Value of Sydney bus externalities and optimal Government subsidy

DRAFT REPORT

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Table of Contents

1 Executive summary

Bus services provide benefit to the NSW community in two main ways. Bus passengers derive consumer surplus by purchasing bus journeys at prices that are less than their private valuation of those journeys. Non-bus passengers derive benefits from the fact that others purchase bus journeys and therefore consume less private automobile 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 external benefits created by Sydney bus services. The analysis has been conducted in such a way that it is possible to consider what level of external benefit would be achieved at various different levels of average fare, bus patronage, and Government subsidy.

Our approach to the question of what level of Government financial support for Sydney bus services 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 bus subsidy. With an empirically grounded understanding of the relationship between net welfare and bus patronage, I 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 Nature of externality

In the present setting, an externality is a cost or a benefit to a party other than the purchaser or provider of bus services that is caused by the provision or consumption of bus 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 bus 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 bus 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 that its purpose is to assist IPART in developing a framework to estimate the social costs and benefits (also known as externalities) arising from bus services, and to use this framework to derive the optimal contribution by the Government to bus service costs. It is therefore useful to view the process of establishing an appropriate Government contribution as an optimisation problem.

The following main pieces of work have been undertaken to provide empirical substance to the conceptual analysis summarised above.

- Estimation of the marginal cost function for bus services;
- Estimation of the displacement of automobile and rail traffic by bus services;
- Estimation of the marginal external benefit function for bus services based on their ability to displace automobile traffic.

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. The quantitative analysis follows the same approach employed in an earlier LECG study, "An empirical estimate of CityRail's marginal costs and externalities," prepared for IPART by Mike Smart, 20 Nov 2008.

1.2 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 bus 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 bus travel.

Relationships between bus patronage and these external costs to motorists were able to be established with some confidence through the Sydney Strategic Travel Model runs.

1.3 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 bus;

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 bus patronage scenario in a manner that reflected the higher fuel consumption rates per vehicle kilometre when congestion slows traffic.

I applied a carbon price of \$25/tonne CO2 for the estimate of greenhouse gas externalities. For conventional air pollution effects of automobiles and buses, I employed pollution-related health cost estimates contained in Beer (2002).

1.4 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 bus patronage.

1.5 Marginal external benefit function

It has been possible to combine the relationships between each type of external benefit and bus patronage into a single marginal external benefit function. The most important individual contributor to overall marginal external benefit is relief from the congestion cost experienced by motorists (experienced as the value of time spent driving or being a passenger in a car).

Using a value of travel time of $15.80/hr and a carbon cost of $25/tonne of CO2, the results of the foregoing estimations can be translated to linear marginal external costs functions of patronage, for each component of the external cost of bus service, shown in Table 1.1 below. As bus patronage increases (going down the table), there are some small changes to the marginal external cost per bus passenger journey.

In examining costs per bus passenger journey, it is important to recognise that fuel consumption is driven primarily by bus-kilometres travelled. An empty bus is likely to generate nearly as much conventional air pollution as a full one travelling the same distance, because fuel consumption is not strongly affected by the number of passengers carried (although the stopping pattern, which is affected by the passenger load, will have some effect on fuel consumption.) The modelling framework adopted here has focused on bus passenger journeys as the driver of external costs and benefits. Where there are wide variations between bus passenger journeys (for which the external cost of bus air pollution is assessed here) and bus-kilometres (which are the actual main driver of bus air pollution), the figures produced in this study may tend to exaggerate the per-passenger-journey impact of bus air pollution for lightly utilised bus services.

Table 1.1 Marginal external costs per bus passenger journey estimated for work trips 2006-07

Marginal external costs ($/BPJ)

	work trips									
BPJ/workday	auto VOT	CRF train VOT CRF	bus VOT	auto GHG	auto airpol	auto fuel	bus GHG	bus airpol	bus fuel	mec
-	- 1.07	-	-	- 0.03	- 0.52	- 0.03	0.00	0.19	-	-1.46
50,000	- 1.06	-	-	- 0.03	- 0.52	- 0.03	0.00	0.19	-	-1.45
100,000	- 1.05	-	-	- 0.03	- 0.52	- 0.03	0.00	0.19	-	-1.44
150,000	- 1.05	-	-	- 0.03	- 0.52	- 0.03	0.00	0.19	-	-1.43
200,000	- 1.04	-	-	- 0.03	- 0.52	- 0.03	0.00	0.19	-	-1.42
250,000	- 1.03	-	-	- 0.03	- 0.52	- 0.03	0.00	0.19	-	-1.42
300,000	- 1.02	-	-	- 0.03	- 0.52	- 0.03	0.00	0.19	-	-1.41
400,000	- 1.01	-	-	- 0.03	- 0.52	- 0.03	0.00	0.19	-	-1.39
500,000	- 0.99	-	-	- 0.03	- 0.52	- 0.03	0.00	0.19	-	-1.38
600,000	- 0.98	-	-	- 0.03	- 0.51	- 0.03	0.00	0.19	-	-1.36
700,000	- 0.96	-	-	- 0.03	- 0.51	- 0.03	0.00	0.19	-	-1.34
800,000	- 0.95	-	-	- 0.03	- 0.51	- 0.03	0.00	0.19	-	-1.33

This table shows how each of the components of the marginal external benefits of bus travel vary with the overall level of bus patronage, shown in the first column. The components are, from left to right: automobile congestion (“auto VOT”), train congestion (“CRF train VOT”, which is zero), bus congestion (“bus VOT”, which is assumed to be zero), automobile greenhouse gas emissions (“auto GHG”), conventional air pollution from automobiles (“auto airpol”), the external costs associated with excess fuel consumption by motorists in congested conditions (“auto fuel”), bus greenhouse gas emissions (“bus GHG”, which are a disbenefit to bus travel), conventional air pollution from buses (“bus airpol”, also a disbenefit to bus travel), the external costs associated with excess fuel consumption by buses in congested conditions (“bus fuel”, which is assumed to be zero), and the sum of these externalities (“mec”, which stands for the marginal external cost of bus travel, expressed in units of $ per bus passenger journey).

As the net marginal external cost of bus travel are negative, they represent a marginal external benefit.

The total marginal external benefit to bus is the marginal external cost with the sign reversed. A negative cost is a positive benefit and vice versa. For work trips, the marginal external benefit (which is the sum of the components shown in the table above) begins at the maximum value of $1.46/bus passenger journey ("BPJ") when bus patronage is near zero and decreases as bus patronage increases—the marginal external benefit per passenger journey declines as more passengers choose to travel by bus.

The principal contributor to the marginal external benefit is the marginal external cost of congestion for automobiles (labelled "auto VOT", referring to the value of travel time incurred because of congestion). Of the other components of the marginal externality, the adverse effects of automobile air pollution are also significant, even when the adverse effects of bus air pollution are netted off. Other terms in the calculation make only a second-order contribution to the overall result.

Total external benefits at current levels of patronage have been estimated based on the marginal external benefit functions summarised above. These are presented in Table 1.2 below, along with per-passenger journey figures for CityRail derived in a separate study by LECG.

Table 1.2 Total external benefit of bus and rail—totals and per journey 2006-07

	Total external benefit $m/yr		Total external benefit $/pax journey		
Source of benefit	**Four largest contract regions (reg 6-9)**	**Metro buses**	**Four largest contract regions (reg 6-9)**	**Metro buses**	**CityRail**
Avoided road congestion	176.0	236.8	1.07	1.03	4.94
Net Avoided air pollution	37.3	75.8	0.23	0.33	1.61
Net Avoided greenhouse gas	3.2	6.1	0.02	0.03	0.09
Avoided noise pollution	-	-	-	-	-
Avoided road accidents	-	-	-	-	-
Avoided road damage	-	-	-	-	-
Total net external benefits	216.5	318.7	1.32	1.39	6.64

This table shows total external benefits by benefit type for the four largest contract regions (regions 6 to 9 operated by the State Transit Authority ("STA")) buses and for buses as a whole in the Sydney metropolitan area. The box on the right-hand side of the table presents the same information on a basis of dollars per passenger journey. These unit values are compared to unit values derived in the 2008 externality study for CityRail. Since the CityRail study, the air pollution cost figures have been updated, resulting in higher external benefits for this effect.

It is significant that the avoided road congestion benefits of buses are much smaller than those for CityRail services on a per passenger journey basis. Not only do buses carry far fewer passenger kilometres than rail, but each rail passenger journey displaces a greater number of automobile passenger kilometres. This result arises in part because train journeys are significantly longer on average than bus journeys. The effect of displaced auto passenger kilometres on travel time is non-linear: doubling the number of passenger kilometres will make a four-fold difference to travel time. Another contributing factor is likely to be the spatial layout of the rail network. Rail lines tend to parallel the most congested road arteries into and out of the CBD and other urban centres such as Parramatta and North Sydney, so a motorist switching to rail will be removed from a highly congested route. In contrast, the bus network is more evenly dispersed across the metropolitan area, covering a great many areas of lower traffic density, so a motorist switching to bus will often be removed from an uncongested route. A further factor, which may not be reflected in the traffic modelling results, is that trains get commuters off the road entirely, whereas buses keep them on the road contributing something to congestion.

The air pollution benefit per passenger journey is greater in the metropolitan area overall than it is in the four largest contract regions alone. The reason is that bus journeys are shorter, on average, in the four largest contract regions, owing to the fact that homes and workplaces are generally closer together in those regions. As the bus journeys are shorter, a bus journey displaces a shorter automobile journey in the four largest contract regions. The air pollution thus avoided is less, per bus journey, than it would be in the outer regions of Sydney.

1.6 Optimisation

I developed a framework to estimate the social costs and benefits arising from bus passenger services, and to use this framework to derive the appropriate contribution by Government to bus service costs. It is apparent that the social benefits depend on the extent to which passengers use buses, and that the fare is an important determinant of passenger use. There is, in fact, a tradeoff: higher fares mean buses are 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 bus 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 (an operating loss) and significant tax distortions (to fund the operating loss through government subsidy), but high patronage, consumer surplus, 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.

There are three main uncertainties that determine the optimal levels of fare, patronage and Government subsidy:

- The true marginal cost of bus service;
- The value of passenger time (ranging from \$9.23/hr or \$22.60/hr, with a central value of \$15.80/hr), which influences the slope and y-intercept of the marginal external benefit function; and
- 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).

The first six rows in the Table 1.3 below show the optimal single fare (in column p*) for the Sydney metropolitan bus service region as a whole. Whether this optimal fare is higher or lower than the current fare, “p0,” depends largely on the assumed value of the marginal cost. Higher marginal costs lead to higher optimal fares, and vice versa. In the central case (highlighted in the table), with marginal cost set at the arithmetic mean of the high and low values and with the taxation factor, “d,” set to 0.1, the optimal fares are close to current fares. Importantly, the welfare gain to be had by moving from current to optimal fares (shown in column “W* - W0”) is quite low in this central case.

Table 1.3 Optimisation results with sensitivities shown 2006-07

Sensitivity result table									
			$/BPJ	$/BPJ	pax/workday	$/workday	$m/yr	% fare	$m/yr
case name	reg name	d	p0	p*	q*	W* - W0	W* - W0	increase	GC*
sf low MC	MBSC	0	1.51	0.64	1,329,061	156,583	39.15	-58%	697.06
sf low MC	MBSC	0.1	1.51	0.88	1,154,602	63,679	15.92	-41%	581.46
sf mid MC	MBSC	0	1.51	1.15	1,033,840	20,626	5.16	-24%	510.78
sf mid MC	MBSC	0.1	1.51	1.51	919,398	0	0.00	0%	405.61
sf high MC	MBSC	0	1.51	1.68	878,708	3,615	0.90	11%	360.48
sf high MC	MBSC	0.1	1.51	2.15	791,549	42,302	10.58	42%	259.12
sf low MC	MBSC-hiVOT	0.1	1.51	0.54	1,429,829	202,303	50.58	-65%	760.00
sf mid MC	MBSC-hiVOT	0.1	1.51	1.11	1,047,222	23,738	5.93	-26%	522.59
sf high MC	MBSC-hiVOT	0.1	1.51	1.73	867,430	5,760	1.44	15%	347.73
sf low MC	MBSC-loVOT	0.1	1.51	1.27	990,468	7,936	1.98	-16%	461.88
sf mid MC	MBSC-loVOT	0.1	1.51	1.91	831,342	17,705	4.43	27%	318.49
sf high MC	MBSC-loVOT	0.1	1.51	2.56	734,680	103,336	25.83	69%	188.96
sf low MC	4 largest regions	0	1.47	0.90	807,334	44,293	11.07	-39%	353.39
sf low MC	4 largest regions	0.1	1.47	1.18	718,943	8,452	2.11	-19%	283.09
sf mid MC	4 largest regions	0	1.47	1.28	697,243	4,236	1.06	-13%	268.96
sf mid MC	4 largest regions	0.1	1.47	1.67	623,009	3,444	0.86	14%	192.30
sf high MC	4 largest regions	0	1.47	1.67	622,808	3,903	0.98	14%	188.31
sf high MC	4 largest regions	0.1	1.47	2.18	558,355	36,433	9.11	48%	106.33

Table 1.3 also shows the optimisation results for the four largest contract regions considered separately. In the central case optimal fares are 14% higher than actual fares but the welfare gains from fare reform are modest (approximately 0.5% of the current Government Contribution.)

The effect of employing the high and low estimates of the value of time, which flows through to the congestion externality, is also shown in Table 1.3. As the congestion externality is numerically the most significant external effect, changing the value of time has a marked influence on the results.

