will be discussed in chapter 8 below.

We assume that the rate of bus fuel usage per bus passenger kilometre is constant. This assumption is motivated by the SSTM modelling assumption that the bus fleet and timetable frequencies will be adjusted as needed to meet the demand for bus travel. This adjustment seems likely to be done in such a way that load factors are maintained at relatively constant average levels. With constant load factors and constant average bus speeds across the scenarios considered here, the rate of bus fuel usage per bus passenger kilometre is likely to be constant. That being the case, the decision by a marginal bus user to travel by bus will not increase the amount of fuel consumed per inframarginal bus user journey. Thus the bus fuel purchase externality would be zero under the assumptions adopted here.

Nevertheless, fuel consumption savings by inframarginal motorists as a result of the congestion-reducing effect of increasing rail patronage constitute an additional component of meb(q). It may be estimated using the same procedure as applied to automobile time savings. The chart below plots automobile fuel consumption versus apk. A best-fit quadratic equation is superposed.

24 There is some evidence that automobile commuters tend to have higher valuations of travel time than public transport commuters, possibly because average incomes are higher among motorists.



Perhaps surprisingly, the quadratic term of the best-fit equation has a negative sign, meaning that the average fuel consumed per automobile passenger kilometre decreases as the number of automobile passenger kilometres increases. This result is not the expected consequence of increasing road congestion.

Close inspection of the SSTM scenarios reveals that a reduction in rail patronage leads to an increase in both the number of automobile passenger journeys and average vehicle occupancy. As rail patronage decreases, automobile vehicle kilometres increase less than proportionally to the increase in automobile passenger kilometres because of this increasing vehicle occupancy. While congestion does indeed increase the fuel consumed per vehicle kilometre, the increasing vehicle occupancy effect works in the opposite direction on consumption per person-kilometre. The net effect is a decline in automobile fuel consumption per passenger-kilometre as apk increases.

Accepting this logic, the automobile fuel purchase cost externality works in the opposite direction to the automobile travel time effect of congestion. The component of meb(q) representing the auto fuel purchase cost effect is given by:

$$meb(q)_{\text{auto fuel purchase cost}} = (\$/\text{litre fuel price}) * \partial\,(\text{Area B})/\,\partial q$$

$$= (\$/\text{litre}) * (q*slope\_apk^2 + yint\_apk*slope\_apk) * (-\ 1.86e\text{-}8)$$

$$= (\$/\text{litre}) * ((-16.86)^2\ q - 16.86*44{,}873)* (-\ 1.86e\text{-}8)$$

$$= (\$/\text{litre}) * (-\ 5.11e\text{-}6\ q\ - 0.014)$$

Where ($/litre) is simply the current price of petrol. Adopting a current value of approximately $1.40/litre for the price of petrol, this auto fuel purchase marginal external cost of rail transport is approximately $0.02/PJ for all values of q between 0 and 370mPJ/yr.

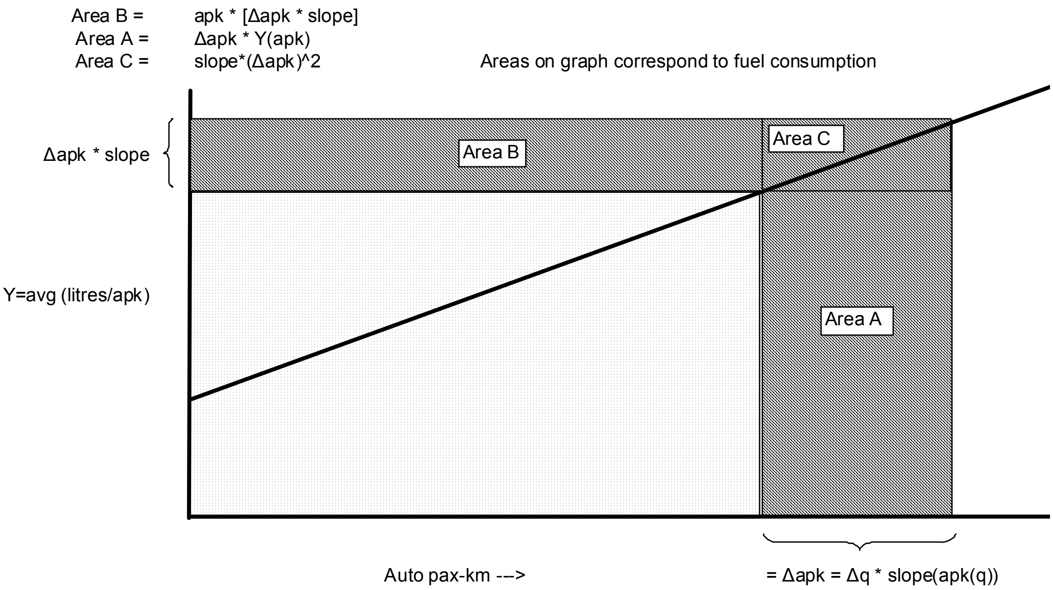
8. EMISSION EFFECT EXTERNALITIES

Automobile and bus emissions contribute to two recognised types of social cost: increased health risk from conventional pollutants and increased risk of environmental harm from greenhouse gases. The quantity of each pollutant dispersed into the atmosphere varies directly with the quantity of fuel consumed.[25] Therefore fuel consumption is the metric best suited to link the quantum of commuter transport in Sydney with the air pollution it causes.

It is important to note that every litre of fuel consumed creates some external effect via air pollution. The effect is external because the sufferers of air pollution (persons inhaling it and becoming unwell, or persons affected by global warming) are, in the overwhelming majority, different people to the car drivers whose modal choice caused the pollution. Put another way, every gram of carbon monoxide and every tonne of carbon dioxide has an effect on a great many people.

This situation may be contrasted to the fuel purchase cost externality referred to in chapter 7 above. The fuel purchase cost is only a congestion externality for the extra fuel that an inframarginal motorist consumes as a result of congestion. The emission externalities apply to every litre of fuel consumed, including litres consumed by marginal motorists. The distinction can be seen clearly in the diagram below.

25 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. We ignore these second-order complications.



The litres of fuel consumed that contribute to the emission externality are represented by the sum of areas A, B, and C, shaded with diagonal lines. The calculation of this sum of areas proceeds in the same way as the calculation of area B was done for the fuel purchase cost congestion externality in chapter 7. The necessary information was derived there from the relationship between automobile fuel consumption and apk, and the relationship between bus fuel consumption and bpk.

8.1. METHODOLOGY FOR QUANTIFYING EMISSION EFFECTS

The empirical determination we wish to make is whether CityRail reduces the costs of emissions and by how much. We are not attempting to endogenize this calculation.[26] The emissions externality calculation will be performed once the change in road vehicle kms is determined by the SSTM runs. The core steps in the analytical approach are:

1. Estimate the fuel savings per passenger-kilometre associated with a mode shift from private vehicle 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.

26 In other words, the impact of carbon pricing on fuel prices is not taken into account in this analysis.

Regarding greenhouse gas emissions, we assumed that the pre-2010 cost sharing arrangements apply, there are no ETS in place and therefore we simply value the emissions externality avoided.

However, if we were taking a longer term perspective beyond 2010, then we would need to consider the feedback effects from a carbon price into fuel costs (relative rail and road fuel costs) and rail fares. Given that increased fuel prices infer some degree of internalisation of the externality associated with carbon emissions, we would probably need to reconsider the question about whether any of that additional cost should be borne by government with respect to rail fares.

We note that Rail consumes energy in production (equipment, tracks, and so on) and operation, and emits pollution in doing so. We adopt values published in Karpouzis et. al. for the negative externalities imposed by CityRail.

8.2. DATA SOURCES AND ISSUES FOR EMISSION EFFECT ANALYSIS

8.2.1. Fuel consumption

Fuel consumption was estimated as follows. The web site:

http://www.climatechange.gov.au/cgi-bin/transport/fuelguide/fuelguide.pl?querytype=advancedquery&min_cons=&max_cons=&manufacturer=any&year=2003&transmission=any&fuel=any&vehicletype=any&model=&minenginesize=&maxenginesize=&mincityfuel=&maxcityfuel=&minhighwayfuel=&maxhighwayfuel=&sort1=manufacturer&sort2=year

contains highway and city consumption figures for each of approximately 980 different 2003 models of passenger cars in use in Australia. The simple average of highway consumption of these vehicles was 7.2 litres per 100 km. The average of city consumption was 10.8 litres per 100 km.

We assumed that the city consumption figure applied to the speed band between 30 and 35 km/hr,[27] and that the highway figure was relevant to the speed band between 80 and 85 km/hr. Fuel consumption rates for other speed bands was calculated by linear interpolation between these points and extrapolation for higher and lower values. The resulting fuel consumption rates are shown below.

27 SSTM model runs predicted a business as usual average automobile speed of 37km/hr, which dropped to approximately 34km/hr in the no-rail scenarios for typical working days in Sydney.

Speed band km/hr		litres fuel consumed by cars / vkm
min	max	
0	5	0.130
5	10	0.126
10	15	0.122
15	20	0.119
20	25	0.115
25	30	0.112
30	35	0.108
35	40	0.104
40	45	0.101
45	50	0.097
50	55	0.094
55	60	0.090
60	65	0.086
65	70	0.083
70	75	0.079
75	80	0.076
80	85	0.072
85	90	0.068
90	95	0.065
95	100	0.061
100	105	0.058
105	110	0.054

8.2.2. Cost of greenhouse gas emissions

The assumed relationship between fuel consumption and the quantity of CO2 emitted was 2.64 kg CO2 per litre of petrol consumed. That figure is between the fuel conversion rates cited by

www.nqclimatealliance.org.au/Business_Travel_ServiceSector_v2.0_Final.xls

for petrol (2.34) and diesel (2.68).

Given our short-term, ie prior to 2010, emphasis we could have used the NSW NGAC (NSW Greenhouse Abatement Certificate) price, currently around A$12/tCO2e. If one were looking at a longer term perspective then one would need to make some assumptions about the carbon price under a national emissions trading scheme (ETS) – likely to be in the order of about $10/tCO2e.

For our analysis we have adopted a higher carbon price of $25/tonne CO2.

8.2.3. Cost of conventional pollutant emissions

Maddison, et. al.,[28] surveyed the literature on a range of external costs of road transport. Those authors (citing Calthrop, 1995) present an estimated marginal external health cost per litre of unleaded petrol of 9 pence sterling in 1993. The marginal external health cost per litre of diesel was 84 pence sterling in the same year.[29] We convert these values to Australian dollars, but do not apply an inflation adjustment for the time difference.[30]

9. ACCIDENT IMPACT EXTERNALITIES

By reducing automobile usage, CityRail reduces the likelihood of traffic accidents. Published figures are readily available on the rate of accidents per vehicle kilometre, and the total costs imposed by these accidents. However, it is important to distinguish between internalised accident costs and external costs. The accident externality phenomenon involves two complications that must be considered.

First, some of the costs of accidents are borne by the accident victims. If the accident victim is a marginal motorist (i.e., one who decides to switch from train to car commuting or vice versa) then the probability-weighted cost to that victim of the accident is an internal cost, not an externality. This logic applies whether the accident cost is a cash cost (vehicle repairs or property damage), or the loss of quality of life associated with permanent incapacitation or death. The latter may be difficult to quantify, but it is a cost to the marginal motorist associated with the decision to drive—not an externality.

The fact of automobile accident insurance tends, if anything, to internalise more of the accident-related costs.[31] For example, third party injury and property damage insurance brings the costs borne by non-motorists who are injured or lose property in a car accident into the motorist's modal choice calculation.

