sapere research group

Public transport externalities, optimal ticket pricing and subsidies

Mike Smart

Outline

1. Overall approach
2. Marginal cost estimation
3. Marginal external costs
    1. Congestion
    2. Emissions
    3. Accidents
4. Road pricing
5. Optimum fares and subsidies

Nature of externalities

Externality is a cost or benefit to a party other than the buyer or seller of a service;

1st Example: congestion

- One more car joining crowded road suffers delay
- The new car delays all others
- Only the delay to all others is an externality

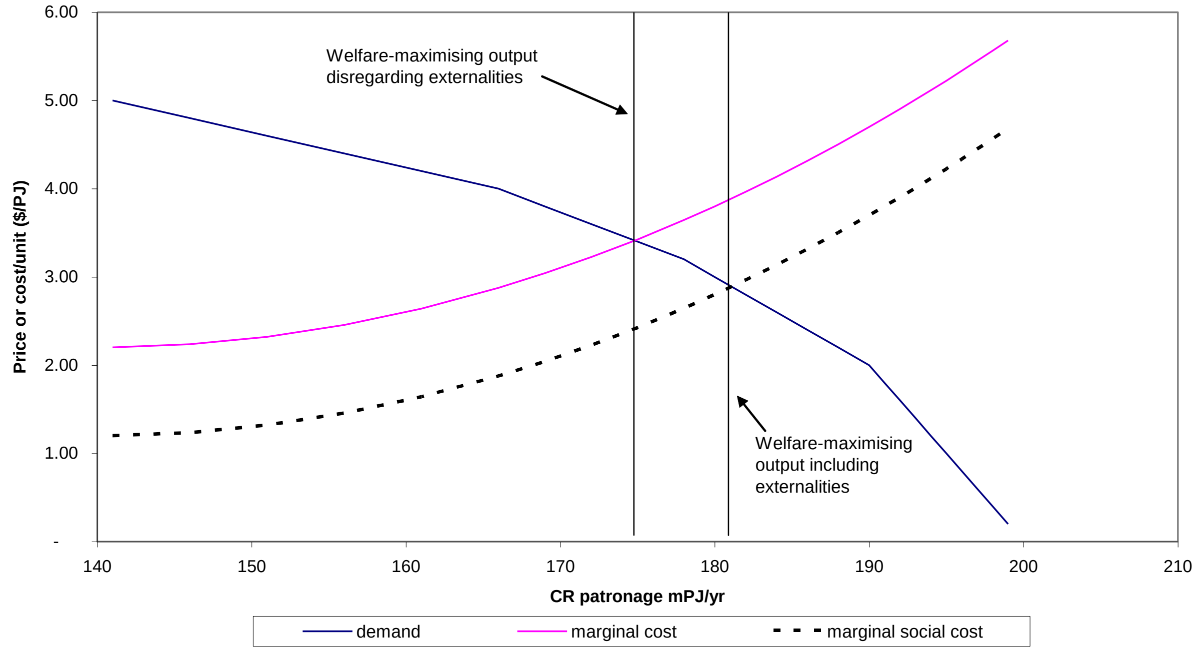
2nd Example: air pollution

- Polluter may suffer ill health from atmospheric smoke, lead, etc
- Non-drivers may also suffer ill health
- Ill health of all sufferers except the polluter is an externality

External benefit is generated by public transport usage, not mere availability

Optimisation – conceptual approach

Example externality analysis



sapere research group

Optimisation - mathematical approach

For all public transport, the optimal fare maximises social welfare, assuming no further changes to road pricing. In general, the following system of equations needs to be solved (see Appendix 2):

$$\sum_i e^{ij} X^i [(1 + \lambda)(c^i - p^i) + \sum_h mec^i_h] = \lambda p^j X^j \qquad (5)$$

The optimal price of each mode, p^i, depends on the price of each other mode, p^j, the marginal external costs (mec) of each mode summed over all affected individuals, h, the marginal cost of each mode, c, the number of passenger km travelled on each mode, X, the own and cross-price elasticities, e, and the marginal excess burden of taxation, λ.

X and p are related by the demand schedule for each mode.

Mathematical approach—(2)

To simplify the explanation, assume λ = 0. Prices for all other modes: c, b, t are fixed. Equation (5) can be written:

$$e^{cf}X^{c}\,[c^{c} - p^{c} + \sum mec^{c}] + e^{bf}X^{b}\,[c^{b} - p^{b} + \sum mec^{b}] +$$
$$e^{tf}X^{t}\,[c^{t} - p^{t} + \sum mec^{t}] + e^{ff}X^{f}\,[c^{f} - p^{f} + \sum mec^{f}] = 0$$

To solve for the optimal ferry price, p^f, assuming current rail and bus fares, and current road pricing levels ($p^c - c^c$) levels, it is necessary to know:

- Marginal costs of each public transport mode (c^j);
- Marginal road price for cars ($p^c - c^c$);
- Marginal external costs for each transport mode ($\sum mec^j$);
- Patronage on each mode at optimal ferry prices (X^j); and
- The percentage change in patronage on each mode as a result of a 1% change in the ferry price holding other prices constant (e^{if}).