1.7 Conclusions

This study has proposed a new method of calculating the optimal settings for bus average fare per passenger journey, bus patronage, and the total level of Government subsidisation for the bus system's operating loss. 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 bus system subsidy. With an empirically grounded understanding of the relationship between net welfare and bus patronage, I have been able to calculate optimal levels of net welfare, and the policy settings (average fare and Government subsidy) needed to obtain those optima.

The quantification of externalities performed in this study has permitted us to reach the following conclusions.

1. The marginal external benefit derived from bus travel in the Sydney metropolitan region is approximately $1.40 per bus passenger journey. The precise value depends on the total quantum of bus travel during a typical workday.

2. The total external benefit from the four largest contract regions is estimated to be $217m/yr, of which $176m/yr is attributable to avoided road congestion and $37m/yr is attributable to net avoided air pollution.

3. For buses in the Sydney metropolitan region overall (including all contract regions), the total external benefit is estimated to be $319m/yr, of which $237m/yr is attributable to avoided congestion and $76m/yr is attributable to net avoided air pollution.

4. Bus fares overall are close to optimal levels, if the marginal cost of bus travel is reasonably approximated by the arithmetic mean of the high and low marginal cost values estimated in this report, and if the marginal excess burden of taxation is 0.1.

5. If the marginal cost is the arithmetic mean of the high and low marginal cost values and the marginal excess burden of taxation is 0.1, optimal bus fares for the four largest contract regions are 14% higher than current fares, although moving fares to the optimal levels would have only a slight positive impact on welfare. If the marginal excess burden of taxation were zero, however, small fare reductions would be optimal. The conclusion is therefore sensitive to this uncertain parameter.

6. Current effective average bus fares for non-work trips are lower than for work trips, owing to the fact that a different mix of ticket types is purchased by non-work travellers, and significant sections of the non-work travelling public (particularly students travelling on the SSTS) pay nearly nothing to use buses.

7. Of course, it is recognised that social policy objectives, including subsidised student and pensioner travel, are served by the current fare settings for non-work travel and these objectives must be weighed against economic efficiency criteria.

8. These conclusions have been tested for sensitivity to changes in the marginal cost of bus travel, marginal excess burden of taxation, and to the value of time. The optimal fare outcomes are highly sensitive to changes in the marginal cost value. The present marginal cost estimates may not form a sufficiently reliable basis for fare-setting since they are based on contract, rather than resource costs

and they do not capture fully the relationship between marginal cost and bus occupancy.

9. In order to improve estimates of marginal cost it would be necessary to investigate the accounts and operating methods of the bus operating companies in some detail. Two issues, in particular, require further investigation:

   - The relationship between bus contract costs and actual efficient costs faced by the bus operators; and

   - The relationship between traffic-sensitive costs of the bus operator and average bus occupancy.

An additional important caveat applies to the optimisation results presented in this draft report. Marginal external benefit rates have been calculated using data from the Transport Data Centre's Sydney Strategic Travel Model ("STM") for work trips only. It has been assumed that the same marginal external benefit rate per bus passenger journey applies to non-work trips. So far, it has not been possible to test this assumption, but it is entirely possible that it may lead to an overstatement of the congestion-avoidance attributable to non-work bus trips, since many of these trips occur outside of peak hours.

2 Introduction

2.1 The task

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

LECG was also asked to consider work and non-work journeys separately, and to estimate, to the extent possible, optimal fares and levels of Government support for each of the 15 metropolitan bus service contract regions.

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 bus services that is caused by the provision or consumption of bus 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 bus service. For example, many of the external benefits ascribed to bus 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 bus mode instead of road, the more these external costs are avoided. The existence of a bus alternative makes it possible to avoid some of these external costs. The actual usage of bus is what generates the external benefit. A bus network that no one used would generate negligible external benefits.

Externalities are relevant to the assessment of the benefits generated by the bus system. A simple assessment of the bus system's benefits would look at the consumer surplus it generates to users, but bus has two important characteristics that require extensions to the analysis. First, bus is subsidised by the government because fares are set below average costs. Second, because bus competes with automobiles 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 public transport 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, I have undertaken analysis with a distinctly empirical emphasis that is firmly grounded in the particular circumstances facing bus services in Sydney. I 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 bus services would be welfare-optimal?

The external costs and benefits associated with urban public transport 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 bus use. However it is impractical to study this modal shift in a meaningful way without taking into account the specific spatial characteristics of the Sydney commuter network and of passenger flows through Sydney.

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

- 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 public transport 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 buses 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 bus 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 bus 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, the bus system finds itself in a second-best world wherein Government subsidies are required to achieve the internal and external welfare benefits that might otherwise have been achieved with road pricing and a fully commercial bus 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 bus services. The remainder of this report proceeds on the presumption that the bus system 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 that its purpose is to assist IPART in developing a framework to estimate the social costs and benefits (also known as externalities) arising from bus services, and to use this framework to derive the optimal contribution by the Government to bus service costs. It is therefore useful to view the process of establishing an appropriate Government contribution as an optimisation problem.

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 the bus system 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 the bus system. As noted earlier, however, service quality is difficult to measure on a consistent historic basis.

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 bus 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. 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.

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 buses, the greater the subsidy level the Government should consider appropriate. This does not mean, however, that the dollar value of the Government subsidy should necessarily exactly equal the dollar value of the external benefit generated by buses.

The mathematically optimal subsidy may not precisely equal the external benefit at the optimum patronage level. Also, there are obstacles, in the form of information deficiencies, that impede attainment of a highly accurate estimate of the mathematically optimal subsidy. For this reason, among others, IPART applied a different approach to mathematical optimisation in its determination of CityRail fares.

3.2.2 Discussion of welfare effects of externalities

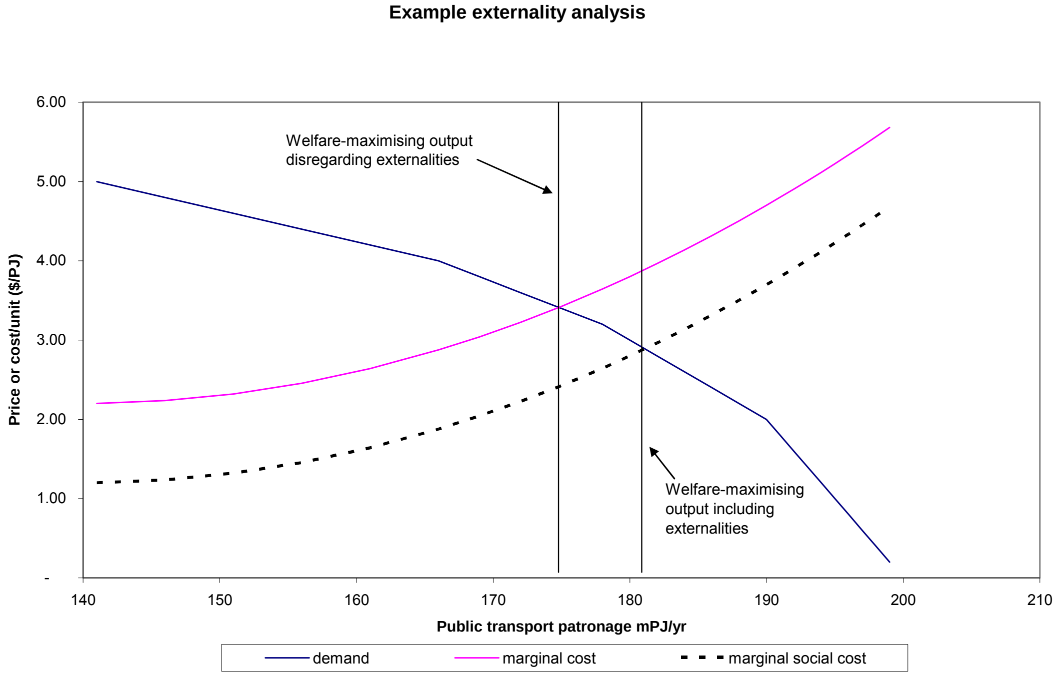
In the absence of externalities and ignoring the welfare costs associated with taxation, the socially optimal level of bus patronage would be the amount at which price equals marginal cost,[1] as the deadweight loss is minimised at that point. In the present case, however, the bus system generates external benefits which depend most directly on the amount of usage of bus services. The implications of this fact for the socially optimal level of bus output is set out below in conceptual terms.

Figure 3.1 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.

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 bus 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.

[1] This statement ignores the welfare costs of imposing taxation to fund the subsidy required to meet the fixed costs of bus operation. If users of bus 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 bus travel are significant in total and widely dispersed motivates the use of subsidy funding from taxation receipts.

Figure 3.1 Hypothetical example of the effect of externalities on optimal prices



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. 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 leisure 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.[2] This loss should be part of the marginal welfare analysis used in the optimisation of Government subsidy to buses. In subsequent analysis I assume that the deadweight loss associated with taxation raised to fund the bus operating deficit, is 0.1 times the amount of tax revenue raised,[3] and I 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 bus fare structure. LECG'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 the bus system. This objective might conceivably be achieved by attempting to set average fares equal to the average cost per passenger journey of running buses. 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.

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2 Commodity taxes, for example, shift the supply schedule for all taxed commodities upward. This shift moves the equilibrium prices up and the equilibrium quantities purchased down. As a result there is a deadweight loss to society from the imposition of the tax. Some consumers will not purchase some goods and services even though their private valuation of these products exceeds the marginal cost of producing them. This loss is separate from and in addition to the administrative cost of collecting the tax. This loss is also separate from the loss of revenue by the firms that are taxed, which is simply a transfer from themselves to government. Income taxes shift the demand schedule downward for almost all goods and services (except, perhaps, for taxation advice!). This shift will also reduce equilibrium quantities, but it will likely lead to a decrease in prices. The reduction in quantities purchased will also lead to a deadweight loss.

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 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.

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 bus 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 bus system, which are substantial. If a primary driver of bus subsidisation is the desire to capture external benefits generated by bus, 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 our research program, the following steps have been undertaken:

1. Determine the socially optimal level of bus patronage, given current or expected future settings of the key environmental variables;
2. Determine what average bus fare level, given current fare structures and relativities between different fare categories, would encourage that optimal level of patronage; and

3. Determine what level of Government subsidy would be necessary to support the bus system 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

The following main pieces of work have been undertaken to provide empirical substance to the conceptual analysis summarised above.

1. Econometric estimation of the marginal cost of bus service was performed using confidential bus contract data provided by the Ministry of Transport.

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

3.3.2 Externality calculation process

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

Third, it is necessary to establish the relationship between bus 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 buses.

Fourth, with a knowledge of the quantitative extent of automobile displacement by bus 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 CO_2 and other pollutants released to the atmosphere.

- 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 bus patronage scenarios there are more automobile kilometres travelled each day, but the average speed may decrease as congestion becomes more severe.[4] 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 4 – 10 below. Following that presentation, chapter 11 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 12 presents the derivation of inputs needed for a region-specific optimisation analysis, and chapter 13 presents the results and sensitivity analysis at the regional level. Chapter 14 presents the conclusions.

4 Prices and demand elasticity for bus services

In this chapter I address two empirical questions:

(1) what is the actual average bus fare paid by passengers for work and non-work trips? and

(2) what is the own-price demand elasticity for bus travel for work and non-work purposes?

One subsection is devoted to each of these questions below.

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

4.1 Actual average bus fares

Confidential contract data for the 15 MBSC regions for the 2006-07 year was used to derive average fares. They were calculated by dividing the farebox revenue total for each region by the number of non-SSTS bus passenger journeys in that region. The results are confidential so they cannot be shown.

Note that these average fares were derived by dividing the total fare revenue in each region by the total number of passengers, excluding SSTS passengers. They therefore represent a weighted average of full-fare tickets and concession tickets. For this reason one cannot directly draw conclusions for full-fare ticket prices from these numbers. Nevertheless, if full-fare and concession ticket prices are changed by the same percentage, and if these price changes do not alter the relativity of full-fare to concession passenger numbers, then the percentage price changes considered later in this report could be applied to current full-fare ticket prices to derive new full-fare prices.

It is notable that the average fares derived in this manner differ markedly from the average fares reported by the STA for 2006-07. The reported average fare for Sydney Buses was approximately $2.40 per passenger, as derived from a chart in the Auditor General's Report to Parliament 2007 Volume Five, p. 286. While the average fares reported in that chart for the four prior years are slightly lower, they are all above $2.00 per passenger. The note to that chart states that "*Revenue from 2001-02 to 2004-05 includes revenue received from passengers and payments from Government for providing free and concessional travel and CSOs. Revenue for 2005-06 to 2006-07 includes payments received under the provisions of the Metropolitan Bus System Contracts.*"

The difference between the average fare based on contract data and the average fare based on annual report data arises because a significant part of the STA's reported operational revenue is derived from the Government rather than passengers. This conclusion is confirmed by the following facts. The difference between the gross contract payments[5] to STA for both its MBSC and OMBSC regions and the farebox revenue derived in those regions (the net requirement for Government support derived from the contract data) is nearly exactly equal to the 2006-07 budgeted amount for "State Transit Authority Services" in the 2006-07 Budget Estimates for the Ministry of Transport.[6]

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5 This gross contract payment aligns closely with, and therefore appears to be the revenue reported by STA in its annual report.

6 NSW Budget Estimates 2006-07, 50.2.1 Contracting and Regulating Transport Services (cont), p. 19-24.

The significance of this point is twofold. First, the cost shares borne by passengers versus Government will only be understood accurately if the fares used in analysis represent payments by passengers. Second, the elasticity of demand for bus travel will only be meaningful if the price used is the price actually paid by passengers. In short, the average fare figures reported in the STA annual reports do not represent a reliable basis for economic analysis because they include an element of Government subsidy, even though it is not referred to as "subsidy".