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28 Maddison, D., D. Pearce, O. Johansson, E. Calthrop, T. Litman, and E. Verhoef, The True Costs of Road Transport, CSERGE, London, 1997.

29 Maddison, et. al., 1997, Box 4.11, p. 76.

30 As these marginal external health costs are based on research in the United Kingdom, where population densities are higher, the dose-response relationships are not likely to be exactly the same as for traffic in Sydney. Given this inexactness, it did not seem appropriate to perform a precise calibration for inflation effects.

31 This statement assumes, of course, that the insurance industry is workably competitive so that insurance premiums change in response to changes in accident costs.

Nevertheless, there remain some types of accident-related costs that are borne by the community at large, rather than the marginal motorists, even when insurance premiums are taken into account. The standby capacity at public hospitals for accident victims, police and emergency services, traffic congestion caused by accidents, and the uninsured detriment to the quality of life of third parties are examples of these external costs of traffic accidents.

The second complication is that one must establish a quantitative relationship between the incidence of traffic accidents and the number of automobile (and bus) passenger kilometres travelled. This link is difficult to establish empirically, beyond making the intuitively obvious observations that the likelihood of accidents should generally increase with automobile passenger kilometres travelled, and that higher average speeds should lead to more frequent and more severe accidents. In the absence of detailed information on this relationship, the most plausible simplifying assumption is that the incidence of accidents is proportional to apk or bpk.

If the assumption is made of a constant accident rate per apk (or per bpk), then the complication arises because inframarginal motorists (or bus passengers) do not experience any increase at all in their accident risk as apk (or bpk) rises. In other words, because of this assumption, all of the increased accident risk caused by the marginal motorist is internal to the marginal motorist's modal choice decision. There is no external accident cost.

Note that this counterintuitive conclusion is dependent on the assumption that the accident rate per apk is constant. There may be grounds to believe that the accident cost per apk falls as apk increases: congestion slows the traffic, making it easier to avoid accidents and lessening the severity of those accidents that do occur. It is not clear from the available material that the traffic accident externality is necessarily a point in favour of increasing CityRail patronage.

It is recognised that this finding runs counter to the conventional wisdom on accident externalities. There is no denying that increasing usage of automobiles increases the total cost of accidents, some varying proportion of which may be borne externally to the marginal motorists with whom we are concerned. However, when calculating the marginal external benefit to CityRail usage the best that can be said is that it is too close to zero to measure accurately with the information available, and possibly it is negative.

The total external benefit of accident avoidance through current total levels of CityRail patronage is likely to be large, but the marginal external benefit from an incremental increase in CityRail patronage is too small to measure reliably.

Finally, it is worth noting as well that rail accidents occur, and that these sometimes involve fatalities and serious injury. The Bureau of Transport Economics' Report 108 (2002) examined rail accidents in Australia. That report identified level crossing collisions with motor vehicles and suicides as by far the most prevalent form of fatal accident for rail in Australia. Arguably, neither of these categories are applicable to the number of fatal accidents caused by CityRail conducting its commuter transport operations. There are virtually no level crossings in the CityRail area covered by this study. Given the nature of suicide it appears unlikely that the suicide rate is affected by the level of patronage on CityRail. Actual train crashes involving death of passengers or other commuters are exceedingly rare, and the average number of rail passengers killed each year in CityRail train crashes pales into insignificance compared to the number of road fatalities. For these reasons we do not include any amount for the dollar value of external costs imposed by rail accidents.[32]

9.1. METHODOLOGY FOR QUANTIFYING ACCIDENT IMPACT EXTERNALITIES

Given the problems just noted with measuring the marginal external benefits of rail in reducing accident costs, we do not attempt a quantification of $meb(q)_{road\ accidents}$. Nevertheless, to shed some light on the magnitude of total external benefits of traffic accident avoidance, the following approach could be used.

BTRE 2000, Road Crash Costs in Australia, Report 102 provides a summary breakdown of all road crash costs for 1996 by cost type. For each cost type, a judgement is made in the table below of the proportion of that cost that would be covered by insurance. The remaining portion of costs is assumed to represent an estimate of the costs not borne by the marginal motorist. What is not clear is whether these costs would increase more than proportionally with increasing automobile or bus passenger kilometres. In fact, they may increase less than proportionally, either because:

- congestion-induced traffic slowing would make roads safer, or
- higher vehicle occupancy with higher apk would lead to fewer accidents per passenger km if the accident rate per vehicle km was constant.

32 For example, there were 1037 driver fatalities in road crashes in 1996 Australia-wide. The last fatal crash on CityRail was the Waterfall derailment in January 2003 which killed 7 people. Prior to that the Glenbrook accident in 1999 claimed a similar number of lives.

Source of total costs: BTE report 102 "Road Crash Costs in Australia" p. xi

Human costs $million	Total cost	guessed % insured	internal cost	external cost
Medical/ambulance/rehabilitation	361.00	100%	361.00	-
Long-term care	1,990.00	50%	995.00	995.00
Labour in the workplace	1,625.00	50%	812.50	812.50
Labour in the household	1,494.00	0%	-	1,494.00
Quality of life	1,769.00	0%	-	1,769.00
Legal	813.00	0%	-	813.00
Correctional services	17.00	0%	-	17.00
Workplace disruption	313.00	0%	-	313.00
Funeral	3.00	0%	-	3.00
Coroner	1.00	0%	-	1.00
Total	8,385.00			
Vehicle costs				
Repairs	3,885.00	100%	3,885.00	-
Unavailability of vehicles	182.00	50%	91.00	91.00
Towing	43.00	100%	43.00	-
Total	4,110.00			
General costs				
Travel delays	1,445.00	0%	-	1,445.00
Insurance administration	926.00	100%	926.00	-
Police	74.00	0%	-	74.00
Non-vehicle property damage	30.00	0%	-	30.00
Fire and emergency services	10.00	0%	-	10.00
Total	2,485.00			
Overall total	14,980.00		7,113.50	7,867.50
Note All figures in $m 1996 dollars				
1996 b vehicle km	166.45		166.45	166.45
total cost $/m vehicle km	90.00		42.74	47.27
	TOTAL		Internal	External
Ratio of external cost to total=	52.5%			

9.2. DATA SOURCES AND ISSUES IN ACCIDENT IMPACT ANALYSIS

Historical data on the range of severity of accidents and the range of costs per accident could be applied to determine expected values of accident-related cost per car kilometre travelled. The data employed to estimate accident impacts were sourced primarily from the Australian Transport Safety Bureau (ATSB) and BTRE, particularly BTRE 2000, Road Crash Costs in Australia, Report 102. BTRE obtained data on the number of fatalities and serious injury traffic accidents from the ATSB. Estimates of the number of minor injury and property only damage crashes was obtained from insurance reports.

Based on these sources, crash types were classified as either:

- Fatal ($1.7m per incident average total cost in 1996 dollars);

- Serious ($408,000 per incident);
- Minor ($14,000 per incident); or
- Property damage only ($6,000 per incident).

The dollar value assigned to each accident of a given type is shown in parentheses above. The assumed incidence of automobile accidents was derived from tables contained in the BTRE report as shown:

Source: BTE Report 102, p. xii

crash type	cost 1996 ($b)	avg cost /crash	implied #crashes	cost $/mvkt	#crashes /bvkt
FATAL	2.92	1700000	1,718	17.54	10.32
SERIOUS	7.15	408000	17,525	42.96	105.28
MINOR	2.47	14000	176,429	14.84	1,059.93
PDO	2.44	6000	406,667	14.66	2,443.14
TOTAL	14.98		602,337	90.00	3,618.67

Source: BTE Report 102, p. 6

veh type	driver fatalities	fatal/bvkt	implied bvkt
car	770	5.08	151.57
motorcycle	179	117.3	1.53
rigid truck	55	8.18	6.72
articulated	33	6.48	5.09
bus	0	0	1.54
overall	1037	6.23	166.45

For public transport accidents (i.e., buses), the assumed incidence rates were:

- Fatal: 1.5 / billion passenger kilometres; and
- Serious: 9.95 / billion passenger kilometres.

Unfortunately, as noted at the beginning of this chapter, the assumption of fixed accident rates per passenger kilometre leads to the conclusion that the marginal external accident benefit is zero. Under the alternative assumption of a fixed accident rate per vehicle kilometre, increasing vehicle occupancy with rising apk means that accident rates per passenger kilometre would reduce—conceivably a point in favour of increased automobile usage.

10. SUMMARY OF EXTERNALITY RESULTS

It has been possible to combine the relationships between each type of external benefit and rail patronage into a single marginal external benefit function. The most important individual contributor to overall marginal external benefit is the congestion cost experienced by motorists (experienced as the value of time spent driving or being a passenger in a car), which is counteracted increasingly at high rail patronage levels by the value of time spent by rail commuters on the train, waiting for the train, or walking to and from the train station.

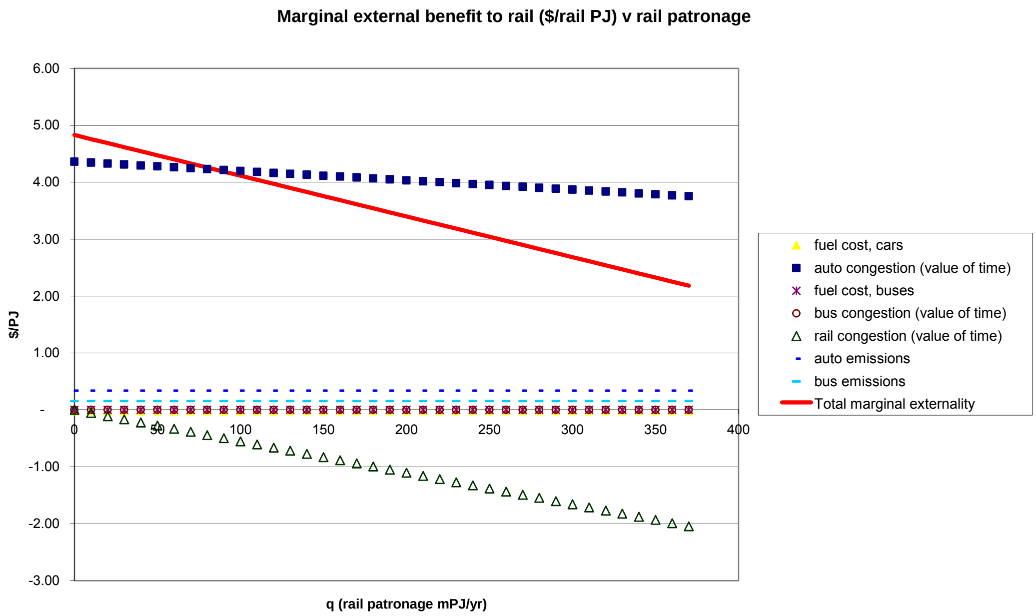
Having set out the methodology and data sources for calculation of congestion, emission, and accident externalities in the previous three chapters, we present the results in this chapter. The intention is to use this analysis to establish the marginal external benefit of rail patronage in dollars per passenger journey as a function of rail patronage: meb(q). Total external benefits at any level of patronage can be estimated by integrating the marginal external benefit function.