Displacement of automobiles

Displacement of road traffic—method

Transport Data Centre's Sydney Strategic Travel Model used to assess impact on road traffic of changes to public transport patronage;

SSTM account for time of day and specific road layout;

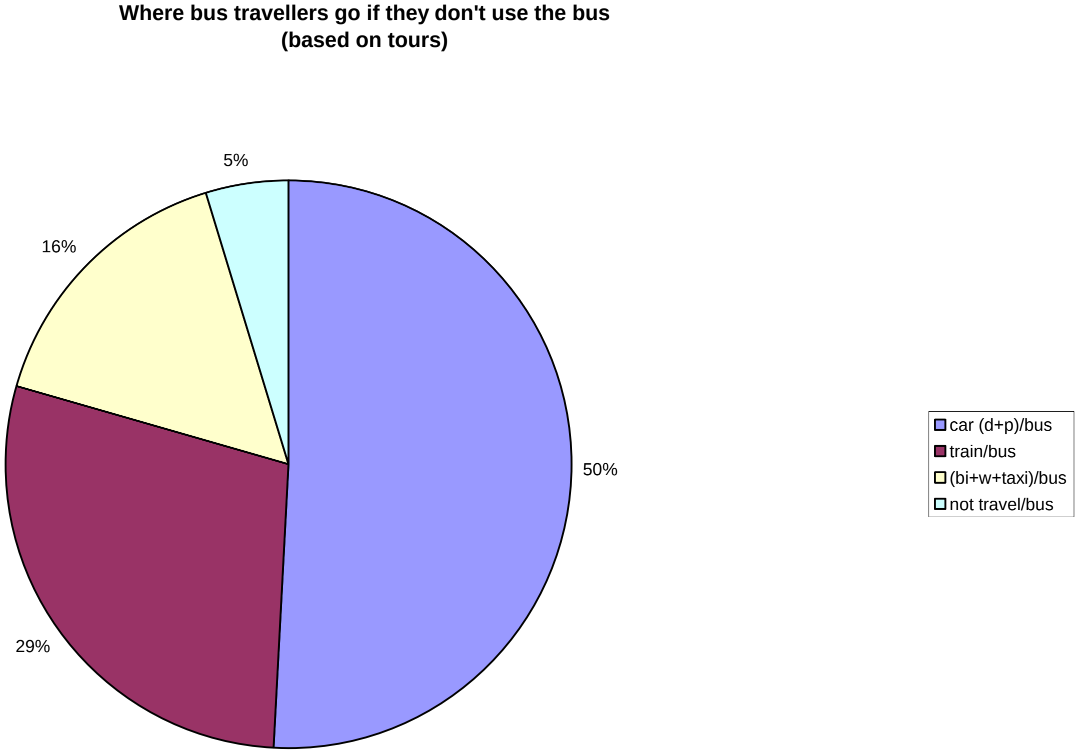
Measured price sensitivity of travellers, waiting and walking time for public transport are taken into account.

Displacement of road traffic—results of SSTM

IPART Externalities Study
Results from the Sydney Strategic Travel Model

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

Where displaced bus journeys go



TDC model runs permit quantitative estimate of substitution effect between buses and cars or trains.