4.2 Differences between work and non-work fares

Bus ticket pricing does not distinguish between journeys undertaken for a work purpose and those undertaken for a non-work purpose. Nevertheless, certain ticket types are more likely to be used by commuters than non-work travellers, and other ticket types are more likely to be used for non-work trips. Significant bus patronage is derived from school students travelling on the SSTS program, and this class of non-work traveller pays nearly nothing on a per trip basis. Pensioner excursion tickets, used for non-work travel, are quite inexpensive on a per trip basis. As a result, the effective average fare paid per bus journey varies between work and non-work trips—it is generally lower for non-work trips.

Incidentally, it is worth emphasising the difference between peak travel and work travel. While the two coincide to some degree, some non-work passengers travel during the peak. Notably, school students travel during peak times for a non-work purpose. SSTS patronage represents roughly 20% in aggregate of all bus patronage, so this effect is material.

The Transport Data Centre provided a breakdown of bus ticket sales for the 2006 year, based on the Household Travel Survey. This information set contained ticket prices and numbers of tickets sold on a typical weekday, broken down by ticket types, by journey purpose (i.e., work or non-work), and by concession status of purchaser (e.g., adult, child, student, pensioner, etc.). SSTS and pensioner excursion ticket data was not included.

In Table 4.2 below, this information set is used to derive weighted average bus fares per use, taking into account that some ticket types allow multiple uses.

Table 4.2 Estimated average bus fares by ticket type and journey purpose 2006

		Single ticket used	Return ticket used	Full day	Weekly	Quarterly	Yearly	Fixed multiple trips (e.g. TravelTen)	Total
Work	count	73,517	10,307	8,052	50,392	3,577	2,048	103,022	254,241
Non-work	count	144,910	29,726	102,843	33,398	1,875	2,585	55,858	375,315
Total	count	218,427	40,033	110,895	83,790	5,453	4,633	158,880	629,556
Work	avg fare $/ticket	$ 2.62	$ 5.03	$ 2.63	$ 35.94	$ 389.10	$ 1,770.26	$ 32.14	$ 41.05
Non-work	avg fare $/ticket	$ 2.01	$ 10.82	$ 2.09	$ 27.97	$ 291.26	$ 978.57	$ 17.12	$ 15.67
Total	avg fare $/ticket	$ 2.22	$ 9.33	$ 2.13	$ 32.76	$ 355.45	$ 1,328.53	$ 26.86	$ 25.92
uses/ticket		1.00	2.00	1.00	14.00	168.00	672.00	10.00	-
Work	avg fare $/use	$ 2.62	$ 2.51	$ 2.63	$ 2.57	$ 2.32	$ 2.63	$ 3.21	$ 2.84
Non-work	avg fare $/use	$ 2.01	$ 5.41	$ 2.09	$ 2.00	$ 1.73	$ 1.46	$ 1.71	$ 2.25
Total	avg fare $/use	$ 2.22	$ 4.66	$ 2.13	$ 2.34	$ 2.12	$ 1.98	$ 2.69	$ 2.49

The overall average fare of $2.49/BPJ is reasonably close to the average fare derived from the STA annual report data. Note, however, that as SSTS and PET (pensioner excursion tickets) are excluded from this analysis, this figure overstates the average payment by passengers for their journeys.

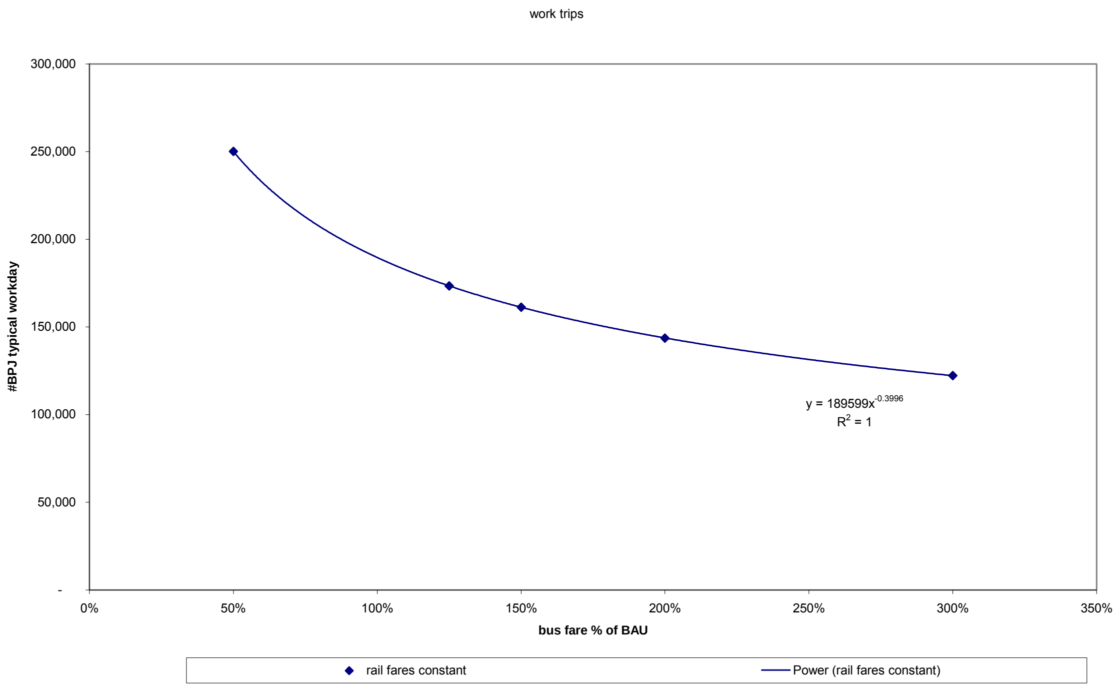
4.3 Demand elasticity

Having established the average actual bus fares, the next quantitative link that must be established is that between the bus fare and bus patronage. LECG did not undertake any new empirical work to estimate demand elasticity. Instead, the elasticity values implicit in the STM were employed.

The process through which these elasticity values were reverse-engineered from the model results is illustrated in Chart 4.1 below. A set of model runs is presented on a chart plotting the number of bus journeys undertaken on a typical work day versus the bus fare expressed as a percentage of the business-as-usual (BAU) bus fare.

The points in Chart 4.1 refer to work trips. It is assumed that rail fares are held constant at the new fare levels determined by IPART to come fully into effect in 2012, while bus fares vary.

Chart 4.1 Price elasticities for the entire MBSC region for work trips 2006



A best-fit power law function is superimposed on the points. The parameters of the power law function are shown on the graph. The coefficient represents the number of daily bus work trips at current fares. The exponent of x represents the elasticity of demand. When rail fares are held constant, the elasticity of work-trip bus demand is -0.3996.

The STM employs a constant elasticity functional form for the demand schedule, as can be seen from the nearly perfect fit of these power law (constant elasticity) functions to the data points. Constant elasticity may be a reasonable approximation to reality for fare variations within the range 50% to 300%. However, for more extreme fare variations it is unlikely that constant elasticity assumptions would continue to hold. Consequently, some caution is required in attempting to extrapolate these demand schedules to extreme low (or high) bus fares.

The elasticities presented here focus on work trips because, STM estimates for non-work trips should be treated with some caution. While the STM explicitly calculates modal shares and quantities of transport undertaken for work purposes, the corresponding figures for non-work trips are derived through a mathematical manipulation (within the STM) of the work-trip results. It is possible that some distortions may have been introduced into the demand figures for non-work trips through this procedure.

5 Estimation of marginal bus costs

The analysis of optimal bus fares in the presence of external benefits requires valid estimates of the marginal cost of bus travel. As fares are expressed on a per-passenger journey basis, it is essential that external benefits and marginal costs also be expressed on that basis. The marginal cost estimated in this chapter is the additional cost to the bus operator imposed by one passenger's decision to travel by bus instead of the mode that passenger previously used.

In studying per-passenger-journey marginal costs, it makes some difference whether or not the bus is full. One imagines, ex ante, that the additional cost faced by the bus operator in accommodating one additional passenger on a relatively empty bus is relatively small. On the other hand, if the bus is full, then a new bus service must be introduced to cater for the additional passenger journey. The costs of doing so, even after smoothing over the range of possible passenger numbers, are likely to be higher.

In proceeding to quantify costs, it is important to recognise that the resource costs of bus service cannot be directly observed because these services have been contracted out by the Government. Under the bus contracts, which correspond to 15 geographic regions in the Sydney metropolitan area and 10 in the outer-metropolitan area, operators are required to report monthly on patronage, ticket revenue, and costs under various categories set out in the contract.

This contract information, properly interpreted, can shed light on the marginal cost question. I proceed through the following steps to derive a range for marginal costs of bus travel (per passenger journey) for the metropolitan bus service contract area (MBSC) overall, and for individual contract regions.

First, I establish an empirical relationship between costs and the number of bus-kilometres of service supplied by the operator. This is done separately for the four largest contract regions and the Private Bus Operator (PBO) regions.

Second, I establish empirical relationships between costs and bus passenger journeys based on the month-to-month variation in costs as the number of bus passenger journeys fluctuates for each contract region. These relationships represents what I call "Contract SRMC" values.

Third, I calculate contract average costs per passenger journey, including passengers using the School Student Travel Scheme (SSTS). This category of passenger represents a substantial portion of the ridership of PBO regions.

Fourth, I calculate bus utilisation for each contract region. Comparing contract SRMC values with contract average costs, it becomes clear that the two are most similar for regions where bus utilisation is typically high, and most different where utilisation is low. This phenomenon reflects the ex ante expectation that marginal costs of accommodating a single passenger are low (and average costs per bus kilometre are high) when the bus is relatively empty, but as utilisation approaches capacity, marginal and average costs per passenger tend to converge.

Fifth, I attempt to isolate utilisation and marginal cost for work and non-work trips. This part of the procedure is somewhat more speculative, since the underlying information set is incomplete.

5.1 Costs versus bus-kilometres

In this section, I set out the data sources used for all cost regressions presented in this chapter. I also set out methodology and results for the analysis of costs as a function of bus-kilometres—distance travelled by the bus itself, as opposed to the passengers on it.

Ex ante, one would expect most costs, apart from fixed costs, to be driven by bus-kilometres, as the main cost categories of labour, fuel and equipment costs all depend relatively linearly on bus-kilometres.

5.1.1 Data Sources for Cost Functions

Monthly data on cost and patronage by contract region was provided by the Ministry of Transport on a confidential basis. Costs represent actual costs to the Government, which include any profit margin earned by private bus operators.

The observations employed come from the 2006-07 financial year. There are 12 observations (one per month) for each of 15 contract regions. The panel dataset had 180 observations.

As the raw data is highly confidential, it is not summarised here.

5.1.2 Methodology

The cost model employed for the cost per bus-km estimation was:

$$\text{Total cost} = B_0 + B_1\text{*bus-km} + \sum B_{i+1}\text{*}D_i$$

The variables D_i represent dummies for the bus contract regions, which take the value 1 for observations in region “i” and zero otherwise.

The coefficient B_1 can be interpreted as the marginal cost per bus-km in any of the 11 private bus operator (PBO) regions. Coefficient B_0 can be interpreted as the average monthly fixed cost of the bus contract in region 15.

The coefficients B_i for i = 2 …6, 11...15 represent the adjustments to the average monthly fixed cost for each specific region 1 …5, 10 ... 14. In other words, the monthly fixed cost for contract region x would be:

$B_0 + B_{x+1}$

There is no dummy for region 15 because including it would overspecify the model. For observations pertaining to contract region 15, all 14 dummies are equal to zero.

These coefficients B_i for $i > 1$ represent region-specific fixed costs. They are included in the cost function specification to avoid the problem of upward bias in the coefficient for cost per bus-km that might otherwise arise from any correlation between fixed costs in a region and number of bus-km in that region.

An analogous calculation is also done for the four largest contract regions.

5.1.3 Results

The estimated relationship between total costs and bus-km for PBO regions contains confidential information so it cannot be shown.

The estimated relationship between total costs and bus-km for the four largest contract regions also contains confidential information, so it cannot be shown.

Both cost models generate statistically significant estimates of the cost per bus-km.

5.2 Contract SRMC

In this section, I set out the regression methodology and results of the contract SRMC estimation.

5.2.1 Methodology for contract SRMC calculation

Ordinary least-squares regression was applied to monthly bus contract data on patronage (bus passenger journeys), and total costs by contract region for the 2006-07 financial year to develop region-specific estimates of contract short-run marginal costs and fixed costs.

After experimenting with different cost models, two were chosen: one for the four largest bus contract regions (regions 6 – 9) and another for the remaining eleven contract regions (regions 1-5 and 10-15).

For the largest regions 6 – 9, it was possible to derive reliable estimates of marginal cost for each region. The cost model employed for this estimation was:

$$\text{Total cost} = B_0 + \sum B_{i+1}{*}\text{patronage}_i{*}D_i$$

The constant B_0 represents the fixed cost per month of the bus contracts in each of the four regions 6 – 9. The coefficients B_1, B_2, B_3, and B_4 represent the marginal costs for regions 6, 7, 8 and 9, respectively.