10.1. RESULTS

The primary drivers of quantifiable external benefits are passenger travel hours and fuel consumption. Results of the SSTM modelling for each of these drivers and figures derived from them in the eight most relevant scenarios are tabulated below.

	increm0	increm+10	increm+20	increm-10	increm-20	no rail b100 p0	no rail b100 p50	no rail b100	no cars or no buses
Automobiles									
m pkm average workday	151.768	152.011	152.184	151.520	151.200	169.463	169.323	169.237	
m vkm average workday	120.118	120.299	120.424	119.950	119.751	132.373	132.262	132.191	
litres fuel consumed (m)	11.842	11.862	11.876	11.824	11.800	13.204	13.191	13.181	
litres fuel consumed (m/yr)	3,138	3,143	3,147	3,133	3,127	3,499	3,496	3,493	0.000
litres/pkm	0.0780	0.0780	0.0780	0.0780	0.0780	0.0779	0.0779	0.0779	
car pax+driver hr m workday	4.512	4.524	4.530	4.497	4.483	5.342	5.331	5.325	
pax hr m/yr	1,196	1,199	1,200	1,192	1,188	1,416	1,413	1,411	0.000
hrs/pkm	0.0297	0.0298	0.0298	0.0297	0.0296	0.0315	0.0315	0.0315	
Buses									
m pkm average workday	7.570	7.664	7.748	7.475	7.359	14.558	14.777	14.937	0.000
litres fuel consumed (m)	0.091	0.092	0.093	0.090	0.088	0.174	0.177	0.179	0
litres fuel consumed (m/yr)	24	24	25	24	23	46	47	47	0.000
litres/pkm	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120	0.0120	
pax hr m workday linked trip	0.647	0.654	0.660	0.640	0.631	1.129	1.144	1.156	
pax hr m/yr	171	173	175	170	167	299	303	306	0.000
hrs/pkm	0.0855	0.0853	0.0852	0.0856	0.0858	0.0775	0.0774	0.0774	
Rail									
m pkm average workday	19.773	19.400	19.083	20.201	20.674	0.137	0.138	0.139	
litres fuel (equiv) consumed (m)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
pax hr m workday linked trip	0.889	0.870	0.854	0.911	0.935	0.013	0.013	0.013	
pax hr m/yr	236	231	226	241	248	-	-	-	
hrs/PJ	0.8544	0.8523	0.8502	0.8568	0.8596	-	-	-	
rail fare (avg $/PJ)	1.823	2.006	2.188	1.641	1.459	9999.000	9999.000	9999.000	
rail patronage (m pax-km) avg workday	19.773	19.400	19.083	20.201	20.674	0.000	0.000	0.000	
rail patronage (mPJ/avg workday)	1.041	1.021	1.004	1.063	1.088	0.000	0.000	0.000	
avg journey length	19.000 km								
q=mPJ/yr	275.78	270.57	266.16	281.75	288.34	-	-	-	
aapk=auto pax-km/yr	40,218	40,283	40,329	40,153	40,068	44,908	44,870	44,848	-
abpk=bus pax-km/yr	2,006	2,031	2,053	1,981	1,950	3,858	3,916	3,958	-

Using a value of travel time of $13.15/hr and a carbon cost of $25/tonne of CO2, these results can be translated to linear functions meb(q) for each component of the external benefit of rail, shown graphically below.



The total marginal external benefit to rail, meb(q), is the solid line. It begins at the maximum value of $4.83/PJ and decreases as rail patronage increases—the marginal external benefit per passenger journey declines as more passengers choose to travel by rail.

The principal contributor to meb(q) is the marginal external cost of congestion for automobiles, which is the top row of square symbols. Rail travel time counteracts the automobile travel time effect. The other components of the marginal externality calculation make only a second-order contribution to the overall result.

The results shown graphically here are tabulated below.

			marginal external benefit to rail ($/rail PJ)							
q (mPJ/yr)	aapk	abpk	auto fuel cost extern	auto VOT extern	bus fuel cost extern	bus VOT extern	rail VOT extern	auto emissions extern	bus emissions extern	Total meb $/PJ
0	44,873	3,910	- 0.02	4.36	-	-	-	0.33	0.15	4.83
10	44,705	3,841	- 0.02	4.34	-	-	- 0.06	0.33	0.15	4.76
20	44,536	3,772	- 0.02	4.33	-	-	- 0.11	0.33	0.15	4.69
30	44,368	3,703	- 0.02	4.31	-	-	- 0.17	0.33	0.15	4.61
40	44,199	3,634	- 0.02	4.30	-	-	- 0.22	0.33	0.15	4.54
50	44,030	3,565	- 0.02	4.28	-	-	- 0.28	0.33	0.15	4.47
60	43,862	3,497	- 0.02	4.26	-	-	- 0.33	0.33	0.15	4.40
70	43,693	3,428	- 0.02	4.25	-	-	- 0.39	0.33	0.15	4.33
80	43,525	3,359	- 0.02	4.23	-	-	- 0.44	0.33	0.15	4.26
90	43,356	3,290	- 0.02	4.21	-	-	- 0.50	0.33	0.15	4.19
100	43,187	3,221	- 0.02	4.20	-	-	- 0.55	0.34	0.15	4.11
110	43,019	3,152	- 0.02	4.18	-	-	- 0.61	0.34	0.15	4.04
120	42,850	3,083	- 0.02	4.16	-	-	- 0.66	0.34	0.15	3.97
130	42,682	3,014	- 0.02	4.15	-	-	- 0.72	0.34	0.15	3.90
140	42,513	2,945	- 0.02	4.13	-	-	- 0.77	0.34	0.15	3.83
150	42,344	2,876	- 0.02	4.12	-	-	- 0.83	0.34	0.15	3.76
160	42,176	2,808	- 0.02	4.10	-	-	- 0.88	0.34	0.15	3.68
170	42,007	2,739	- 0.02	4.08	-	-	- 0.94	0.34	0.15	3.61
180	41,839	2,670	- 0.02	4.07	-	-	- 1.00	0.34	0.15	3.54
190	41,670	2,601	- 0.02	4.05	-	-	- 1.05	0.34	0.15	3.47
200	41,502	2,532	- 0.02	4.03	-	-	- 1.11	0.34	0.15	3.40
210	41,333	2,463	- 0.02	4.02	-	-	- 1.16	0.34	0.15	3.33
220	41,164	2,394	- 0.02	4.00	-	-	- 1.22	0.34	0.15	3.25
230	40,996	2,325	- 0.02	3.98	-	-	- 1.27	0.34	0.15	3.18
240	40,827	2,256	- 0.02	3.97	-	-	- 1.33	0.34	0.15	3.11
250	40,659	2,187	- 0.02	3.95	-	-	- 1.38	0.34	0.15	3.04
260	40,490	2,119	- 0.02	3.93	-	-	- 1.44	0.34	0.15	2.97
270	40,321	2,050	- 0.02	3.92	-	-	- 1.49	0.34	0.15	2.90
280	40,153	1,981	- 0.02	3.90	-	-	- 1.55	0.34	0.15	2.83
290	39,984	1,912	- 0.02	3.89	-	-	- 1.60	0.34	0.15	2.75
300	39,816	1,843	- 0.02	3.87	-	-	- 1.66	0.34	0.15	2.68
310	39,647	1,774	- 0.02	3.85	-	-	- 1.71	0.34	0.15	2.61
320	39,478	1,705	- 0.02	3.84	-	-	- 1.77	0.34	0.15	2.54
330	39,310	1,636	- 0.02	3.82	-	-	- 1.82	0.34	0.15	2.47
340	39,141	1,567	- 0.02	3.80	-	-	- 1.88	0.34	0.15	2.40
350	38,973	1,498	- 0.02	3.79	-	-	- 1.94	0.34	0.15	2.32
360	38,804	1,430	- 0.02	3.77	-	-	- 1.99	0.34	0.15	2.25
370	38,635	1,361	- 0.02	3.75	-	-	- 2.05	0.34	0.15	2.18

10.2. COMPARISON OF EXTERNALITY RESULTS TO RAILCORP ANALYSIS

RailCorp's own analysis of the external and other benefits to the NSW community of CityRail[33] provides a useful point of comparison for the results obtained in this study. The RailCorp results are summarised below (Karpouzis, et.al, Table 9, p. 14)

33 Karpouzis, et.al., op. cit.

Estimated CityRail benefits and costs to the community of NSW in 2006-07 and the 10 year average from 1997-98 to 2006-07
In 2006-07 prices

Description	2006-07 ($m)	Average 1997-98 to 2006-07 ($m)
Revenue [(a)]	760.6	874.9
Total costs	-2 411.1	-2 013.9
Shortfall [(b)]	-1 650.5	-1 139.0
Rail user benefits [(c)]	2 055.7	2 364.6
Road user benefits [(d)]	740.5	726.4
Air pollution	71.0	69.6
Greenhouse gas emission	52.1	51.1
Noise pollution	20.4	20.0
Accidents	114.6	112.4
Road damage	3.7	3.6
Fleet externality cost	-18.0	-18.0
Total rail benefit	3 039.9	3 329.8
Net benefit to community	1 389.4	2 190.8
Benefit to subsidy ratio	1.8	3.1

Notes

a) Revenue is equal to farebox, revenue from other rail entities, other income and concession revenue from government.
b) Surplus/shortfall before government funding — total costs minus revenue (producer surplus).
c) Rail user benefits are equal to rail user consumer surplus.
d) Road user benefits are equal to road decongestion benefits associated with having a rail network.

Our results are compared to previously published results for CityRail in the table below. In order to facilitate comparability, the format of the published CityRail table has been adopted in this table. Two different demand schedules are considered in this table—both are consistent with the demand estimations performed in this study.

Comparison of external benefits			linear demand	exponential demand
		elasticity	-0.24	-0.35
assumed carbon price $/t CO2:			25	25
assumed value of time ($/hr):			13.15	13.15
Description	2006-07 ($m)	Average 1997-98 to 2006-07 ($m)	($m)	($m)
Shortfall [(b)]	- 1,650.5	- 1,139.0	-1363.9	- 1,363.9
Rail user benefits ©	2,055.7	2,364.6	1,031.3	1,414.3
Road user benefits [(d)]	740.5	726.4	923.1	923.1
Air pollution	71.0	69.6	109.1	109.1
Greenhouse gas emission	52.1	51.1	25.3	25.3
Noise pollution	20.4	20.0		
Accidents	114.6	112.4	too small to measure	
Road damage	3.7	3.6		
Fleet externality cost	- 18.0	- 18.0	- 18.0	- 18.0
Total rail benefit	3,039.9	3,329.8	2,070.7	2,453.8
Net benefit to community	1,389.4	2,190.8	706.8	1,089.9
	CityRail results		*CRA results*	
sum of externalities	1,002.3	983.1	1,057.5	1,057.5

The two columns to the left represent the results of the earlier study published by RailCorp staff members Karpouzis et. al. The two rightmost columns represent the results of the study presented in this report.

The "shortfall" could be interpreted as the Government funding requirement. These figures would not be expected to match exactly between RailCorp's calculation and ours because RailCorp includes in its revenue figure, in addition to the farebox: concession income from Government, payments (including access charges) from other rail entities, and other income, whereas we include only the farebox. There are differences in the total cost calculation as well. Nevertheless, the two shortfall estimates are of the same order of magnitude.

Rail user benefits are defined by RailCorp as the consumer surplus attributed to rail users. If the negative exponential functional form for the demand schedule with the low value of fare elasticity were adopted, our estimate of consumer suplus would closely match that of RailCorp. However, as noted above, the house price analysis suggests that particular demand schedule may tend to overstate the consumer surplus. If, instead, either the linear demand schedule with low fare elasticity or the negative exponential demand schedule with high fare elasticity (the two demand schedules found to be consistent with the property price analysis) is adopted, our estimate of consumer surplus is substantially lower than RailCorp's.

Total external benefits to rail, consisting primarily of congestion relief provided by the rail system, are very similar between our estimate (using VOT = $13.15/hr) and RailCorp's. Note that our road user benefit value includes air pollution and greenhouse gas emission externalities, which are listed separately in RailCorp's table.

The extent of road user benefits is quite sensitive to the assumption about the value of travel time. Using the higher value of $22.60/hr, corresponding to a blended private and business value, the road congestion effect increases significantly to the point where our total externality figure exceeds the RailCorp figure (summing all externalities, including noise pollution, accidents, and road damage).

Overall, taking either of the two demand schedule considered in this study, the total benefit of CityRail derived by Karpouzis et. al. is higher than the values produced by our study. RailCorp estimates of consumer surplus are significantly higher than ours. RailCorp estimates of total external benefits is similar in magnitude to ours, although the contribution of different types of externalities differs: our estimate of congestion and air pollution costs are higher, but our estimate of the greenhouse gas and road accident externalities are lower, substantially so in the latter case. Additionally there is a question as to whether the noise pollution externality works in rail's favour (trains are not quieter than cars). Arguably, road damage costs are not external to motorists' modal choice decision.

Having made this comparison at the total welfare benefit level, we proceed to consider the relationships between rail fare, marginal cost and marginal external benefit in order to determine the level of Government subsidy that would maximise overall welfare. That topic is taken up in the next chapter.

11. OPTIMISATION OF FARE, SUBSIDY & PATRONAGE

We set out to develop a framework to estimate the social costs and benefits arising from CityRail's passenger services, and to use this framework to derive the appropriate contribution by Government to CityRail's costs. It is apparent that the social benefits depend on the extent to which passengers use CityRail, and that the fare is an important determinant of passenger use. There is, in fact, a tradeoff: higher fares mean CityRail is less unprofitable and a lower Government subsidy is needed, but they also mean lower ridership and lower external benefit. There is likely to be a preferred fare setting at which total welfare is maximised, and this study has developed a framework through which that preferred point can be determined.

Welfare is formally defined as the sum of what are known as consumer surplus, producer surplus, and externalities less the welfare costs of taxation. It depends on CityRail patronage in a subtle way that reflects the tradeoff between producer surplus on one hand, and the combination of consumer surplus and externalities on the other. Low fares mean highly negative producer surplus and significant tax distortions, but high patronage, consumer suplus, and external benefit. High fares mean lower patronage, consumer surplus and external benefit, but less negative producer surplus and less tax distortion. At some intermediate point, any increase in fares would lead to a greater loss of consumer surplus and external benefit than the gain in producer surplus and reduction in tax distortion, and at the same point, any decrease in fares would lead to a greater loss of producer surplus and increase in tax distortion than the gain in consumer surplus and external benefit. That point is the optimum. There will be a unique level of Government support that corresponds to it.

In order to find this optimum point, it has been necessary to understand, in a quantitative way, the relationship between fares and patronage, between patronage and consumer surplus, between patronage and producer surplus, and between patronage and external benefit. The bulk of the analytical work presented in this report has been directed to obtaining the quantitative understanding of these relationships.

This chapter employs the empirical findings reported so far in this report to explore the optimal mix between farebox and Government funding for CityRail. This task is construed as a problem in mathematical optimisation. We specify this problem and derive analytical formulae for the optimal values. A spreadsheet tool has been developed by CRAI to calculate these optimal values and to explore the sensitivity of optima to changes in the key parameters. The results of this sensitivity analysis are reported later in this chapter.

11.1. Specification of optimisation problem

In order to state clearly what optimisation is being undertaken in this chapter, this subsection sets out the objective function in mathematical terms and derives formulae for the optimal values of fare, patronage, welfare, and government contribution.

11.1.1. Objective function

The objective function employed in the externality study is social welfare, defined as follows:

Welfare = Consumer Surplus + Producer Surplus + External benefits to rail – marginal excess burden of taxation*Government Contribution

Equivalently, in the notation that will be adopted below:

$$W = CS + PS + EXT - d\,GC$$

"d" is the marginal excess burden rate for taxation. Each of these components can be further defined as follows. Note that the marginal costs (MC) and the marginal external benefit rate (meb) may vary with rail patronage. The rail fare is "p" and patronage is "q".

Consumer surplus depends on the functional form of the demand schedule, v(q):

$$CS = \int_0^q (v(s) - p(s))\, ds = \int_0^q v(s)\; ds - pq$$

Producer surplus depends on the functional form of the supply schedule, MC(q):

$$PS = \int_0^q (p - MC(s))\, ds = pq - \int_0^q MC(s)\, ds$$

$$EXT = \int_0^q meb(s)\, ds$$

$GC = F - PS$, where F is the fixed cost of CityRail for 2006/07

Combining these components and simplifying,

$$W = \int_0^q [v(s) - MC(s) + meb(s)]ds - d[F + \int_0^q MC(s)\, ds - pq]$$

11.1.2. Optimality conditions

At the local optimum point of W, the following first order condition is satisfied:

$$\partial W/\partial q = v(q) - MC(q) + meb(q) + d[(p + q\partial p/\partial q) - MC(q)] = 0$$

Since the price must lie on the demand schedule, v(q) = p. The first order condition may be simplified to:

$$\partial W/\partial q = (1+d)[p - MC(q)] + meb(q) + d\; q\partial p/\partial q = 0$$

This equation has a simple natural interpretation if the marginal excess burden of taxation, d, is set to zero: the optimum welfare point is attained when price equals marginal cost less the marginal external benefit rate.

The second order condition is:

$$\partial^2 W/\partial q^2 = (1+d)[\partial p/\partial q - \partial MC(q)/\partial q] + \partial meb(q)/\partial q + d\; \partial(q\partial p/\partial q)/\partial q$$

When typical conditions apply, that is, downward sloping demand, upward sloping supply, and downward sloping marginal external benefit schedules as functions of rail patronage, the first three terms will be negative definite. For a linear demand schedule, the final term will also be negative definite, making the second derivative of the welfare function negative definite. For a negative exponential demand schedule, the final term will be zero, making the second derivative of the welfare function negative definite in that case also. These second order conditions establish that the optimum point determined by the first order condition is a local maximum of welfare when the demand schedule has either linear or negative exponential functional form.

In order to solve for optimal fare and patronage (p*, q*) it is necessary to specify the functional form of the demand schedule. Two possible functional forms are considered below.

11.1.3. Linear demand schedule

The linear functional form for $q(p) = a + bp$. The inverse form is $p(q) = -a/b + (1/b)q$. The coefficients a and b are presumed constant and $b < 0$.

$$\partial p/\partial q = 1/b$$

$$\partial W/\partial q = (1+d)[p - MC] + meb + d\, q/b = 0$$

$$MC(q) = \theta\, q + \varphi$$

$$meb(q) = \mu\, q + \omega$$

To simplify the notation, let $\Psi = \mu + da/b - (1+d)\,\theta$. Making these substitutions, simplifying and solving for values of q, consumer surplus, producer surplus, and total externalities at the optimum patronage point q*:

$$\Rightarrow \quad p^* = [(1+d)\,\varphi - \omega - a\,\Psi] / [1+d + b\,\Psi]$$

$$q^* = a + bp^*$$

$$CS^* = \int_0^{q^*} v(s)\ ds - p^*q^* = (-a/b - p^*)q^*/2$$

$$PS^* = p^*q^* - \int_0^{q^*} MC(s)\ ds = (p^* - \varphi - \theta\, q^*/2)q^*$$

$$EXT^* = \int_0^{q^*} meb(s)\ ds = (\mu\, q^*/2 + \omega)q^*$$

11.1.4. Negative exponential demand schedule

The negative exponential functional form for q(p) = g exp(h p). The inverse form is p(q) = (1/h)(ln q – ln g). The coefficients g and h are presumed constant and h < 0.

$$\partial p/\partial q = 1/(hq)$$

$$\partial W/\partial q = (1+d)[p - MC] + meb + d/h = 0$$

$$\Rightarrow \quad p^* = [(1+d)MC - meb - d/h]/(1+d)$$

$$q^* = g \exp(h\, p^*)$$

Unfortunately, substitution of linear functions for MC(q) and meb(q) does not lead to an analytical solvable expression for p* as it did in the linear demand case. Numerical solution methods are required to determine p* for any set of parameter values.

The expression for EXT* does not depend on the form of the demand schedule, so it is the same as for the linear case, discussed above. While the expression for PS* does depend on the demand schedule, that dependency is captured in the p* term, so the PS* formula given for linear demand above continues to apply.

For the negative exponential functional form,

$$CS^* = \int_0^{q^*} v(s)\ ds - p^*q^* = -\, q^*/h$$

As the derivation of this simple result is quite involved it is left to the appendix.

11.1.5. Appendix on optimisation algebra

$$CS^* = \int_0^{q^*} v(s)\ ds - p^*q^*$$

For the negative exponential functional form, v(s) = (1/h)(ln s – ln g), where s is the patronage variable. Substituting for v(s) and integrating, noting that the indefinite integral of lnx = x lnx – x,

$$CS^* = (1/h) \int_0^{q^*} \ln s\ ds - (1/h)(\ln g)q^* - p^*q^*$$

$$= (1/h)[q^* \ln q^* - q^* - 0 \ln 0 - (\ln g)q^*] - p^*q^*$$

Noting that the limit of x lnx as x approaches zero is zero, this expression simplifies to:

$$CS^* = q^*[(1/h)(\ln q^* - \ln g) - 1/h] - p^*q^*$$

$$= q^*[p^* - 1/h] - p^*q^* = - q^*/h \qquad \text{(QED)}$$

11.2. RESULTS

Based on our sensitivity analysis, there are five main uncertainties that determine the optimal levels of fare, patronage and Government subsidy:

a) The point fare-elasticity of demand (-0.24 or -0.35);

b) The functional form of the demand schedule (e.g., linear or negative exponential);

c) The value of passenger time (ranging from \$9.23/hr or \$22.60/hr, with a central value of \$13.15/hr), which influences the slope and y-intercept of the marginal external benefit function;

d) The slope and y-intercept of the CityRail marginal cost function; and

e) The marginal excess burden of taxation, “d” (0.1 or zero, corresponding to the case where the deadweight loss of taxation is excluded from the analysis).

As discussed earlier, only two of the four possible permutations of a) and b) are consistent with the property price analysis: linear demand with elasticity of -0.24 and negative exponential demand with elasticity of -0.35. Only these permutations will be considered in the sensitivity analysis.

The following parameter selections were adopted for the central case, from which sensitivity analyses were conducted:

- Marginal cost (q) = \$0.0331/(PJ^2) q – \$4.05/PJ (corresponding to marginal cost of \$2.57/PJ at q=200mPJ/yr and \$5.88/PJ at q=300mPJ/yr)
- meb(q) = -\$0.004526/(PJ^2) q + \$3.34/PJ (corresponding to a value of passenger time of \$13.15/hr)
- d = 0.1

Adopting these central case settings, the optimum welfare point for each type of demand schedule is shown below, and compared with outcomes at the 2005/06 patronage level.

Common settings

			values for year 2005/06	
d =	0.1		q0 =	275 mPJ/yr
MC =	0.0331 q +	-4.05 $/PJ	p0 =	1.8 $/PJ
meb =	-0.007157 q +	4.83 $/PJ		
F =	1,721	$m 2006/07		

Linear demand function case

q = alpha + beta * p

e0 =	-0.24
alpha =	341 ("a")
beta =	-36.66667 ("b")

Optimal values for linear demand schedule			
p* =	2.32	q* =	255.78
GC* =	1,173	PS* =	548
CS* =	892	EXT* =	1,001
W* =	2,324		

Values of welfare components at 2005/06			
p0 =	1.80	q0 =	275.00
GC* =	1,364	PS* =	357
CS0 =	1,031	EXT* =	1,057
W0 =	2,309		

W0/W*= 99.4%

Negative exponential demand function

q = gamma * exp(delta * p)

e0' =	-0.35
gamma =	390.24358 ("g")
delta =	-0.1944444 ("h")

Optimal values for neg. exponential demand			
p* =	2.17	q* =	256.03
GC* =	1,214	PS* =	507
CS* =	1,317	EXT* =	1,002
W* =	2,704		

Values of welfare components at 2005/06			
p0 =	1.80	q0 =	275.00
GC* =	1,364	PS* =	357
CS0 =	1,414	EXT* =	1,057
W0 =	2,693		

W0/W*= 99.6%

Outcomes are shown for a linear demand schedule with point elasticity equal to the estimated short-run fare elasticity of -0.24 and for a negative exponential demand schedule with point elasticity equal to the long-run fare elasticity of -0.35.