For the remaining contract regions 1-5 and 10-15, it was not possible to derive reliable estimates of marginal cost for each region individually. However it was possible to derive a reliable marginal cost rate that applied across all of those 11 regions and reliable fixed costs for each region. The cost model employed for that estimation was:

$$\text{Total cost} = B_0 + B_1\text{*patronage} + \sum B_{i+1}\text{*}D_i$$

The coefficient B_1 can be interpreted as the marginal cost per bus passenger journey in any of the 11 regions. Coefficient B_0 can be interpreted as the average monthly fixed cost of the bus contract in region 15. The coefficients B_i for $i = 2 \ldots 6, 11 \ldots 15$ represent the adjustments to the average monthly fixed cost for each specific region 1 …5, 10 ... 14. In other words, the monthly fixed cost for contract region x would be:

$$B_0 + B_{x+1}$$

There is no dummy for region 15 because including it would overspecify the model. For observations pertaining to contract region 15, all 14 dummies are equal to zero.

5.2.2 Results for contract SRMC estimation

The estimated cost function for regions 6 – 9 contains confidential information so it cannot be shown.

The F and R squared values are high, indicating that the model accounts for most of the variation in the dependent variable, total cost. The coefficients representing the marginal cost in each of the four regions are significant at the 1% level. The constant term is not statistically different from zero.

The estimated cost function for regions 1 – 5 and 10 – 15 contains confidential information, so it cannot be shown.

5.3 Contract average costs

In this section, I briefly set out the calculation of contract average costs per bus passenger journey, including SSTS journeys. The reason for including SSTS journeys is that they impose costs on the bus operator even though they do not pay a per-journey price to ride. Excluding this costly source of patronage would artificially inflate the apparent unit costs of providing bus service. In contrast, SSTS passengers were excluded from the average fare calculation because the control variable in the optimisation exercise is the fare per paying passenger.

The calculation is straightforward. In each region, the 2006-07 total contract cost is divided by the total number of journeys. As the contract costs are confidential, they cannot be shown.

5.4 Separate work and non-work MC estimates

It is presently not possible to derive reliable estimates of separate work and non-work marginal costs. The bus contract data does not distinguish between work and non-work trips, nor does it distinguish between peak and off-peak trips.

The marginal cost for the four largest contract regions for non-work trips is quite difficult to determine. A figure near the calculated SRMC for the region in question may be appropriate, pending further investigation of bus costs.

6 Displacement of automobile use by bus

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

The STM represents 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 bus patronage is not necessarily one-for-one with changes in passenger journeys by car or train. The STM 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: incremental bus fare change scenarios, and several no-bus scenarios. 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 centred on the 2006 year Household Travel Survey data.

In the bus fare change scenarios, train fares were held constant at the levels determined recently by IPART to apply in full from 2012. The bus fares applied in specific scenarios were the following percentages of the actual 2006 bus fares:

- 50%
- 125%

- o 150%
- o 200%
- o 300%

The business as usual case corresponds to no bus fare change (100% of current fares).

There were 16 different no-bus scenarios. The first of these involved no bus service at all in the metropolitan bus service contract region # 1 (corresponding to the Western region bounded by Penrith and Blacktown) and normal service levels in the other 14 contract regions. The second involved no bus service in the metropolitan contract region #2, and so on up to scenario 15 and region #15. The 16th no-bus scenario involved no bus service in any of the 15 metropolitan bus contract regions (but bus service was maintained in the 10 Outer-metropolitan bus contract regions).

In total there were 22 scenarios: business as usual, 16 no-bus scenarios, and 5 bus fare change scenarios with constant rail fares. The model outputs produced for each scenario are shown in Table 6.1 below. I converted figures expressed on a per-working-day basis to annual figures by multiplying by 250.

Table 6.1 STM specification of model outputs

MODEL OUTPUTS obtained for each model run
1) passenger trips, kilometres and hours per working day by mode (rail, bus, and car)
2) bus kilometres and bus hours per working day
3) train kilometres and train hours working day
4) automobile vehicle kilometres (per working day) by speed band, in increments of 5 km/hr
5) road volume to capacity ratio for the AM peak 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

All results were reported separately for work trips and non-work trips. The reported outputs for passengers were also broken down into separate figures for each of the 15 metropolitan bus contract regions.

6.2 Methodology for quantifying displacement of automobiles

The methodological basis of the STM 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, the STM is a multi-modal travel demand estimation tool that analyses travel behaviour responses to different transport network or land use scenarios, including the impact of new infrastructure, changed service levels, congestion or different fares.

It can be used to address the following question: suppose bus fares increased by a certain amount, what impact would this change have on mode choice, destination choice, and for this purpose, highway traffic, travel speeds and delay?

Note that land use assumptions are inputs to the model – while people might choose different destinations with a different transport scenario, the total amount of population and employment in different areas remains fixed for each scenario.

6.3 Automobile displacement converted to external benefits

Some of the most important externalities associated with bus 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, I 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 bus patronage.

6.4 Results for automobile displacement analysis

The STM model results are summarised in Tables 6.2 and 6.3 below. The first of these shows a range of useful statistics for a subset of the scenarios that were tested. Person kilometres and vehicle kilometre statistics are provided in this table. Vehicle kilometres are subdivided by vehicle speed bands. This information on the distribution of automobile speeds is useful for estimating fuel consumption and potential traffic accident effects.

The scenarios shown are a subset of the scenarios tested: business as usual, no bus in region 6, no bus in any of the 15 metro contract areas, and the five scenarios in which bus fares were changed while rail fares were held constant. Outputs for the other scenarios are in the same format, but they are not tabulated here, as the complete output table would be unwieldy.

Table 6.2 shows a marked reduction in bus passenger km travelled in the “NoBusAll” scenario, as one would expect. This reduction in bus usage corresponds to a small increase in rail and car passenger km, and some reduction in the total passenger km travelled across all of these modes.

There are also subtle changes to the speed distribution of automobiles, shown at the bottom of Table 6.2, when bus travel ceases, but it is difficult to recognise the pattern based on casual inspection of the table. These subtle changes are brought to light more effectively by the spreadsheet analysis that is discussed later in this report.

A comparison across the rows shows, focusing on the last five columns (in which the bus fare is gradually increased from 50% of its current level to 300%), that bus passenger km decline, and both rail and car passenger km increase as the bus fare is raised.

Table 6.2 STM results (abridged) with speed-bands shown

IPART Externalities Study
Results for GMA from the Sydney Strategic Travel Model
Updated: 24/03/2009

Scenario:	BAU	NoBus6	NoBusAll	BusFare050	BusFare125	BusFare150	BusFare200	BusFare300
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	Current	Current	Current
Bus services	Current	***None-region6***	***None-GMA***	Current	Current	Current	Current	Current
Bus fares	Current	Current	Current	***-50%***	***+25%***	***+50%***	***+100%***	***+200%***
Rail fares	Current	Current	Current	Current	Current	Current	Current	Current
Bus speeds	Current	Current	Current	Current	Current	Current	Current	Current
CBD parking costs	Current	Current	Current	Current	Current	Current	Current	Current
Results								
Passenger km by mode (average weekday) (Million PKT)								
Rail	21.9	21.9	22.3	21.4	22.0	22.1	22.2	22.4
Bus	7.6	6.9	0.0	10.1	7.0	6.4	5.7	4.9
Car	149.1	149.1	149.5	148.7	149.1	149.2	149.3	149.3
Total	178.5	177.9	171.8	180.3	178.0	177.7	177.2	176.6
Passenger km by mode - work (average weekday) (Million PKT)								
Rail	12.0	12.1	14.0	11.7	12.1	12.2	12.3	12.4
Bus	2.0	1.9	0.0	2.7	1.9	1.7	1.6	1.3
Car	38.4	38.5	39.0	38.2	38.5	38.5	38.6	38.7
Total	52.5	52.5	53.0	52.5	52.5	52.5	52.5	52.4
Passenger km by mode - non_work (average weekday) (Million PKT)								
Rail	9.8	9.9	8.4	9.8	9.9	9.9	9.9	9.9
Bus	5.6	5.0	0.0	7.5	5.1	4.7	4.2	3.5
Car	110.6	110.6	110.5	110.5	110.6	110.6	110.7	110.7
Total	126.0	125.5	118.8	127.8	125.5	125.2	124.7	124.1
Public transport services (1-hour AM peak)								
Bus km	39,618	35,525	1	39,618	39,618	39,618	39,618	39,618
Bus hours	1,845	1,597	0	1,845	1,845	1,845	1,845	1,845
Train km	10,913	10,913	10,913	10,913	10,913	10,913	10,913	10,913
Train hours	248	248	248	248	248	248	248	248
Vehicle kilometres travelled (average weekday) (Million VKT)								
0-5 kph	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
5-10 kph	0.9	0.9	1.0	0.9	0.9	0.9	0.9	0.9
10-15 kph	2.6	2.6	2.7	2.5	2.5	2.6	2.6	2.6
15-20 kph	5.1	5.1	5.3	5.1	5.1	5.1	5.1	5.1
20-25 kph	8.6	8.6	9.0	8.5	8.6	8.7	8.6	8.8
25-30 kph	12.3	12.3	12.2	12.4	12.3	12.3	12.3	12.3
30-35 kph	14.3	14.3	14.3	14.2	14.3	14.3	14.3	14.2
35-40 kph	12.5	12.5	12.5	12.6	12.6	12.5	12.6	12.7
40-45 kph	11.0	11.1	11.0	10.9	11.0	11.0	10.9	10.9
45-50 kph	12.1	12.0	12.0	12.0	12.0	12.2	12.1	12.1
50-55 kph	10.4	10.4	10.3	10.5	10.5	10.5	10.6	10.5
55-60 kph	11.6	11.5	11.7	11.5	11.6	11.5	11.4	11.5
60-65 kph	5.6	5.6	5.5	5.6	5.6	5.7	5.6	5.6
65-70 kph	10.6	10.5	10.6	10.5	10.5	10.5	10.5	10.5
70-75 kph	1.8	1.8	1.9	1.8	1.9	1.8	1.8	1.8
75-80 kph	2.6	2.7	2.7	2.7	2.6	2.6	2.7	2.6
80-85 kph	1.2	1.2	1.0	1.2	1.2	1.2	1.2	1.2
85-90 kph	1.4	1.4	1.4	1.5	1.4	1.4	1.5	1.4
90-95 kph	1.9	1.9	1.8	1.9	1.9	1.9	1.9	1.9
95-100 kph	7.2	7.2	7.3	7.2	7.2	7.2	7.2	7.2
100-105 kph	-	-	-	-	-	-	-	-
105-110 kph	-	-	-	-	-	-	-	-
Total	133.8	133.9	134.3	133.6	133.8	133.9	134.0	134.0

Table 6.3 presents information on passenger hours by mode and by scenario. For public transport modes, waiting time and time spent walking to the bus stop or train station is also calculated.

Table 6.3 STM results (abridged) with travel times shown

Global Stats									
	Updated	24/03/2009							
	Description	BAU	NoBus6	NoBusAll	BusFare050	BusFare125	BusFare150	BusFare200	BusFare300
Person Travel - all trips									
Person Trips - Linked Trips									
	Car Driver	10,514,000	10,526,000	10,628,000	10,473,000	10,524,000	10,531,000	10,542,000	10,555,000
	Car Passenger	4,416,000	4,421,000	4,464,000	4,399,000	4,420,000	4,423,000	4,428,000	4,433,000
	Train	752,000	758,000	842,000	735,000	757,000	760,000	765,000	771,000
	Bus	725,000	646,000	7,000	974,000	660,000	610,000	540,000	455,000
	Total Trips	16,408,000	16,351,000	15,941,000	16,581,000	16,360,000	16,325,000	16,275,000	16,213,000
Person Kms - Linked Trips									
	Car Driver	110,487,000	110,503,000	110,953,000	110,224,000	110,483,000	110,570,000	110,616,000	110,682,000
	Car Passenger	38,670,000	38,676,000	38,834,000	38,579,000	38,669,000	38,699,000	38,715,000	38,739,000
	Train	21,687,000	21,762,000	22,016,000	21,279,000	21,813,000	21,898,000	22,019,000	22,174,000
	Bus	7,690,000	6,941,000	0	10,226,000	7,015,000	6,511,000	5,786,000	4,905,000
	Total Kms	178,535,000	177,882,000	171,804,000	180,307,000	177,980,000	177,679,000	177,136,000	176,499,000
Person Hours - Linked Trips									
	Car Driver	3,453,000	3,457,000	3,497,000	3,440,000	3,456,000	3,460,000	3,461,000	3,466,000
	Car Passenger	1,209,000	1,210,000	1,224,000	1,204,000	1,210,000	1,211,000	1,211,000	1,213,000
	Train	591,000	589,000	533,000	579,000	595,000	597,000	601,000	605,000
	Bus	348,000	304,000	0	463,000	317,000	294,000	261,000	221,000
	Total Hours	5,601,000	5,559,000	5,255,000	5,686,000	5,578,000	5,562,000	5,534,000	5,506,000
PT Out of Vehicle Hours - Linked Trips									
	Train Waiting	147,000	146,000	108,000	145,000	148,000	149,000	149,000	150,000
	Train Walking	325,000	352,000	1,075,000	320,000	327,000	328,000	330,000	332,000
	Bus Waiting	101,000	92,000	0	136,000	91,000	84,000	74,000	63,000
	Bus Walking	246,000	245,000	26,000	332,000	224,000	207,000	183,000	155,000
Train In Vehicle Hours									
	Train	408,000	417,000	504,000	400,000	411,000	413,000	415,000	418,000
	Light Rail	3,000	4,000	16,000	3,000	3,000	3,000	3,000	3,000
	Ferry	0	2,000	4,000	0	0	0	0	0
	Bus or Car	178,000	162,000	0	174,000	179,000	179,000	180,000	181,000
	Total Train In-vehicle	590,000	586,000	523,000	578,000	593,000	596,000	599,000	604,000
Commercial Vehicles (Passenger Car Equivalents)									
	Trips	1,022,000	1,022,000	1,022,000	1,022,000	1,022,000	1,022,000	1,022,000	1,022,000
	Distance	35,554,000	35,556,000	35,567,000	35,549,000	35,552,000	35,557,000	35,555,000	35,556,000

Equivalent information was also provided separately for work trips and non-work trips.

Table 6.3 shows some equivalent information to Table 6.2, such as passenger km travelled by mode. However, Table 6.3 also provides information on the number of trips, and the number of person hours of travel by mode in a typical workday. The information on passenger hours of travel is further broken down, for public transport modes rail and bus, into in-vehicle-hours, waiting time, and time taken to walk to the train station or bus stop.

As with Table 6.2, Table 6.3 shows a trend of increasing car and train use, together with decreasing bus use as the bus fares are increased. The increasing number of travel hours per automobile journey and per automobile km is not directly observable from this table, but it can be calculated by dividing the hours by number of trips or kms as is done later in this report.

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.

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 bus, along with the price of fuel and car ownership, the bus fare, the time penalty associated with bus travel (including time in the bus, time waiting for the bus, and time walking to and from the bus stops 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 bus 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 bus travel.

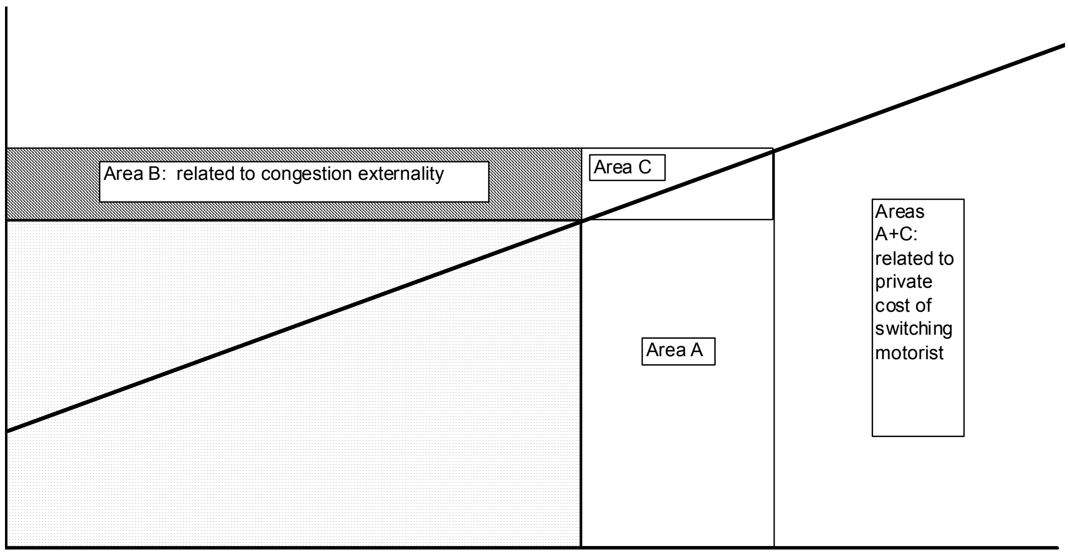
The pre-existing motorists (inframarginal drivers) suffer a new increment of cost as a result of the marginal driver’s decision to join. The inframarginal motorists take longer to make the same journey as a direct result of the marginal motorist’s decision. The personal cost of the inframarginal motorists’ own additional commuting time and fuel consumption is an external cost that is not reflected in the demand or supply schedules for bus 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, I 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 Figure 7.1 below.

Figure 7.1 Illustration of congestion externality calculation by areas on a graph



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.[7] 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

[7] In this report I assume, in fact, that automobile person hours is a quadratic function of automobile person-kilometres travelled. I estimate the quadratic coefficients from empirical data derived from the STM later in this chapter.

of automobile person hours of travel time corresponding to apk0 automobile person kilometres travelled. To see this, note:

Area = XY = (apk0)(aph/apk) = aph_{apk0}

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 bus system in reducing congestion costs incurred by motorists, I employed the STM to simulate traffic conditions resulting from different levels of bus 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 bus patronage cause roads to become more crowded. Knowing the distribution of vehicle-kilometres by speed band in each STM 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 STM 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 STM.

7.2 Data sources and issues for congestion effect estimation

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

7.2.1 Person hours per automobile person kilometre

The essence of road congestion is that as more automobile passenger kilometres are travelled in a given geographic region in a given space of time, the average speed attained by that traffic decreases. Another way of expressing this point is that the number of automobile passenger hours increases more than proportionally to the number of automobile passenger kilometres in a fixed region of space and time. We assume, in what follows, that automobile passenger hours are a quadratic function of automobile passenger kilometres. Equivalently, the ratio of auto passenger hours to auto passenger kilometres: (aph/apk) increases linearly as apk increases.

In order to estimate this quadratic relationship, we need a minimum of three pieces of information:

- aph when apk = 0;
- the ratio of (aph/apk) when apk = 0; and
- aph when apk = the actual 2006 value.

When apk = 0, there is no automobile travel, so aph = 0. The ratio of (aph/apk) when apk = 0 is assumed to be the inverse of the average traffic speed when congestion is completely absent. I assume that this speed is the typical speed limit for built-up areas: 60 km/hr. Even under extremely low traffic levels, the speed limit would continue to apply. These initial conditions are expected to be the same for all spatial regions and all journey purposes.

Values for aph and apk under actual 2006 traffic conditions are provided by the STM simulations. These values differ, depending upon which spatial regions and journey purposes are being considered.

This information is now sufficient to derive an empirical relationship between aph and apk for each region (and group of regions) separately for work and non-work trips. The following formula:

$$aph(apk) = A\,(apk)^2 + B\,apk + C$$

can be estimated using the three data points established above. Since aph(0) = 0, C = 0. The ratio (aph/apk), given by:

$$aph/apk = A\,apk + B$$

must be equal to 1/60 km/hr, when apk = 0. Therefore, B = 1/60 = 0.01667 hr/km. Let Y0 = aph at 2006 and X0 = apk at 2006. The coefficient A can now be estimated as follows:

$$Y0/X0 = A\,X0 + B$$

$\Rightarrow A = (Y0/X0 - B)/X0$

Unlike B and C, A will depend on the region and journey purpose. Knowing the slope (A) and y-intercept (B) of the ratio (aph/apk) as a function of apk, it is possible to calculate the marginal external benefit associated with an incremental change in bus patronage, Δq. To do so, however, it is first necessary to quantify the relationship between automobile passenger kilometres and bus passenger journeys. The estimation of this relationship is explained in the next section.

7.2.2 Auto pax-km per bus pax journey

In what follows, I assume that if a bus passenger is displaced from the bus, either because the fare has become unattractive compared to modal alternatives or because bus service is no longer available, that passenger is likely to undertake the same trip using another mode.

I acknowledge that this assumption is contentious. While it may be valid in the short term for work trips, in the longer term it is more likely that a change to the attractiveness or availability of bus service may lead to changes in the origin or destination of these trips (because, for instance, of a change in location of home or work in response to changing transport alternatives). In the case of non-work trips, they may no longer be undertaken at all.

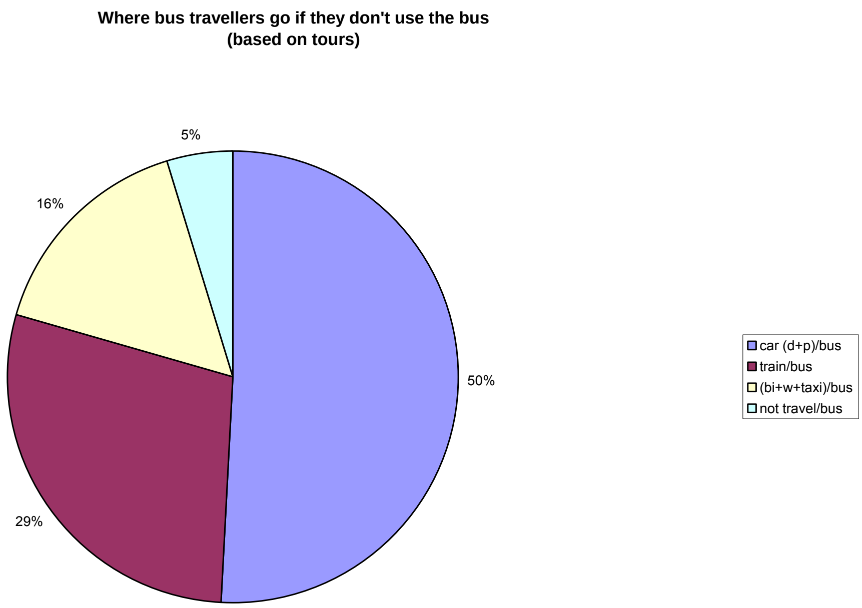
Given that assumption, the relationship between auto passenger kilometres travelled and bus passenger journeys depends on two factors:

- The probability that a bus passenger who no longer uses the bus mode will use the automobile mode instead, and
- The average distance that passenger travelled on the bus per journey.

It is the average bus journey length that is important, rather than the average automobile passenger journey, because a bus passenger changing modes is likely to make the same trip as before. This car journey will more closely reflect the distance of the corresponding bus journey than the average distance per journey across existing car users (whose characteristics may differ markedly from those of bus users). The average distance travelled per bus passenger journey can be established readily through the STM runs. For work trips in the MBSC area overall, this average distance is 10.8 km. For work trips in the four largest contract regions, this average distance is lower: 8.6km.

The probability that a bus user will switch to car, rather than train or some other mode can be established from the STM. For this purpose, the Transport Data Centre has recommended the use of a set of intermediate model outputs. The pie chart in Chart 7.1 below shows the results of this calculation.

Chart 7.1 Alternative mode probabilities for bus users, MBSC work trips 2006



Based on this analysis, there is approximately a 50% chance that a bus passenger who no longer uses bus because of a fare increase would switch to automobile travel, a 29% chance of switching to rail, 16% chance of switching to walking, cycling or catching a taxi, and a 5% chance of opting not to travel at all.

The external benefits of bus travel are nearly all based on the avoidance of negative externalities associated with automobile travel. Therefore, it is only the proportion of bus travellers that would have switched to car that generate external benefits.

Based on work trips for the MBSC area overall, the relationship between a change in auto pax-km (Δ apk) and the corresponding change in bus pax journeys (Δ q) is given by:

$$\Delta \text{ apk} = -50\% * (10.86 \text{ bus pax-km/BPJ}) * \Delta \text{ BPJ} = -5.43\ \Delta \text{ q}$$

The sign is negative because car and bus are substitutes in this context. Assuming that the same 50% factor applies to the four largest contract regions, the corresponding relationship for the four largest contract regions is:

$$\Delta \text{ apk} = -50\% * (8.64 \text{ bus pax-km/BPJ}) * \Delta \text{ BPJ} = -4.32\ \Delta \text{ q}$$

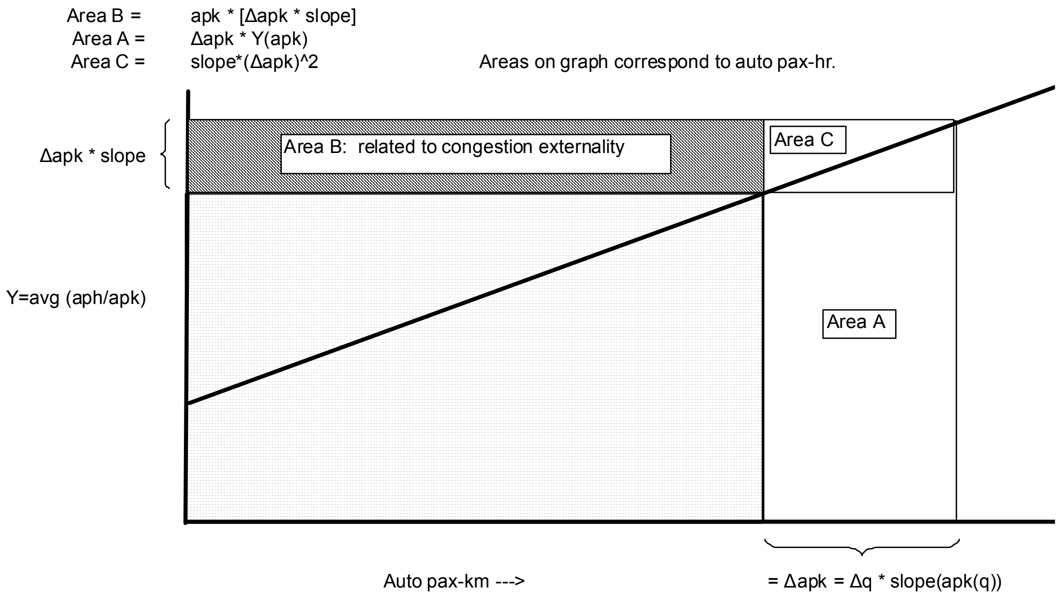
The relationship for the four largest contract regions should be treated with some care, as it is not based on a specific analysis of mode switching behaviour in the four largest contract regions. That analysis cannot easily be done with the current set of STM outputs.

Note also that these relationships were derived from work trip data. It is entirely possible that mode switching decisions would differ somewhat for non-work trips, leading to different quantitative relationships. However with the STM modelling currently available it is not possible to determine how, or even in what direction, these estimates should be changed for non-work trips.

7.2.3 Quantifying the car congestion externality

I adopt the linear relationship between Δq and Δapk quantified in the prior section. In the Figure 7.2 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.