The optimal welfare outcome for the central case (negative exponential functional form) is achieved with an average fare of $2.17/PJ, which is a 21% increase over the $1.80/PJ average fare level that prevailed in 2005/06. The optimal level of Government Contribution to CityRail of $1,214m/yr is approximately $150m/yr lower than the level that prevailed in 2005/06 (an 11% reduction in Government funding).). Significantly, the optimal level of patronage of 256.03m passenger journeys per annum is 7% lower than 2005/06 patronage.

Given that increased patronage is an explicit policy goal, it might seem counterintuitive that optimal patronage is lower than actual patronage. The explanation is that (subject, of course, to the accuracy of the measurements presented in this report) increases in patronage from the 2005/06 point would lead to an increase in CityRail's operating deficit and in tax distortions that is greater than the increase in consumer surplus and external benefit that it would create. Previous studies have tended to ignore the distortionary effect of taxation and to overestimate both the consumer surplus derived by rail users and the additional external benefit from additional patronage. The conventional wisdom regarding optimal CityRail patronage may have been influenced to some extent by this overestimate.

It is worth noting, however, that the optimal welfare is only $11m/yr higher than the welfare achieved with the 2005/06 fare and patronage settings. In other words, 99.6% of the optimum welfare level could be achieved with no change to the 2005/06 fare, patronage and Government contribution levels.

If the marginal excess burden of taxation is ignored (implemented by setting d = 0), then a new optimum welfare point is derived, as shown below.

Common settings

d =	0			
MC =	0.0331	q +	-4.05	$/PJ
meb =	-0.007157	q +	4.83	$/PJ
F =	1,721	$m 2006/07		

values for year 2005/06		
q0 =	275	mPJ/yr
p0 =	1.8	$/PJ

Linear demand function case

q = alpha + beta * p

e0 =	-0.24	
alpha =	341	("a")
beta =	-36.66667	("b")

Optimal values for linear demand schedule			
p* =	1.96	q* =	269.21
GC* =	1,303	PS* =	418
CS* =	988	EXT* =	1,041
W* =	2,447		

Values of welfare components at 2005/06			
p0 =	1.80	q0 =	275.00
GC* =	1,364	PS* =	357
CS0 =	1,031	EXT* =	1,057
W0 =	2,446		

W0/W*= 100.0%

Negative exponential demand function

q = gamma * exp(delta * p)

e0' =	-0.35	
gamma =	390.24358	("g")
delta =	-0.1944444	("h")

Optimal values for neg. exponential demand			
p* =	1.93	q* =	268.39
GC* =	1,310	PS* =	412
CS* =	1,380	EXT* =	1,038
W* =	2,830		

Values of welfare components at 2005/06			
p0 =	1.80	q0 =	275.00
GC* =	1,364	PS* =	357
CS0 =	1,414	EXT* =	1,057
W0 =	2,829		

W0/W*= 100.0%

Under these assumptions, the optimum patronage is very close to the actual 2005/06 patronage, under either functional form of the demand schedule. The optimum average fare is now between 7% and 9% higher than actual 2005/06 average fares, and the actual 2005/06 welfare outcome was within $1m/yr of the optimal welfare outcome.

This finding gives some hope that, while current CityRail policy settings may not be optimal, they could achieve a near-optimal result without drastic changes to fare, patronage or Government support levels. That result is contingent, however, on the central case parameter settings. Varying some of these choices could significantly affect the conclusion. This possibility is explored in the next section, where sensitivity tests are conducted.

11.3. Sensitivity tests

The sensitivity tests are presented as a series of tables. The first six columns of each table show the parameter settings that define the sensitivity case: point elasticity for the linear demand schedule at the patronage level of 275mPJ/yr (e0), marginal excess burden of taxation (d), the slope (θ) and y-intercept (φ) of the marginal cost function MC(q), and the slope (μ) and y-intercept (ω) of the marginal external benefit function meb(q).

The next four columns show the optimal values for fare (p*), patronage (q*), Government contribution (GC*), and external benefit compared to no-rail case (EXT*). The final two columns compare the estimated actual welfare outcome in 2005/06 (W0) to the optimal welfare outcome given the parameter settings (W*) in two ways: as a ratio, and as a difference.

The sensitivity cases are conducted on the linear functional form of the demand schedule, as the analytical solvability of the expression for p* facilitates this type of analysis. To do the same for the negative exponential functional form it would be necessary to perform a numerical solution for p* for every new setting of the input parameters.

11.3.1. Varying marginal cost

inputs						calculated values					
units:		$/PJ2	$/PJ	$/PJ2	$/PJ	$/PJ	mPJ/yr	$m/yr	$m/yr	%	$m/yr
e0	d	θ	φ	μ	ω	p*	q*	GC*	EXT*	W0/W*	W*-W0
-0.24	0.1	0.0157	-0.57	-0.00716	4.83	1.81	274.46	1657.8	1,056	100.0%	0
-0.24	0.1	0.0331	-4.05	-0.00716	4.83	2.32	255.78	1173.4	1,001	99.4%	14
-0.24	0.1	0.0505	-7.53	-0.00716	4.83	2.63	244.59	746.73	967	98.4%	44

The slope (θ) and y-intercept (φ) of the marginal cost function MC(q) is varied around the central case (middle row). The top row corresponds to the assumption that infrastructure costs at the 300mPJ/yr patronage level increase by 1% when patronage increases by 1%. The central case assumes that infrastructure costs increase by 2% when patronage increases by 1%. The last row corresponds to the assumption that infrastructure costs increase by3% when patronage increases by1%.

In the last case, in which marginal costs are highest at q=300mPJ/yr, optimality requires a substantial increase in fares and a more pronounced decrease in government contribution. Even in this extreme case, though, the actual 2005/06 welfare outcome was within 2% or $44m/yr of the optimal value.

11.3.2. Varying marginal external benefit rate

inputs						calculated values					
units:		$/PJ2	$/PJ	$/PJ2	$/PJ	$/PJ	mPJ/yr	$m/yr	$m/yr	%	$m/yr
e0	d	θ	φ	μ	ω	p*	q*	GC*	EXT*	W0/W*	W*-W0
-0.24	0.1	0.0331	-4.05	-0.00500	3.53	2.60	245.69	1086.4	716	98.5%	32
-0.24	0.1	0.0331	-4.05	-0.00716	4.83	2.32	255.78	1173.4	1,001	99.4%	14
-0.24	0.1	0.0331	-4.05	-0.01230	7.96	1.72	278.07	1397.3	1,738	100.0%	0

The slope (μ) and y-intercept (ω) of the marginal external benefit function meb(q) is varied around the central case (middle row). The top row corresponds to a value of time of $9.23/hr. The central case assumes a value of time of $13.15/hr. The last row corresponds to a value of time of $22.60/hr.

For the central and low values of time, significant fare increases would be optimal, but near-optimality can be achieved with fares close to actual 2005/06 levels. For the high value of time, a fare decrease would be optimal.

The optimal government contribution is not strongly affected by changes in the value of time. This outcome may be contrasted with the large changes in optimal government contribution seen in the sensitivity cases for marginal cost. The reason for this difference is that the estimate of CityRail's fixed costs depends on the marginal cost function. Fixed costs are inferred from actual total 2006/07 costs by subtracting the variable cost element. The variable cost element depends both on the actual 2006/07 patronage and the assumed marginal cost function.

When the marginal cost function changes significantly, the inferred level of fixed costs also changes significantly. Recovery of fixed costs is an important component of the government contribution.

11.3.3. Varying fare elasticity

inputs						calculated values					
units:		$/PJ2	$/PJ	$/PJ2	$/PJ	$/PJ	mPJ/yr	$m/yr	$m/yr	%	$m/yr
e0	d	θ	φ	μ	ω	p*	q*	GC*	EXT*	W0/W*	W*-W0
-0.24	0.1	0.0331	-4.05	-0.00716	4.83	2.32	255.78	1173.4	1,001	99.4%	14
-0.28	0.1	0.0331	-4.05	-0.00716	4.83	2.24	256.02	1194.5	1,002	99.4%	13
-0.32	0.1	0.0331	-4.05	-0.00716	4.83	2.18	256.22	1210.2	1,002	99.4%	12
-0.36	0.1	0.0331	-4.05	-0.00716	4.83	2.14	256.40	1222.4	1,003	99.4%	11
-0.4	0.1	0.0331	-4.05	-0.00716	4.83	2.10	256.54	1232	1,003	99.4%	11
-0.44	0.1	0.0331	-4.05	-0.00716	4.83	2.07	256.67	1239.9	1,004	99.4%	10
-0.48	0.1	0.0331	-4.05	-0.00716	4.83	2.05	256.79	1246.4	1,004	99.4%	10
-0.52	0.1	0.0331	-4.05	-0.00716	4.83	2.03	256.89	1251.8	1,004	99.5%	10
-0.56	0.1	0.0331	-4.05	-0.00716	4.83	2.01	256.98	1256.5	1,005	99.5%	9
-0.6	0.1	0.0331	-4.05	-0.00716	4.83	2.00	257.06	1260.5	1,005	99.5%	9
-0.64	0.1	0.0331	-4.05	-0.00716	4.83	1.98	257.13	1264.1	1,005	99.5%	9
-0.68	0.1	0.0331	-4.05	-0.00716	4.83	1.97	257.20	1267.2	1,005	99.5%	9
-0.72	0.1	0.0331	-4.05	-0.00716	4.83	1.96	257.26	1269.9	1,006	99.5%	9
-0.76	0.1	0.0331	-4.05	-0.00716	4.83	1.95	257.31	1272.3	1,006	99.5%	8
-0.8	0.1	0.0331	-4.05	-0.00716	4.83	1.94	257.36	1274.5	1,006	99.5%	8
-0.84	0.1	0.0331	-4.05	-0.00716	4.83	1.94	257.41	1276.5	1,006	99.5%	8
-0.88	0.1	0.0331	-4.05	-0.00716	4.83	1.93	257.45	1278.3	1,006	99.5%	8
-0.92	0.1	0.0331	-4.05	-0.00716	4.83	1.92	257.49	1279.9	1,006	99.5%	8
-0.96	0.1	0.0331	-4.05	-0.00716	4.83	1.92	257.53	1281.4	1,006	99.5%	8
-1	0.1	0.0331	-4.05	-0.00716	4.83	1.91	257.57	1282.8	1,007	99.5%	8

Optimal patronage is hardly affected at all by large changes to the fare elasticity. The effect on optimal fares is somewhat greater, but the influence of changing elasticity on government contribution, externalities, and welfare are all minor.

11.3.4. Varying marginal excess burden of taxation

inputs						calculated values					
units:		$/PJ2	$/PJ	$/PJ2	$/PJ	$/PJ	mPJ/yr	$m/yr	$m/yr	%	$m/yr
e0	d	θ	φ	μ	ω	p*	q*	GC*	EXT*	W0/W*	W*-W0
-0.24	0	0.0331	-4.05	-0.00716	4.83	1.96	269.21	1303.1	1,041	100.0%	1
-0.24	0.1	0.0331	-4.05	-0.00716	4.83	2.32	255.78	1173.4	1,001	99.4%	14
-0.24	0.2	0.0331	-4.05	-0.00716	4.83	2.61	245.12	1081.7	969	98.3%	38
-0.24	0.3	0.0331	-4.05	-0.00716	4.83	2.85	236.45	1014.5	942	96.7%	70
-0.24	0.4	0.0331	-4.05	-0.00716	4.83	3.05	229.26	963.75	919	94.7%	107
-0.24	0.5	0.0331	-4.05	-0.00716	4.83	3.21	223.21	924.52	900	92.2%	149

The extent to which optimal fares, patronage and government contributions differ from actual 2005/06 levels depends strongly on the assumed marginal excess burden rate for taxation. The more distorting the tax base, the higher the fares and the lower the government contributions that would be optimal.

11.3.5. Summary of sensitivity test results

The optimal government contribution level is most sensitive to changes in the marginal cost function and the assumed marginal excess burden rate for taxation. It is quite insensitive to the changes in the price elasticity of demand, and relatively insensitive to changes in the marginal external benefit function within the ranges established by the empirical work reported here.

The importance of knowing the marginal cost function is highlighted by these sensitivity test results. It strongly suggests that CityRail should strive to measure this important metric for its future operations, particularly as there are large-scale infrastructure investments contemplated that could conceivably have a marked effect on marginal costs.

Nevertheless, sensitivity analysis also shows that while the optimal patronage, fare and Government contribution levels are quite sensitive to assumptions about marginal cost and marginal external benefit rates, a willingness to accept somewhat suboptimal net welfare outcomes expands the range of policy options greatly for the current infrastructure configuration.

Another way of formulating the sensitivity test is to ask:

- what would need to change to make a fare reduction optimal?
- what would need to change to make a fare increase of more than 30% optimal? and
- how plausible are changes of this type?

Within the sensitivity ranges considered above, the only change that would make a fare reduction optimal would be an increase in the value of time to a figure above $21/hr. Such a change would increase the marginal external benefit rate sufficiently to suggest an average fare reduction. While this high valuation of time is not implausible, it is near the top end of the range considered in this study.

On the other hand, there are several changes that would make a fare increase of more than 30% optimal:

- demand less price-elastic than -0.23;
- marginal excess burden of taxation (“d”) greater than or equal to 0.11;
- marginal cost greater than in the central case; or
- value of time less than the $13.15/hr figure used in the central case.

Each of these values is plausible. Therefore it is certainly plausible that a fare increase of 30% or more would be optimal.

12. CONCLUSIONS

CityRail provides benefit to the NSW community in two main ways. Rail passengers derive consumer surplus by purchasing rail journeys at prices that are less than their private valuation of those journeys. Non-rail passengers derive benefits from the fact that others purchase rail journeys and therefore consume less private automobile and bus transport than they otherwise would.

This second effect, externality, represents a type of market failure that justifies Government intervention in the form of subsidisation, although Government subsidies could also be justified in the absence of externalities if there are scale economies. This report has described an empirical analysis of the value of both the consumer surplus and the external benefits created by CityRail. The analysis has been conducted in such a way that it is possible to consider what level of consumer surplus and external benefit would be achieved at various different levels of average fare, rail patronage, and Government subsidy.

Our approach has been to optimise net welfare, defined as the sum of consumer surplus, producer surplus, and external benefit less the deadweight loss to the community arising from distortions to consumption decisions of the taxation needed to support the CityRail subsidy. With an empirically grounded understanding of the relationship between net welfare and CityRail patronage, we have been able to calculate optimal levels of net welfare, and the policy settings (average fare and Government subsidy) needed to obtain those optima.

Two caveats should be borne in mind when interpreting the optima derived from this study. First, the empirical work has been unable to finally resolve several important uncertainties: namely the precise marginal external benefit rate per passenger journey, and the marginal cost of CityRail service. For this reason, the results have been presented in the form of sensitivity tables so that the dependence on these uncertain parameters is clearly evident. This sensitivity analysis has revealed, however, that the results are not particularly sensitive to the functional form of the demand schedule.

Second, the net welfare function exhibits very broad and flat peaks. This finding is significant because it means that the selection of a precisely optimal value of fare, Government subsidy and patronage is not necessary to achieve a nearly optimal outcome in net welfare terms. In other words, the net welfare function is relatively forgiving of policy miscalculations.

It appears to be well accepted that CityRail's system is facing profound capacity constraints during peak hour that are able to be remedied only with extremely large capital investment in new trackwork and stations in and near the CBD of Sydney. Any significant expansion in patronage would require such investments. Properly speaking, the true long-run marginal cost of a CityRail passenger journey should include these capital costs of expansion (expressed in DCF terms and amortised over the lifetime numbers of passenger journeys that they would support). It was not within our scope to conduct such a long-run marginal cost estimate, but the high-patronage marginal cost value employed in this study ($5.88/PJ) was derived on a basis that treated all train operating costs as fully variable (constant returns to scale), and rail infrastructure costs as exhibiting diseconomies of scale at patronage levels nearing those experienced during the Sydney 2000 Olympics.

If the lower value of the marginal external benefit rate (corresponding to a value of time of $9.23/hr) were applied instead of the central case settings, the optimal level of government support would not change drastically, but the optimal fare levels would change significantly.

Importantly, in the high marginal cost sensitivity case the optimal level of Government support was most different from present levels. These calculations reveal that the optimal level of Government support is highly dependent on the extent of long-run marginal costs, which are dependent on the Government's intended capital works programme. New capital investment (as opposed to renewal work) that does not contribute to the removal of pertinent capacity constraints or the attraction of new patronage will involve heavy Government expenditure that has a negligible positive impact on either consumer surplus or external benefits, both of which are dependent upon actual ridership of CityRail.

Previous published estimates of external benefit and consumer surplus have tended to overestimate the social benefits flowing from CityRail's ongoing operations. While these benefits are significant and important, the point of indifference for further capital expenditure on CityRail is somewhat closer than prior studies have indicated—to the extent these other studies provided a means of determining that point. The unthinkable scenario, in which CityRail did not exist at all, would lead to profound changes in the way traffic into the CBD is orchestrated, but these changes would not be so drastic as to prevent Sydney from functioning. The majority of commuter journeys are not to or from the CBD, and rail's share of total passenger kilometres is only 11%.

This study has proposed a new method of calculating the optimal settings for CityRail average fare per passenger journey, CityRail patronage, and the total level of Government subsidisation for CityRail's operating loss. This calculation is subject to a number of important uncertainties, which should be narrowed before concrete steps are taken in pursuit of these optimal settings. The most likely case values of the uncertain parameters lead to the conclusion that average fares should be higher, optimal patronage should be somewhat lower than at present, as should optimal Government subsidies.

These conclusions may appear surprising, given the policy intent to increase rail patronage. Nevertheless, they follow from the quantitative comparison of costs, passenger demand, and external benefits that are presented in this report. To the extent that external benefits of rail may have been overstated, the rationale for current levels of public subsidy of rail is weakened. Given the low price elasticity of rail commuters, the case for fare increases is strengthened.

13. APPENDIX 1—NETWORK TOPOLOGY

This appendix contains the details of construction for CityRail of spatial variables of the type employed in the Winston and Maheshri paper. In the end, these variables were not used in our study. Nevertheless, there may be some value in setting out the process used to construct these variables in case they may be used in some future cross-city comparison of public transport systems.

Railcorp confidentially provided a table of suburban and intercity track sector lengths, from which the table below was derived. The list of sectors is abbreviated in order to conserve space. The summary statistics on the first few rows were derived from the complete table of sectors. The limits of the CityRail network for the purpose of this exercise were taken to be: Newcastle, Macarthur, Lithgow, Nowra, which correspond generally to the limits of the electrified system.

Length of shortest route between 2 farthest stations:			321.313		avg link length	2.52	2.54	2.53	2.55
Newcastle	168.013	Nowra	153.3		sum length	643.192	633.792	613.416	607.835
					#links	255	250	242	238
STATION	KM			Link km	VIA	2000-present	1987-1999	1979-1986	pre-1979
Rosehill	22.422	Camellia	22.952	0.53	Carlingford	1	1	1	1
Clyde	20.66	Granville	21.224	0.564	SYDNEY - GOULBURN via	1	1	1	1
St James	4.401	Museum	4.99	0.589	City Circle	1	1	1	1
Macdonaldtown	2.476	Newtown	3.1	0.624	SYDNEY - GOULBURN via	1	1	1	1
Arncliffe	8.42	Banksia	9.064	0.644	ILLAWARRA	1	1	1	1
Harris Park	22.533	Parramatta	23.206	0.673	Granville -	1	1	1	1
East Richmond	59.996	Richmond	60.681	0.685	Richmond Line	1	1	1	1
Milsons Point	4.435	North Sydney	5.134	0.699	Central -	1	1	1	1
Petersham	5.499	Lewisham	6.246	0.747	SYDNEY - GOULBURN via	1	1	1	1
Lewisham	6.246	Summer Hill	7.032	0.786	SYDNEY - GOULBURN via	1	1	1	1

These network characteristics were calculated for each of four eras: pre-1979, 1979 – 1986, 1987 – 1999, and 2000 – present. The significance of the separating dates is as follows:

- In 1979 the Eastern Suburbs Line was opened;
- In 1987 the East Hills Line was completed between Kingsgrove and East Hills;
- In 2000 the Airport Rail Link was completed, as was the Olympic Park loop.

From this information, the following parameters needed in the Winston-Maheshri method were derived:

	2000-2007	1987-1999	1979-1987	1950-1979
#stations "n"	247	242	235	231
#edges "e"	255	250	242	238
sum of edge lengths (km)	643.192	633.792	613.416	607.835
average edge length (km)	2.52	2.54	2.53	2.55
Area served "A"				
length of shortest distance between two most distant stations "d"	321.313	321.313	321.313	321.313

Prior to 1979, the only new stations opened since 1950 were Lapstone in 1964 and Circular Quay in 1956. The spatial parameters were updated to reflect these changes in the 1950 – 1956, 1957 – 1964, and 1965 – 1979 periods.

14. APPENDIX 2—PROPERTY PRICE ANALYSIS

We obtain an estimate of the effect of rail provision on land values in the Sydney metropolitan area using the results of a previously published hedonic regression analysis of Sydney house prices. This value is converted into an annuity.

14.1. METHODOLOGY FOR PROPERTY PRICE ANALYSIS

Hill and Mesler[34] report the results of a hedonic regression analysis of Sydney house prices over the period 2001 to 2003. About 200,000 sales records were obtained covering 128 postcodes in Sydney.

Many of the approximately 200,000 observations contained insufficient information on household characteristics to be used in the Hedonic regression analysis. Thus the sample of around 200,000 houses was trimmed down to just over 40,000 house sales for the hedonic regression analysis.

For the just over 40,000 house sales, data was available on the core characteristics of the property sold. These core characteristics include property type (i.e. house, unit, terrace, townhouse, cottage, semi, villa, duplex) and the number of bedrooms, and number of bathrooms.

In addition geo-spatial characteristics of the properties sold were derived. The variables included in the analysis are detailed in Table 1.