Figure 7.2 Congestion externality formulae for areas on the graph



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

Area B = apk * Δapk * slope of line (aph/apk)

= apk * Δapk * A pax-hrs/(pax-km)^2

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

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

For non-work trips, the formula is the same but the parameter "A" has a different value.

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

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

$= -VOT * (q*slope\_apk^2+yint\_apk*slope\_apk) * A$

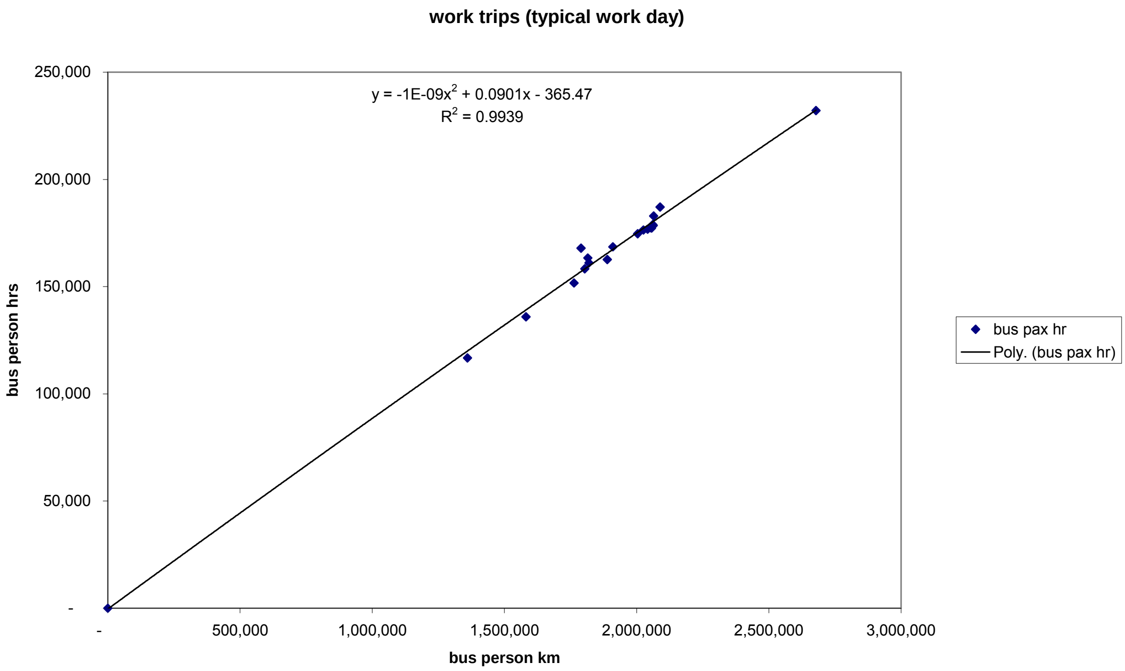
Where VOT is the value of time in $/person-hr. Published values for that input are discussed later in this chapter.

7.2.4 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. Chart 7.1 below plots bus passenger hours versus bus passenger kilometres travelled for work trips. A best-fit quadratic equation is superposed.

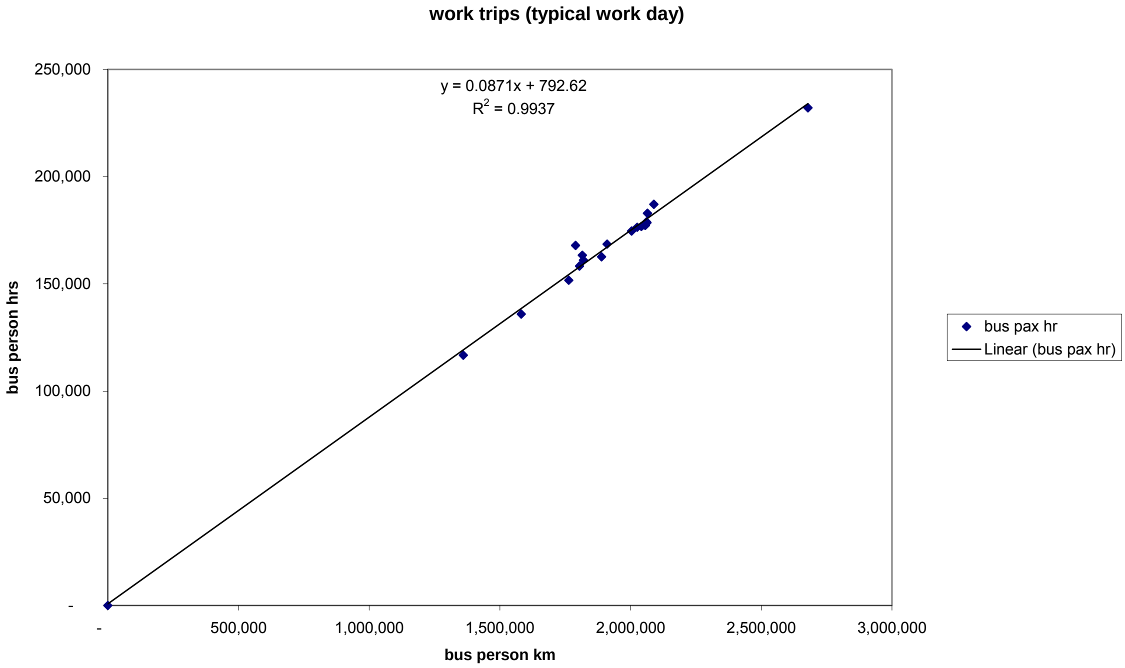
Perhaps surprisingly, the quadratic term of the best-fit equation has a negative sign, meaning that the average time per bus passenger kilometre decreases as the number of bus passenger kilometres increases. This result is not the expected consequence of increasing road congestion.

Chart 7.1 Bus person hours v bus person km, MBSC work trips 2006, with quadratic fit



Visual inspection shows that this quadratic function is nearly linear. Imposing a linear line of best fit, as is done in Chart 7.2 below, results in a very slight reduction in the explanatory power of the best-fit line (R squared drops from 0.9939 to 0.9937).

Chart 7.2 Bus person hours v bus person km, MBSC work trips 2006, with linear fit



Given this result, I assume that the negative quadratic term is simply an artefact of noise in the data and that the marginal external benefit associated with bus passenger VOT is zero. The same phenomenon is observed for non-work trips, and the same assumption is applied.

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 I am unable to quantify this effect, given our assumption that bus speeds do not change. 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 bus is, if anything, understated.

7.2.5 Person hours per rail passenger journey

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. Unfortunately, the STM does not capture this effect.

To the extent it existed, this rail travel time effect would be an external cost of rail transport which must be balanced against the external benefits of a modal shift toward rail. However, the available modelling tool does not permit us to estimate the magnitude of this effect. Therefore, it is assumed that rail travel time is related linearly to the number of rail passenger kilometres travelled, so there is no external rail congestion effect. This assumption is consistent with the approach taken by IPART in the rail externality study.

7.2.6 Value of travel time

In order to convert the STM 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;[8] and
- A high value of $22.60/hr, representing a weighted average of business and private travel in passenger cars in urban areas.[9]

Both reference sources cite a 2004 Austroads publication as the primary source.[10]

In order to compare these values with hourly rates of pay, I 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 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

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

9 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.

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

$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.[11] 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 of the BTE paper 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, I adopt a central case value of time of $15.80/hr, which lies approximately midway between the median ratios for business and commuter travel applied to the hourly rate. For sensitivity testing I retain the range mentioned above: low valuation of $9.23/hr and high valuation of $22.60/hr.

Separate values of time for motorists, bus passengers and rail passengers[12] have not been adopted, but the analytical framework set out here could easily be adapted to reflect mode-specific values of time.

7.2.7 Fuel consumption per person kilometre

There are several distinct external costs associated with fuel consumption, including those involving air pollution. Here I 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.

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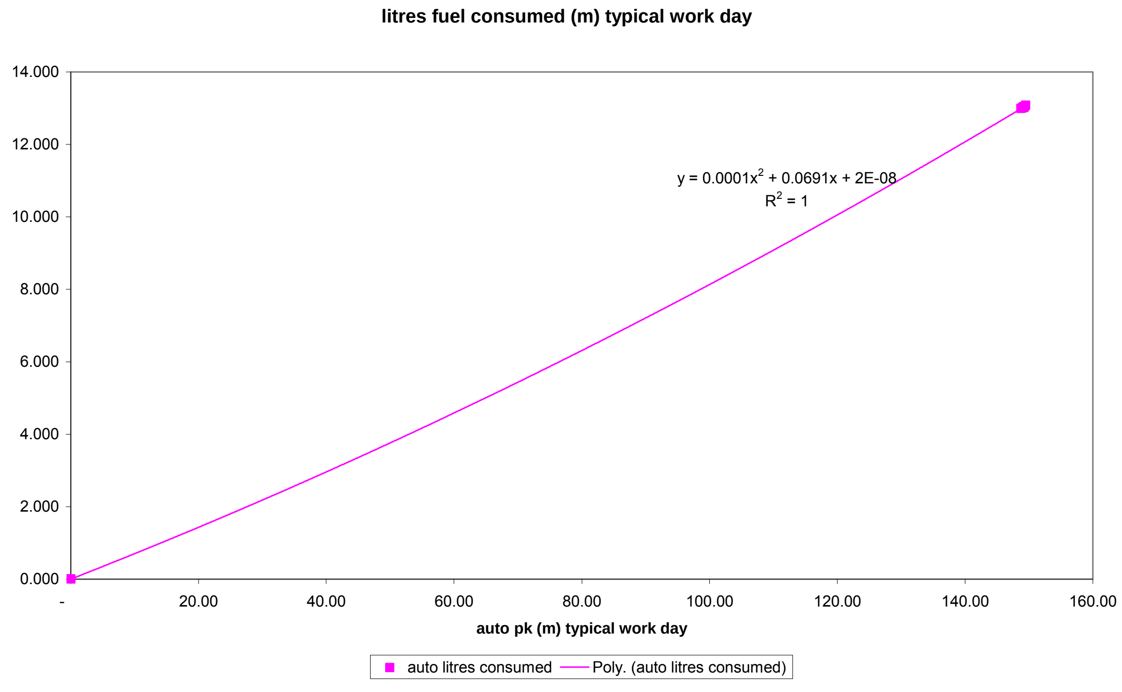
[11] "The Value of Travel Time Savings in Public Sector Evaluation," BTE Occasional Paper 51, AGPS, Canberra, 1982.

[12] 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.

I assume that the rate of bus fuel usage per bus passenger kilometre is constant. This assumption is motivated by the STM 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 bus patronage constitute an additional component of meb(q). It may be estimated using the same procedure as applied to automobile time savings. Chart 7.3 below plots automobile fuel consumption versus apk. A best-fit quadratic equation is superposed.

Chart 7.3 Fuel consumption v auto pax-km with quadratic fit



This quadratic relationship is exactly analogous to that derived above for the congestion effect. Here, though, it is the ratio of auto litres consumed to apk, rather than the ratio of (aph/apk), that depends linearly on apk. There is a corresponding “Area B” on the fuel consumption externality chart. Call this Area Bf. Differentiating Area Bf (for fuel consumption rather than aph), the component of meb(q) representing the auto fuel purchase cost effect is given by:

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

Where ($/litre) is simply the current price of petrol. Even adopting a value of approximately $1.40/litre for the price of petrol, which represents the highs experienced in early-mid 2008, this auto fuel purchase marginal external cost of bus transport is relatively small when expressed in dollars per bus passenger journey (approximately 0.03 cents/BPJ).

8 Emission effect externalities

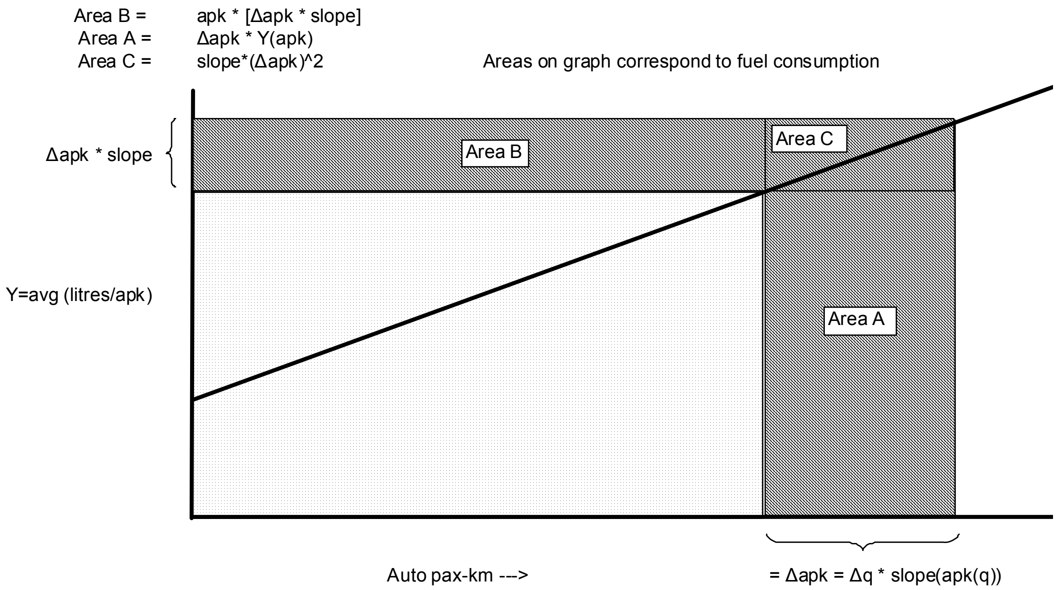
Automobile and bus emissions contribute to two recognised types of social cost: increased health risk from conventional pollutants and increased risk of environmental harm from greenhouse gases. The quantity of each pollutant dispersed into the atmosphere varies directly with the quantity of fuel consumed.[13] 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 Figure 8.1 below.