Table 1: Variables included in hedonic regression model

Core physical characteristics	**Geo-Spatial characteristics**
Unit	Beachfront
Terrace	City views
Semi	Harbour views
Cottage	Waterfront
Townhouse	Distance to airport
Duplex	Distance to beach
Villa	Distance to park
Number of bedrooms	Distance to large shopping centre
Number of bathrooms	Distance to local shopping centre
Other physical characteristics	Distance to hospital
Area	Distance to railway
Extra room	Distance to school
Air conditioner	
Alarm system	

34 Robert J. Hill and Daniel Melser 2007, The Anatomy of a Housing Boom: Sydney 2001-2003, University of New South Wales School of Economics Discussion Paper: 2007/01

- Brick construction
- Ensuite bathroom
- Fireplace
- Garden
- Ground floor
- Gym
- Heating
- Secure parking
- Pool
- Sandstone
- Sauna
- Strata
- Tennis court
- Top floor
- Unrenovated
- Walk-in-Wardrobe

Hill and Melser estimate models including only the core physical characteristics, all physical characteristics and a model with all physical characteristics plus all geo-spatial characteristics. They note that the models that are estimated without the geo-spatial characteristics or the Other physical characteristics were estimated to ascertain the effect on the estimated model of the exclusion of particular sets of variables.

The model with all physical characteristics plus all geo-spatial characteristics was able to explain almost 80 per cent of the variation in the log of house prices. This was described as Model 1 in Hill and Melser's documentation (Table 8). We work with this model for current purposes.

In the models estimated by Hill and Melser the dependent variable is the natural logarithm of house prices. The geo-spatial variables enter the model as the natural logarithm of the variable plus the natural logarithm of the variable, all squared.

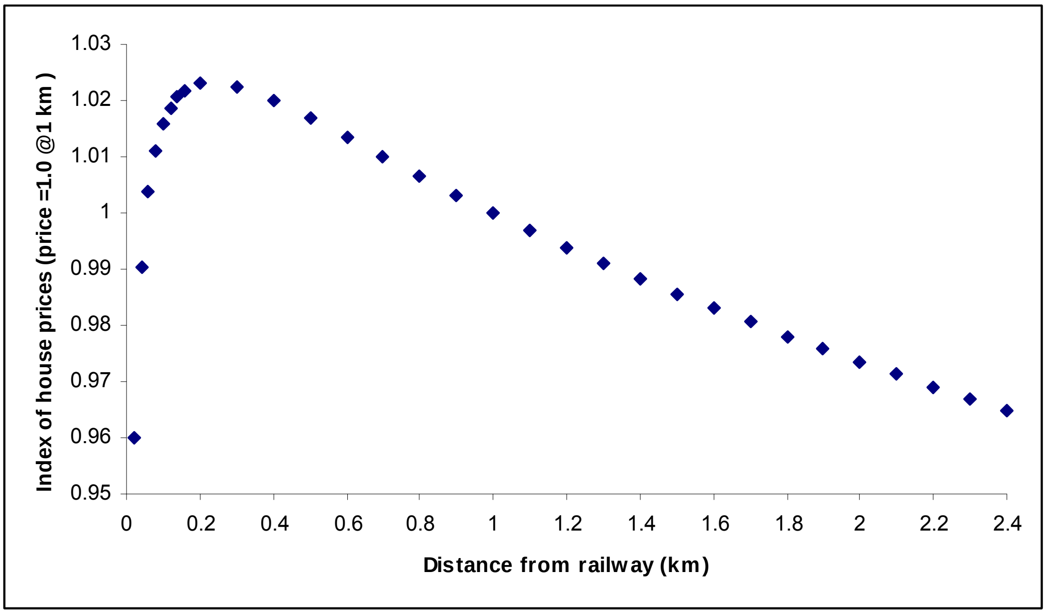
We reproduce in Table 2 the estimated coefficients of the railway distance variables in the Hill and Melser model. Both coefficients are highly significantly different from zero. To examine the estimated effect of distance from a railway has on house prices we need to obtain data on house prices and the distance from the railway of the house.

Table 2: Estimated parameters of distance to railway variable in the Hill and Melser Model 1

Variable	Estimated coefficient	Standard error of estimate
Log(Distance to railway)	-0.0314	0.0034
(Log(Distance to railway))^2	-0.0107	0.0022

We plot the calculated value of a house (indexed to equal 1 when the house is 1 kilometre from a railway) using Hill and Melser's results given in Figure 1.

Figure 1 : Calculated effect of provision of passenger rail services on house prices (Index house price = 1 when house is 1 km from railway)



Source: CRA calculations.

These calculations indicate that:

- Compared to a house 1 kilometre from a railway station, prices are lower if a house is under half a kilometre from a railway station;
- House prices continue to rise as the distance from the station rises to about 0.25 kilometres and thereafter prices fall; and
- Beyond a distance of 1 kilometre from a station house prices are lower compared to a house 1 kilometre from a railway station.

Effectively, what Hill and Melser's regression results have done is to compare house prices relative to houses that are 1 kilometre from a railway, holding all other factors which affect house prices constant.

The effects of rail distance on house prices outlined above have an intuitive appeal. One interpretation is that two interactive effects are at work in the determination of the effect of railway distances and house prices. First, there is an inconvenience effect if residences are located close to a rail station. This could be caused by the proximity to the station leading to additional noise and additional foot and motorised traffic, known as intrusion effects, as people travel by residences to stations to board trains.

This inconvenience effect outweighs the savings in time that residents who live very close to stations accrue as a result of living close to a station. However, as the distance from a station grows the inconvenience factor falls or vanishes and the effect on house prices is dominated by the travel time to stations effects.

Thus after 1 kilometres distance from the station the inconvenience effect is outweighed by the travel effect and house prices are lower than a house that is 1 kilometre from a railway.

14.2. DATA SOURCES AND ISSUES FOR PROPERTY PRICE ANALYSIS

In order to use the Hill and Melser results for the present purpose of valuing CityRail's contribution one needs data on current property prices and distances to railway stations. It is also necessary to hypothesise the distance relationships that would apply in the event that there was no rail service at all in Sydney. The factual basis of the first of these issues is taken up in the next subsection. The second issue is taken up in the following subsection.

14.2.1. House price and distance to rail data

Hill and Melser provided data from their analysis aggregated into 14 broad regions.[35] This data indicates that in most regions houses are located on average more than 1 kilometre from a railway (Table 3). Thus, the calculated effect of distance from railways has, in general, a negative impact on predicted house prices in the Hill and Melser results.

This does not mean that provision of railways reduced house prices in the data base. Rather, it indicates that most houses in the database were more that 1 kilometre away from a railway and so had prices lower that houses that were 1 kilometre away from a railway, other factors equal.

35 Individual house sale data could not be provided as the authors had obtained this data from a commercial data provider and the data was provided on the basis that it would not be provided to third parties. Thus Hill and Melser kindly provided the data aggregated into 14 regions: The broad regions and the postcodes covered by these regions were: Inner Sydney (2000 to 2020), Eastern Suburbs (2021 to 2036), Inner West (2037 to 2059), Lower North Shore (2060 to 2069), Upper North Shore (2070 to 2087), Mosman/Cremorne (2088 to 2091), Manly/Warringah (2092 to 2109), North Western (2110 to 2126), Western Suburbs (2127 to 2145), Parramatta Hills (2146 to 2159), Fairfield/Liverpool (2160 to 2189), Canterbury/Bankstown (2190 to 2200), St George (2201 to 2223), Cronulla/Sutherland (2224 to 2249), Campbelltown (2552 to 2570), Penrith/Windsor (2740 to 2771).

Table 3: House and rail distance data (2001-2003 prices)

Region	Number of house sales	Mean house price ($)	Mean rail distance (km.)
Inner Sydney	2,230	575,768	0.65
Eastern Suburbs	8,264	871,344	2.71
Inner West	3,755	663,499	1.32
Lower North Shore	3,032	847,509	1.29
Upper North Shore	2,588	808,702	1.91
Mosman & Cremorne	2,129	1,026,959	2.55
Manly Warringah	2,159	785,793	9.89
North Western	2,947	566,803	1.76
Western Suburbs	2,922	586,138	1.06
Parramatta Hills	949	438,437	3.41
Fairfield Liverpool	1,816	346,784	2.72
Canterbury Bankstown	1,602	419,452	1.09
St George	4,657	524,314	1.19
Cronulla Sutherland	2,104	642,359	1.78

Source: Daniel Melser, personal communications

We were also able to obtain this information at the postcode level. This data is presented in the table below.

			number			dollars Sep 2007		distance km
Postcode	Group	Group Name	Total private dwellings	Houses (by deduction)	Flats, units & apartments	Median value house price (current, Sep-07)	Median value unit price (current, Sep-07)	Postcode to nearest railway station (average for postcode)
2000	A	Inner Sydney	10,510	2,056	8,454	1,985,500	789,625	0.47
2009	A	Inner Sydney	5,816	1,775	4,041	808,000	483,500	0.20
2010	A	Inner Sydney	15,247	4,404	10,843	859,750	424,000	0.51
2011	A	Inner Sydney	11,035	3,208	7,828	1,927,500	467,750	0.63
2016	A	Inner Sydney	6,155	2,660	3,495	661,500	410,000	0.79
2018	A	Inner Sydney	6,342	3,359	2,982	718,750	330,750	1.82
2021	B	Eastern Suburbs	7,759	3,394	4,365	2,567,250	393,750	1.43
2022	B	Eastern Suburbs	5,031	2,243	2,788	1,251,750	515,000	0.76
2023	B	Eastern Suburbs	4,413	2,325	2,088	3,372,000	598,500	1.51
2024	B	Eastern Suburbs	5,658	2,523	3,135	1,581,500	505,500	1.82
2026	B	Eastern Suburbs	14,947	6,665	8,282	1,600,125	612,250	2.36
2027	B	Eastern Suburbs	4,085	2,152	1,933	4,850,333	1,153,000	0.93
2029	B	Eastern Suburbs	4,777	2,382	2,395	1,997,000	612,000	2.60
2030	B	Eastern Suburbs	6,678	3,275	3,403	2,679,500	555,250	4.69
2031	B	Eastern Suburbs	13,574	7,039	6,535	1,370,500	543,000	2.74
2032	B	Eastern Suburbs	6,591	3,455	3,136	995,000	429,500	3.42
2033	B	Eastern Suburbs	4,798	2,488	2,310	1,420,000	426,000	2.10
2034	B	Eastern Suburbs	8,201	4,253	3,948	1,420,000	528,750	4.23
2035	B	Eastern Suburbs	12,452	6,512	5,940	903,500	518,750	4.79
2036	B	Eastern Suburbs	10,899	5,827	5,072	852,200	367,500	6.46
2037	C	Inner West	6,933	2,130	4,802	788,750	433,750	1.10
2040	C	Inner West	9,375	7,057	2,318	736,250	516,500	0.62
2041	C	Inner West	6,792	5,113	1,680	1,248,167	618,833	1.54
2042	C	Inner West	8,034	4,430	3,603	636,000	339,250	0.50
2046	C	Inner West	11,142	6,822	4,320	967,750	499,600	2.80
2047	C	Inner West	4,780	2,927	1,853	1,046,500	567,500	2.67
2049	C	Inner West	4,663	3,058	1,605	676,000	363,750	0.22
2060	D	Lower North Shore	6,283	2,349	3,933	1,375,500	566,250	0.45
2064	D	Lower North Shore	4,152	2,541	1,611	1,343,500	456,500	0.22
2065	D	Lower North Shore	12,999	6,057	6,942	1,209,400	515,300	0.60
2066	D	Lower North Shore	11,248	6,661	4,586	1,439,000	407,250	2.48
2067	D	Lower North Shore	9,489	5,880	3,609	983,250	477,000	1.23
2068	D	Lower North Shore	6,297	3,876	2,421	1,285,600	451,500	2.42
2069	D	Lower North Shore	4,637	3,668	969	1,421,000	475,500	2.10
2070	E	Upper North Shore	3,923	3,501	422	1,328,750	461,000	1.19
2073	E	Upper North Shore	5,045	4,502	543	993,500	579,500	1.28
2074	E	Upper North Shore	7,087	6,324	763	1,010,625	618,167	1.74
2075	E	Upper North Shore	6,203	5,535	668	968,750	655,000	4.03
2076	E	Upper North Shore	8,039	6,717	1,322	781,167	464,250	0.98
2077	E	Upper North Shore	12,141	9,881	2,260	590,625	388,500	0.89
2086	E	Upper North Shore	5,107	3,568	1,539	764,000	621,000	5.38
2087	E	Upper North Shore	4,859	3,395	1,464	932,250	523,500	4.13
2088	F	Mosman/Cremorne	12,309	6,874	5,435	2,198,000	547,500	3.41
2089	F	Mosman/Cremorne	5,823	2,178	3,646	1,328,000	563,000	1.18
2090	F	Mosman/Cremorne	7,592	2,894	4,698	1,498,500	738,250	2.18
2093	G	Manly-Warringah	8,666	5,401	3,265	1,330,700	454,500	6.77
2095	G	Manly-Warringah	6,558	3,767	2,791	1,510,000	656,500	8.74
2096	G	Manly-Warringah	5,302	3,704	1,598	1,178,667	466,750	9.94
2097	G	Manly-Warringah	5,392	3,767	1,625	921,500	460,000	12.24
2099	G	Manly-Warringah	14,209	9,927	4,282	852,875	485,667	10.74
2100	G	Manly-Warringah	7,586	5,300	2,286	808,500	448,333	8.33
2101	G	Manly-Warringah	6,738	5,492	1,246	931,500	479,500	12.83
2107	G	Manly-Warringah	6,021	5,353	668	1,723,375	445,000	12.98
2111	H	North Western	5,384	3,931	1,453	1,154,000	481,250	4.02
2112	H	North Western	10,204	7,309	2,894	787,000	387,000	1.83
2113	H	North Western	6,546	4,689	1,857	699,750	432,250	3.77
2114	H	North Western	7,871	5,638	2,232	670,250	367,167	0.75
2117	H	North Western	6,889	6,000	889	576,750	351,000	0.79
2118	H	North Western	7,775	6,966	809	627,000	397,000	0.85
2120	H	North Western	7,382	5,608	1,775	647,833	426,000	1.35
2121	H	North Western	9,005	7,071	1,933	750,750	410,500	0.76
2122	H	North Western	11,661	8,525	3,135	744,750	376,500	1.23
2125	H	North Western	5,538	5,035	503	734,000	479,000	3.11
2126	H	North Western	6,587	6,402	185	670,500	466,000	3.14
2131	I	Western Surburbs	9,151	5,126	4,025	702,500	333,500	0.26
2133	I	Western Surburbs	4,017	2,626	1,391	615,000	304,500	1.61

14.2.2. Specification of "no rail" scenario

It remains to identify what rail distance relationship to assume for the case of no rail service at all, in order to quantify the beneficial impact of the rail network on Sydney house prices. The Hill and Melser regression parameters will generate an arbitrarily large rail distance effect when distances to the nearest train station are increased substantially. In practice, though, it seems more likely that some form of distance threshold effect is at work. In other words, once the distance to the nearest train station exceeds some threshold, the station might as well be 100km away.

In selecting a distance cutoff for this purpose, regard was had to two pieces of information. First, the 75th percentile of average distance to the nearest train station for all postcodes included in the Hill and Melser study is 2.74km. Second, the 75th percentile of distances between adjacent train stations is 2.96km. Taking into account these reference points, a cutoff of 3km was selected.

The reasoning behind this choice is that the location of train stations is selected on the basis of likely catchment areas. Large station spacings tend not to be employed because of the risk that potential customers will be unwilling to travel more than a certain distance to access train services. The 75th percentile point for station spacings represents an indicator of how far people may be willing to travel to access train services. A 3 km cutoff would also include, as potential train-using postcodes, more than 75% of the postcodes included in the Hill and Melser study.

14.3. RESULTS OF PROPERTY PRICE ANALYSIS

Employing the Hill and Melser regression parameters for rail distance and a 3km cutoff (that is, assuming that postcodes situated more than 3 km from the nearest train station do not obtain any value from the availability of rail, and that in the absence of a rail network other postcodes would have the rail coefficient equivalent to a 3 km distance to the nearest station), the following aggregate effect on house prices is predicted. The sum of the incremental value of proximity to rail across all postcodes is shown in the upper right corner of the table below.

		number			dollars per dwelling		19,560,988,831
Postcode	Group Name	Total private dwellings	Houses (by deduction)	Flats, units & apartments	House price incr due to rail	Flat price incr due to rail	Incr value housing stock due to rail ($ total)
2000	Inner Sydney	10,510	2,056	8,454	124,971	49,701	677,130,837
2009	Inner Sydney	5,816	1,775	4,041	54,799	32,792	229,758,732
2010	Inner Sydney	15,247	4,404	10,843	53,182	26,228	518,593,330
2011	Inner Sydney	11,035	3,208	7,828	111,663	27,097	570,269,182
2016	Inner Sydney	6,155	2,660	3,495	34,875	21,616	168,315,231
2018	Inner Sydney	6,342	3,359	2,982	17,508	8,057	82,843,310
2021	Eastern Suburbs	7,759	3,394	4,365	87,979	13,494	357,479,252
2022	Eastern Suburbs	5,031	2,243	2,788	67,446	27,749	228,675,203
2023	Eastern Suburbs	4,413	2,325	2,088	108,080	19,183	291,364,277
2024	Eastern Suburbs	5,658	2,523	3,135	38,530	12,315	135,805,182
2026	Eastern Suburbs	14,947	6,665	8,282	20,117	7,697	197,824,570
2027	Eastern Suburbs	4,085	2,152	1,933	234,886	55,836	613,462,253
2029	Eastern Suburbs	4,777	2,382	2,395	15,313	4,693	47,713,793
2030	Eastern Suburbs	6,678	3,275	3,403	-	-	-
2031	Eastern Suburbs	13,574	7,039	6,535	6,554	2,597	63,108,032
2032	Eastern Suburbs	6,591	3,455	3,136	-	-	-
2033	Eastern Suburbs	4,798	2,488	2,310	25,559	7,668	81,304,150
2034	Eastern Suburbs	8,201	4,253	3,948	-	-	-
2035	Eastern Suburbs	12,452	6,512	5,940	-	-	-
2036	Eastern Suburbs	10,899	5,827	5,072	-	-	-
2037	Inner West	6,933	2,130	4,802	34,177	18,795	163,071,232
2040	Inner West	9,375	7,057	2,318	42,960	30,138	373,038,881
2041	Inner West	6,792	5,113	1,680	39,020	19,346	231,989,227
2042	Inner West	8,034	4,430	3,603	39,454	21,045	250,631,156
2046	Inner West	11,142	6,822	4,320	3,541	1,828	32,050,520
2047	Inner West	4,780	2,927	1,853	6,478	3,513	25,472,046
2049	Inner West	4,663	3,058	1,605	45,964	24,733	180,244,044
2060	Lower North Shore	6,283	2,349	3,933	87,397	35,979	346,845,756
2064	Lower North Shore	4,152	2,541	1,611	91,371	31,046	282,166,858
2065	Lower North Shore	12,999	6,057	6,942	71,125	30,305	641,196,074
2066	Lower North Shore	11,248	6,661	4,586	14,467	4,094	115,142,282
2067	Lower North Shore	9,489	5,880	3,609	38,878	18,861	296,681,451
2068	Lower North Shore	6,297	3,876	2,421	14,354	5,041	67,841,165
2069	Lower North Shore	4,637	3,668	969	25,508	8,536	101,832,902
2070	Upper North Shore	3,923	3,501	422	54,138	18,783	197,454,227
2073	Upper North Shore	5,045	4,502	543	38,046	22,192	183,321,064
2074	Upper North Shore	7,087	6,324	763	26,681	16,320	181,181,378
2075	Upper North Shore	6,203	5,535	668	-	-	-
2076	Upper North Shore	8,039	6,717	1,322	36,595	21,749	274,559,183
2077	Upper North Shore	12,141	9,881	2,260	29,392	19,333	334,121,413
2086	Upper North Shore	5,107	3,568	1,539	-	-	-
2087	Upper North Shore	4,859	3,395	1,464	-	-	-
2088	Mosman/Cremorne	12,309	6,874	5,435	-	-	-
2089	Mosman/Cremorne	5,823	2,178	3,646	54,436	23,078	202,672,537
2090	Mosman/Cremorne	7,592	2,894	4,698	24,323	11,983	126,682,626
2093	Manly-Warringah	8,666	5,401	3,265	-	-	-
2095	Manly-Warringah	6,558	3,767	2,791	-	-	-
2096	Manly-Warringah	5,302	3,704	1,598	-	-	-
2097	Manly-Warringah	5,392	3,767	1,625	-	-	-
2099	Manly-Warringah	14,209	9,927	4,282	-	-	-
2100	Manly-Warringah	7,586	5,300	2,286	-	-	-
2101	Manly-Warringah	6,738	5,492	1,246	-	-	-
2107	Manly-Warringah	6,021	5,353	668	-	-	-
2111	North Western	5,384	3,931	1,453	-	-	-
2112	North Western	10,204	7,309	2,894	19,010	9,348	166,004,025
2113	North Western	6,546	4,689	1,857	-	-	-
2114	North Western	7,871	5,638	2,232	36,304	19,888	249,087,092
2117	North Western	6,889	6,000	889	30,430	18,519	199,050,343
2118	North Western	7,775	6,966	809	31,834	20,156	238,059,458
2120	North Western	7,382	5,608	1,775	23,515	15,463	159,309,698
2121	North Western	9,005	7,071	1,933	40,263	22,015	327,281,009
2122	North Western	11,661	8,525	3,135	29,489	14,908	298,145,921
2125	North Western	5,538	5,035	503	-	-	-
2126	North Western	6,587	6,402	185	-	-	-
2131	Western Surburbs	9,151	5,126	4,025	47,672	22,632	335,468,897
2133	Western Surburbs	4,017	2,626	1,391	18,225	9,024	60,414,482

It is necessary to convert the capital value effect of $19.561b to an annuity. In order to do so, it is necessary to specify a real discount rate and a time period over which the capital value is to be amortised. As the valuation in question pertains to the land itself, rather than the dwelling constructed on it,[36] it is appropriate to consider very long time periods. The precise length of the period does not strongly affect the annuity within the range 50 – 300 years, however, so the result is not sensitive to this parameter. The table below illustrates a range of annuity values under various assumptions.

capital value $b 2007	19.561		distance cutoff (km)				3
discount rate	7%	8%	9%	10%	11%	12%	6%
term (yrs)	100	100	100	100	100	100	100
annuity ($m)	1,371	1,566	1,761	1,956	2,152	2,347	1,177
discount rate	7%	8%	9%	10%	11%	12%	6%
term (yrs)	300	300	300	300	300	300	300
annuity ($m)	1,369	1,565	1,760	1,956	2,152	2,347	1,174
discount rate	7%	8%	9%	10%	11%	12%	6%
term (yrs)	50	50	50	50	50	50	50
annuity ($m)	1,417	1,599	1,784	1,973	2,163	2,355	1,241

Employing mid-range real discount rates, the annuity is approximately $1.4b.

36 The effects of dwelling characteristics on house price were identified as separate regression variables in the Hill and Melser study.