[13] 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. I ignore these second-order complications.

Figure 8.1 Estimation of emission externalities by areas on a graph



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 I wish to make is whether bus usage reduces the costs of emissions and by how much. I am not attempting to endogenize this calculation.[14] The emissions externality calculation will be performed once the change in road vehicle-kilometres is determined by the STM runs. The core steps in the analytical approach are:

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

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

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.

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

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

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.

I assumed that the city consumption figure applied to the speed band between 30 and 35 km/hr,[15] and that the highway figure was relevant to the speed band between 80 and 85 km/hr. Fuel consumption rates for intermediate speed bands was calculated by linear interpolation between these points. The fuel consumption rate was assumed to remain constant for speeds above 85 km/hr. The rate of fuel consumption was assumed to rise

15 This figure is roughly consistent with average automobile speeds predicted for STM model runs.

as speed dropped below 30 km/hr. The resulting fuel consumption rates are shown in Table 8.1 below.

Table 8.1 Assumed rates of automobile fuel consumption as a function of speed

Speed band km/hr		
min	max	litres fuel consumed by cars / vkm
0	5	0.321
5	10	0.285
10	15	0.250
15	20	0.215
20	25	0.179
25	30	0.144
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	0.072
90	95	0.072
95	100	0.072
100	105	0.072
105	110	0.072

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 fuel 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 I 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 I have adopted a higher carbon price of $25/tonne CO2.

8.2.3 Cost of conventional pollutant emissions

Health effects of conventional air pollution were costed on a per litre of fuel basis by Maddison, et. al.,[16] who 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.[17] Maddison, et. al.'s results are tabulated below.

Since the time of that study, two trends in Australia and Europe have created the need to update the marginal external health cost for diesel. First, diesel fuel itself has become "cleaner" in both jurisdictions. Second, the bus fleet has been modernised so that conventional diesel engines represent a smaller proportion of the entire fleet. Environmentally friendlier compressed natural gas (CNG) buses and diesel buses that conform to the stricter Euro 5 emission standard represent a larger and growing proportion of the fleet.

A further issue with the Maddison, et. al. study is that it was conducted at the time of introduction in Britain of unleaded petrol. In 1993, comparatively little was known about the adverse health effects of this type of fuel, so these estimates were preliminary.

It has been necessary to replicate the Maddison,et. al. analysis using more recent Australian data on air pollution health costs. I am indebted to Dr Tom Beer of CSIRO for his help in locating and adapting the relevant data in order to make it possible for me to perform this calculation. I take full responsibility for any errors.

Table 8.2 below summarises estimates of health costs associated with various pollutants emanating from the combustion of unleaded petrol and diesel in Australia in 2002.[18]

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

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

18 The source data for this table is derived from Beer, T., "Valuation of pollutants emitted by road transport into the Australian atmosphere," Proceedings of the 16th International Clean Air& Environment Conference, Christchurch, New Zealand, August 2002, pp. 86-90.

Table 8.2 Estimates of Australian health costs based on Beer (2002), allocated to fuels on the basis of their total emissions

Pollutant	Total external health costs m$A 2002	Emissions in Gg		Health costs m$A 2002	
		Petrol	Diesel	Petrol	Diesel
Direct PM_{10}	17,200	17.34	9.47	11,124	6,076
SOx (incl. indirect PM_{10})	1	-	-		
NOx (incl. indirect PM_{10} and ozone)	410	47.90	266.96	62	348
VOCs	12,800	60.67	22.40	9,349	3,451
Lead	-				
Benzene	-				
Other (C0)	6	476.66	61.63	5	1
TOTAL	30,417	603	360	20,541	9,875

In order to derive external health costs per litre, 2002 fuel sales by type were obtained from the ABS Survey of Motor Vehicle Use 2003 (p. 15). The resulting calculation is shown in Table 8.3 below.

Table 8.3 Marginal external health costs per litre of fuel – Australia 2002

Fuel type	Total external cost/ m$A 2002	Fuel sales/ million litres 12 mos to Oct 2002 (ABS SMVU 2003, p. 15)	Marginal external cost/litre cents Aus.
Diesel	9,875	7,267	136
Petrol	20,541	16,507	124
TOTAL	30,416	23,774	128

These figures, $1.36/litre diesel and $1.24/litre unleaded petrol, were used in the estimation of air pollution externalities. Four factors that have changed to some degree since 2002 have not been taken into account:

- The effect of inflation on these costs;

- The effect of tightening fuel and engine standards on the amount of pollution per litre;
- The changing composition of the Sydney automobile fleet since 2002; and
- The changing composition of the bus fleets since 2002.

The first two factors will counteract each other to some degree. In order to take account of the second, third and fourth factors, more information than is currently available would be required.

9 Accident impact externalities

By reducing automobile usage, buses reduce 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 bus 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.[19] 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.

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.

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

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 public transport 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 I am concerned. However, when calculating the marginal external benefit to bus 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 bus patronage is likely to be large, but the marginal external benefit from an incremental increase in bus patronage is too small to measure reliably.

Given the problems just noted with measuring the marginal external benefits of bus in reducing accident costs, I do not attempt a quantification of $meb(q)_{road\ accidents}$.

10 Summary of externality results

It has been possible to combine the relationships between each type of external benefit and bus 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).

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

Using a value of travel time of $15.80/hr and a carbon cost of $25/tonne of CO2, the results of the foregoing estimations can be translated to linear marginal external costs functions of patronage, for each component of the external cost of bus service, shown in Table 10.1 below. As bus patronage increases (going down the table), there are some small changes to the marginal external cost per bus journey.

In examining costs per bus passenger journey, it is important to recognise that fuel consumption is driven primarily by bus-kilometres travelled. An empty bus is likely to generate nearly as much conventional air pollution as a full one travelling the same distance, because fuel consumption is not strongly affected by the number of passengers carried (although the stopping pattern, which is affected by the passenger load, will have some effect on fuel consumption.) The modelling framework adopted here has focused on bus passenger journeys as the driver of external costs and benefits. Where there are wide variations between passenger journeys (for which the external cost of bus air pollution is assessed here) and bus-kilometres (which are the actual main driver of bus air pollution), the figures produced in this study may tend to exaggerate the per-passenger-journey impact of bus air pollution for lightly utilised bus services.

Table 10.1 Marginal external costs per bus passenger journey estimated for work trips 2006-07

Marginal external costs ($/BPJ)

	work trips									
BPJ/workday	auto VOT	CRF train VOT CRF	bus VOT	auto GHG	auto airpol	auto fuel	bus GHG	bus airpol	bus fuel	mec
-	- 1.07	-	-	-0.03	-0.52	- 0.03	0.00	0.19	-	-1.46
50,000	- 1.06	-	-	-0.03	-0.52	- 0.03	0.00	0.19	-	-1.45
100,000	- 1.05	-	-	-0.03	-0.52	- 0.03	0.00	0.19	-	-1.44
150,000	- 1.05	-	-	-0.03	-0.52	- 0.03	0.00	0.19	-	-1.43
200,000	- 1.04	-	-	-0.03	-0.52	- 0.03	0.00	0.19	-	-1.42
250,000	- 1.03	-	-	-0.03	-0.52	- 0.03	0.00	0.19	-	-1.42
300,000	- 1.02	-	-	-0.03	-0.52	- 0.03	0.00	0.19	-	-1.41
400,000	- 1.01	-	-	-0.03	-0.52	- 0.03	0.00	0.19	-	-1.39
500,000	- 0.99	-	-	-0.03	-0.52	- 0.03	0.00	0.19	-	-1.38
600,000	- 0.98	-	-	-0.03	-0.51	- 0.03	0.00	0.19	-	-1.36
700,000	- 0.96	-	-	-0.03	-0.51	- 0.03	0.00	0.19	-	-1.34
800,000	- 0.95	-	-	-0.03	-0.51	- 0.03	0.00	0.19	-	-1.33

This table shows how each of the components of the marginal external benefits of bus travel vary with the overall level of bus patronage, shown in the first column. The components are, from left to right: automobile congestion ("auto VOT"), train congestion ("CRF train VOT", which is zero), bus congestion ("bus VOT", which is assumed to be zero), automobile greenhouse gas emissions ("auto GHG"), conventional air pollution from automobiles ("auto airpol"), the external costs associated with excess fuel consumption by motorists in congested conditions ("auto fuel"), bus greenhouse gas emissions ("bus GHG", which are a disbenefit to bus travel), conventional air pollution from buses ("bus airpol", also a disbenefit to bus travel), the external costs associated with excess fuel consumption by buses in congested conditions ("bus fuel", which is assumed to be zero), and the sum of these externalities ("mec", which stands for the marginal external cost of bus travel, expressed in units of $ per bus passenger journey). As the net marginal external cost of bus travel are negative, they represent a marginal external benefit.

The total marginal external benefit to bus is the marginal external cost with the sign reversed. A negative cost is a positive benefit and vice versa. For work trips, the marginal external benefit (which is the sum of the components shown in the table above) begins at the maximum value of $1.46/bus passenger journey ("BPJ") when bus patronage is near zero and decreases as bus patronage increases—the marginal external benefit per passenger journey declines as more passengers choose to travel by bus.

The principal contributor to meb(q) is the marginal external cost of congestion for automobiles (labelled “auto VOT”, referring to the value of travel time incurred because of congestion). Of the other components of the marginal externality, the adverse effects of automobile air pollution are also significant, even when the adverse effects of bus air pollution are netted off. Other terms in the calculation make only a second-order contribution to the overall result.

Total external benefits at current levels of patronage have been estimated based on the marginal external benefit functions summarised above. These are presented in Table 10.2 below, along with per-passenger journey figures for CityRail derived in a separate study by LECG.

Table 10.2 Total external benefit of bus and rail—totals and per journey 2006-07

	Total external benefit $m/yr		Total external benefit $/pax journey		
Source of benefit	**Four largest contract regions (reg 6-9)**	**Metro buses**	**Four largest contract regions (reg 6-9)**	**Metro buses**	**CityRail**
Avoided road congestion	176.0	236.8	1.07	1.03	4.94
Net Avoided air pollution	37.3	75.8	0.23	0.33	1.61
Net Avoided greenhouse gas	3.2	6.1	0.02	0.03	0.09
Avoided noise pollution	-	-	-	-	-
Avoided road accidents	-	-	-	-	-
Avoided road damage	-	-	-	-	-
Total net external benefits	216.5	318.7	1.32	1.39	6.64

This table shows total external benefits by benefit type for the four largest contract regions and for buses as a whole in the Sydney metropolitan area. The box on the right-hand side of the table presents the same information on a basis of dollars per passenger journey. These unit values are compared to unit values derived in the 2008 externality study for CityRail. Since the CityRail study, the air pollution cost figures have been updated, resulting in higher external benefits for this effect.

It is significant that the avoided road congestion benefits of buses are much smaller than those for CityRail services on a per passenger journey basis. Not only do buses carry far fewer passenger kilometres than rail, but each rail passenger journey displaces a greater number of automobile passenger kilometres. This result arises in part because train journeys are significantly longer on average than bus journeys. The effect of displaced auto passenger kilometres on travel time is non-linear: doubling the number of passenger kilometres will make a four-fold difference to travel time. Another contributing factor is likely to be the spatial layout of the rail network. Rail lines tend to parallel the most congested road arteries into and out of the CBD and other urban centres such as Parramatta and North Sydney, so a motorist switching to rail will be removed from a highly congested route. In contrast, the bus network is more evenly dispersed across the metropolitan area, covering a great many areas of lower traffic density, so a motorist switching to bus will often be removed from an uncongested route.

A further factor, which may not be reflected in the STM results, is that trains get commuters off the road entirely, whereas buses keep them on the road contributing something to congestion.

The air pollution benefit per passenger journey is greater in the metropolitan area overall than it is in the four largest contract regions alone. The reason is that bus journeys are shorter, on average, in the four largest contract regions, owing to the fact that homes and workplaces are generally closer together in those regions. As the bus journeys are shorter, a bus journey displaces a shorter automobile journey in the four largest contract regions. The air pollution thus avoided is less, per bus journey, than it would be in the outer regions of Sydney.

I proceed to consider the relationships between bus 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

I developed a framework to estimate the social costs and benefits arising from bus passenger services, and to use this framework to derive the appropriate contribution by Government to the bus system's costs. It is apparent that the social benefits depend on the extent to which passengers use buses, and that the fare is an important determinant of passenger use. There is, in fact, a tradeoff: given the inelasticity of demand, higher fares mean the bus system 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 bus 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 surplus, 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 the bus system. This task is construed as a problem in mathematical optimisation. I specify this problem and derive analytical formulae for the optimal values. A spreadsheet tool has been developed by LECG 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 bus – 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 bus patronage. The bus 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 Bus 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.

This equation can be simplified in light of the functional forms adopted earlier in this report, namely that:

- $MC(q) = \text{constant } \varphi$,
- $meb(q) = \mu q + \omega$, and
- the elasticity of demand near the optimum is = $-\beta$.

Making the relevant substitutions, the first order condition can be expressed as:

$$\partial W/\partial q = (1+d)[p - \varphi] + \mu q + \omega - d p/\beta$$

$$= (1 + d(1-1/\beta))\, p - (1+d)\varphi + \omega + \mu q = 0$$

The second order condition is:

$$\partial^2 W/\partial q^2 = (1+d(1-1/\beta))\, \partial p/\partial q + \mu$$

Note that μ is negative, and β is between 0.29 and 0.45. As long as $d < 0.4$ (which is likely to be the case for most current State taxes), the expression $(1+d(1-1/\beta))$ will be positive. Therefore, when typical conditions apply, that is downward sloping demand and downward sloping marginal external benefit schedules as functions of bus patronage, the two terms of the second partial derivative will be negative definite. That is sufficient to establish that the values p* and q* which satisfy the first order condition will represent a local maximum of the Welfare function.

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

11.1.3 Constant elasticity demand schedule

The constant elasticity functional form for $q(p) = \alpha (p/p_0)^{-\beta}$.

The inverse form is $p(q) = p_0(q/\alpha)^{-(1/\beta)}$.

The coefficient α is simply q_0. The exponent $-\beta$ is the (constant) bus own-price elasticity of demand. Using this functional form to substitute for q, it is possible to express the first-order condition purely in terms of p and constant factors:

$$\partial W/\partial q = (1 + d(1-1/\beta))\, p^* - (1+d)\varphi + \omega + \mu\, \alpha\, (p^*/p_0)^{-\beta} = 0$$

Where p* is the optimal bus fare and q* = q(p*) is the optimal level of bus patronage. Unfortunately, this functional form does not lend itself to an analytical solution for p*, so numerical solution techniques must be used. Optimal values of consumer surplus (CS*), producer surplus (PS*), and total external benefit (EXT*) are given below:

$$CS^* = \int_0^{q^*} v(s)\, ds - p^*q^* = \int_0^{q^*} p_0(s/\alpha)^{-(1/\beta)}\, ds - p^*q^*$$

$$= p_0[q^{*\,(1-(1/\beta))}][(1/\alpha)^{-(1/\beta)}]/ (1-(1/\beta)) - p^*q^*$$

$$= p^*q^*/ (1-(1/\beta)) - p^*q^* = p^*q^*/(\beta - 1)$$

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

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

11.1.4 Incorporating SSTS patronage in the optimisation analysis

So far, an important complication to the optimisation analysis has been overlooked. A significant proportion of the total bus patronage consists of school students travelling on subsidised passes by virtue of the school student transport scheme (SSTS). These travellers pay nothing per journey, and the total cost of a student pass is significantly lower (when averaged across the number of journeys typically taken) than the normal bus fare.

The optimisation process must, to be useful, focus on the fare that is charged to fare-paying bus passengers. However, optimisation cannot overlook the significant effect of SSTS passengers on bus costs and on the external benefits provided by buses. To incorporate this complication in the analysis, the following assumptions have been employed:

1. Bus contract data excludes SSTS patronage, but includes costs imposed by SSTS;
2. STM runs employ bus patronage figures that include SSTS patronage[20];
3. The number of SSTS passengers is completely insensitive to the bus fare, as these passengers do not pay the fare;
4. Bus travel yields the same marginal external benefit for an SSTS passenger as for a non-SSTS passenger;
5. The bus operator incurs the same marginal cost for carrying an SSTS passenger as for a non-SSTS passenger.

These assumptions have no impact on the valuation of externalities, except that assumption 4 is invoked implicitly in the calculation of total external benefits of bus in $m/yr.

The optimisation process requires modification in light of the existence of SSTS passengers. The bus fare that is optimised, p*, is the fare paid by fare-paying passengers. The initial fare, p0, to which p* is compared, must therefore be calculated on a basis that excludes SSTS passengers: p0 = total fares collected / # fare-paying passengers.

The number of passengers counted in the optimisation process must include SSTS passengers, since these make an important contribution to costs and to external benefits.

[20] This means, among other things, that the bus price elasticities derived from STM runs reflect the response of the entire patronage base q (including SSTS passengers) to changes in the price paid by fare-paying passengers only (p). Only the number of fare paying passengers responds to the price signal, but the elasticity figure is (dq/dp)(p/q). The price elasticity of the fare-paying passengers only is greater, but it is the response of the whole patronage base that is of interest here.

While the marginal cost rate is assumed constant over all levels of patronage, the marginal external benefit rate changes as the number of bus passengers changes.

I introduce the subscripts "fp" and "ss" to refer to "fare-payers" and "school students," respectively.

$$q = q_{fp} + q_{ss}$$

The term q_{ss} is constant, in the sense it is unresponsive to the bus fare levels (see assumption 3 above). It is clear that any change in the number of fare-paying passengers will exactly equal the change in the number of passengers overall.

In the welfare equation from section 11.1.1, the producer surplus changes to:

$$PS = pq_{fp} - \int_0^q MC(s)\, ds$$

to reflect the fact that only q_{fp} passengers pay the fare. Note that the marginal cost is incurred for all q, not just fare-payers. The consumer surplus changes in an analogous way:

$$CS = \int_0^q v(s)\, ds - pq_{fp}$$

Note that some consumer surplus is obtained by all passengers, not just fare-payers. The value placed by SSTS travellers on their bus trip is not easy to determine, however. It cannot necessarily be assumed that they value it more highly than the bus fare, since they do not pay this fare.

The externality term in the welfare equation is not affected by the non-payment of a fare by SSTS passengers because they contribute some marginal external benefit by using buses. The underlying idea, stated at assumption 4 above, is that if these passengers did not use bus then some proportion would travel instead by car, adding to congestion, pollution, etc.

When PS and CS are summed, the first term of the former cancels the second term of the latter. This cancellation would appear to make the SSTS/non-SSTS distinction irrelevant for optimisation purposes. However, the final term in the welfare equation,

$$dGC = d\,(F - PS) = d\,(F - pq_{fp} + \int_0^q MC(s)\, ds\,)$$

is affected by SSTS travellers. The nature of this effect is that a higher Government Contribution is required by virtue of the fact that fewer than q passengers actually pay the fare p. This higher Government Contribution leads to a marginal excess burden of taxation on the tax receipts that must be collected to pay this larger subsidy.

The SSTS version of the first order condition for welfare differs in a small, but important way from the formula given at the beginning of section 11.1.2 above.

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

Flowing from this change, the first order condition in its simplified form must be restated like so:

$$\partial W/\partial q = (1 + d(1 - (1 - (q_{ss}/q))/\beta))\, p - (1+d)\varphi + \omega + \mu\, q = 0$$

This is the version of the first order condition that is used to solve for p* and q* in the presence of SSTS passengers. Note that this formula has been designed so that p* will reflect the fares paid only by fare-paying passengers, but q* includes SSTS passengers.

11.2 Results and sensitivity analysis

There are three main uncertainties that determine the optimal levels of fare, patronage and Government subsidy:

- The true marginal cost of bus service;
- The value of passenger time (ranging from $9.23/hr or $22.60/hr, with a central value of $15.80/hr), which influences the slope and y-intercept of the marginal external benefit function; and
- 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).

The first six rows in the Table 11.1 below show the optimal single fare (in column p*) for the Sydney metropolitan bus service region as a whole. Whether this optimal fare is higher or lower than the current fare, p0, depends largely on the assumed value of the marginal cost, MC. Higher marginal costs lead to higher optimal fares, and vice versa. In the central case (highlighted in the table), with marginal cost set at the arithmetic mean of the high and low values and with the taxation factor, d, set to 0.1, the optimal fares are close to current fares. Importantly, the welfare gain to be had by moving from current to optimal fares (shown in column “W* - W0”) is quite low in this central case.

Table 11.1 Optimisation results with sensitivities shown 2006-07

Sensitivity result table									
			$/BPJ	$/BPJ	pax/workday	$/workday	$m/yr	% fare	$m/yr
case name	reg name	d	p0	p*	q*	W* - W0	W* - W0	increase	GC*
sf low MC	MBSC	0	1.51	0.64	1,329,061	156,583	39.15	-58%	697.06
sf low MC	MBSC	0.1	1.51	0.88	1,154,602	63,679	15.92	-41%	581.46
sf mid MC	MBSC	0	1.51	1.15	1,033,840	20,626	5.16	-24%	510.78
sf mid MC	MBSC	0.1	1.51	1.51	919,398	0	0.00	0%	405.61
sf high MC	MBSC	0	1.51	1.68	878,708	3,615	0.90	11%	360.48
sf high MC	MBSC	0.1	1.51	2.15	791,549	42,302	10.58	42%	259.12
sf low MC	MBSC-hiVOT	0.1	1.51	0.54	1,429,829	202,303	50.58	-65%	760.00
sf mid MC	MBSC-hiVOT	0.1	1.51	1.11	1,047,222	23,738	5.93	-26%	522.59
sf high MC	MBSC-hiVOT	0.1	1.51	1.73	867,430	5,760	1.44	15%	347.73
sf low MC	MBSC-loVOT	0.1	1.51	1.27	990,468	7,936	1.98	-16%	461.88
sf mid MC	MBSC-loVOT	0.1	1.51	1.91	831,342	17,705	4.43	27%	318.49
sf high MC	MBSC-loVOT	0.1	1.51	2.56	734,680	103,336	25.83	69%	188.96
sf low MC	4 largest regions	0	1.47	0.90	807,334	44,293	11.07	-39%	353.39
sf low MC	4 largest regions	0.1	1.47	1.18	718,943	8,452	2.11	-19%	283.09
sf mid MC	4 largest regions	0	1.47	1.28	697,243	4,236	1.06	-13%	268.96
sf mid MC	4 largest regions	0.1	1.47	1.67	623,009	3,444	0.86	14%	192.30
sf high MC	4 largest regions	0	1.47	1.67	622,808	3,903	0.98	14%	188.31
sf high MC	4 largest regions	0.1	1.47	2.18	558,355	36,433	9.11	48%	106.33

Table 1.3 also shows the optimisation results for the four largest contract regions considered separately. In the central case optimal fares are 14% higher than actual fares but the welfare gains from fare reform are modest (approximately 0.5% of the current Government Contribution.)

The effect of employing the high and low estimates of the value of time, which flows through to the congestion externality, is also shown in Table 1.3 (rows labelled "MBSC-hiVOT" for the high value of time case, and "MBSC-loVOT" for the low value of time case). As the congestion externality is numerically the most significant external effect, changing the value of time has a marked influence on the results.

12 Conclusions

The bus system provides benefit to the NSW community in two main ways. Bus passengers derive consumer surplus by purchasing bus journeys at prices that are less than their private valuation of those journeys. Non-bus passengers derive benefits from the fact that others purchase bus 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 the bus system. 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, bus patronage, and Government subsidy.

This study has proposed a new method of calculating the optimal settings for bus average fare per passenger journey, bus patronage, and the total level of Government subsidisation for the bus system's operating loss. 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 bus system subsidy. With an empirically grounded understanding of the relationship between net welfare and bus patronage, I have been able to calculate optimal levels of net welfare, and the policy settings (average fare and Government subsidy) needed to obtain those optima.

The quantification of externalities performed in this study has permitted us to reach the following conclusions.

1. The marginal external benefit derived from bus travel in the Sydney metropolitan region is approximately $1.40 per bus passenger journey. The precise value depends on the total quantum of bus travel during a typical workday.

2. The total external benefit from the four largest contract regions is estimated to be $217m/yr, of which $176m/yr is attributable to avoided road congestion and $37m/yr is attributable to net avoided air pollution.

3. For buses in the Sydney metropolitan region overall, the total external benefit is estimated to be $319m/yr, of which $237m/yr is attributable to avoided congestion and $76m/yr is attributable to net avoided air pollution.

4. Bus fares overall are close to optimal levels, if the marginal cost of bus travel is reasonably approximated by the arithmetic mean of the high and low marginal cost values estimated in this report, and if the marginal excess burden of taxation is 0.1.

5. If the marginal cost is the arithmetic mean of the high and low marginal cost values and the marginal excess burden of taxation is 0.1, optimal bus fares for the the four largest contract regions are 14% higher than current fares, although moving fares to the optimal levels would have only a slight positive impact on welfare. If the marginal excess burden of taxation were zero, however, small fare reductions would be optimal. The conclusion is therefore sensitive to this uncertain parameter.

6. Current effective average bus fares for non-work trips are lower than for work trips, owing to the fact that a different mix of ticket types is purchased by non-work travellers, and significant sections of the non-work travelling public (particularly students travelling on the SSTS) pay nearly nothing to use buses.

7. Of course, it is recognised that social policy objectives, including subsidised student and pensioner travel, are served by the current fare settings for non-work travel and these objectives must be weighed against economic efficiency criteria.

8. These conclusions have been tested for sensitivity to changes in the marginal cost of bus travel, marginal excess burden of taxation, and to the value of time. The optimal fare outcomes are highly sensitive to changes in the marginal cost value. The present marginal cost estimates may not form a sufficiently reliable basis for fare-setting since they are based on contract, rather than resource costs and they do not capture fully the relationship between marginal cost and bus occupancy.

9. In order to improve estimates of marginal cost it would be necessary to investigate the accounts and operating methods of the bus operating companies in some detail. Two issues, in particular, require further investigation:

   - The relationship between bus contract costs and actual efficient costs faced by the bus operators; and

   - The relationship between traffic-sensitive costs of the bus operator and average bus occupancy.

An additional important caveat applies to the optimisation results presented in this draft report. Marginal external benefit rates have been calculated using data from the STM for work trips only. It has been assumed that the same marginal external benefit rate per bus passenger journey applies to non-work trips. So far, it has not been possible to test this assumption, but it is entirely possible that it may lead to an overstatement of the congestion-avoidance attributable to non-work bus trips, since many of these trips occur outside of peak hours.