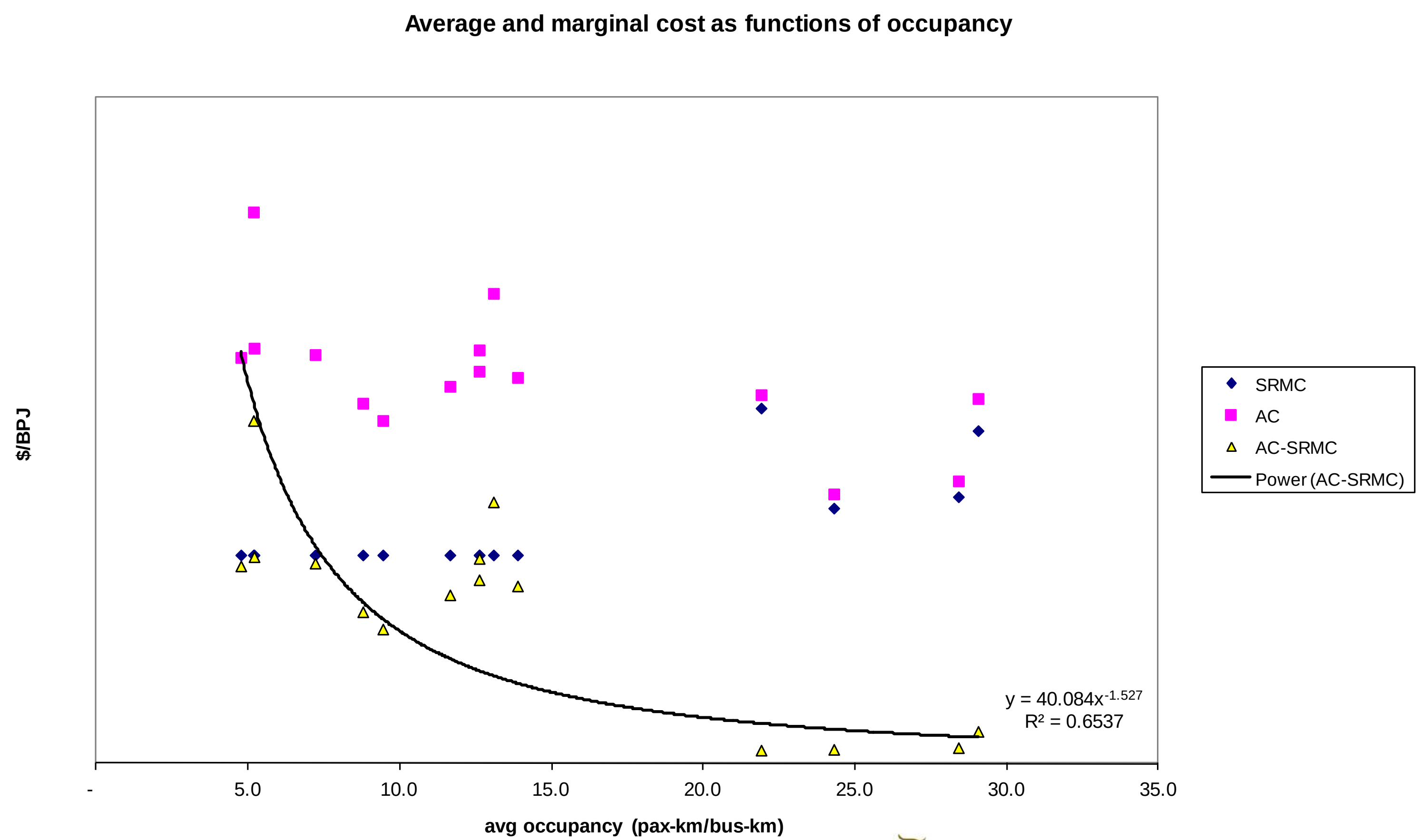
sapere research group

Marginal cost

Estimation of marginal costs - Trains

- 2008 study examined prior 36 years worth of annual reports
- Regression model compared annual total cost to:
  - Unit prices: labour, electricity, cost of capital
  - Usage: patronage and carriage-km travelled
  - Dummy variables: freight, Granville accident
- SRMC estimates per electrified seat-km obtained
- LRMC estimates also obtained by heuristic argument based on core capacity augmentation project costings

Marginal cost results - Bus



Results of simple marginal cost model - Ferry

route	physicals per round trip							financials per round trip				$/PJ				
	duty time (hrs)	fuel (litre)	Crew cost/hr	mtce cost/rev hr	seat capacity	% seat utilis	PJ/ ferry round trip	fuel cost/RT	labour cost/RT	mtce cost/RT	fuel lab mtce cost/RT	fuel lab mtce cost/PJ	Avg cap cost /PJ	SRMC	LRMC	Syd Ferry ticket prices/PJ
Manly (excl Jet Cat)	1.00	348.87	325.41	94.56	1100	21%	233.32	241.78	325.41	94.56	661.74	2.84	1.76	2.84	4.59	4.80
Parramatta R	2.60	220.10	162.70	77.54	230	23%	51.90	152.54	423.03	201.62	777.19	14.97	4.63	14.97	19.60	4.80
Taronga Zoo	0.40	37.00	227.99	95.62	811	15%	117.74	25.64	91.20	38.25	155.08	1.32	0.43	1.32	1.75	3.84
Mosman	0.67	28.97	179.28	20.00	552	11%	59.01	20.07	119.52	13.33	152.93	2.59	0.95	2.59	3.54	3.84
Neutral Bay	0.42	25.94	179.28	20.00	400	9%	34.61	17.98	74.70	8.33	101.01	2.92	2.36	2.92	5.28	3.84
Watsons Bay	0.83	111.11	179.28	147.51	250	23%	56.92	77.01	149.40	122.92	349.33	6.14	2.22	6.14	8.35	3.84
Darling H/Balmain	0.83	51.15	179.28	20.00	400	20%	78.83	35.45	149.40	16.66	201.52	2.56	1.04	2.56	3.59	3.84
Woolwich/Balmain	1.00	62.82	179.28	20.00	400	9%	35.40	43.53	179.28	20.00	242.82	6.86	2.31	6.86	9.17	3.84
Cockatoo Island	1.00	64.09	179.28	20.00	400	9%	35.40	44.42	179.28	20.00	243.70	6.88	2.31	6.88	9.20	3.84
TOTAL inner harbour																
Parramatta EX	1.83	158.44	162.70	77.54	230	23%	51.90	109.81	298.29	142.17	550.26	10.60		10.60		4.80
TOTAL all services																
Unit prices		0.693044														TravelTen
		$/litre														price/10
																excl GST

Estimating marginal external cost

Congestion – Value of Time

Congestion costs depend on the value of travel time

VOT is related to average hourly wage = $28.80 (Feb 08 est)

Literature reveals dispersed values for VOT/wage

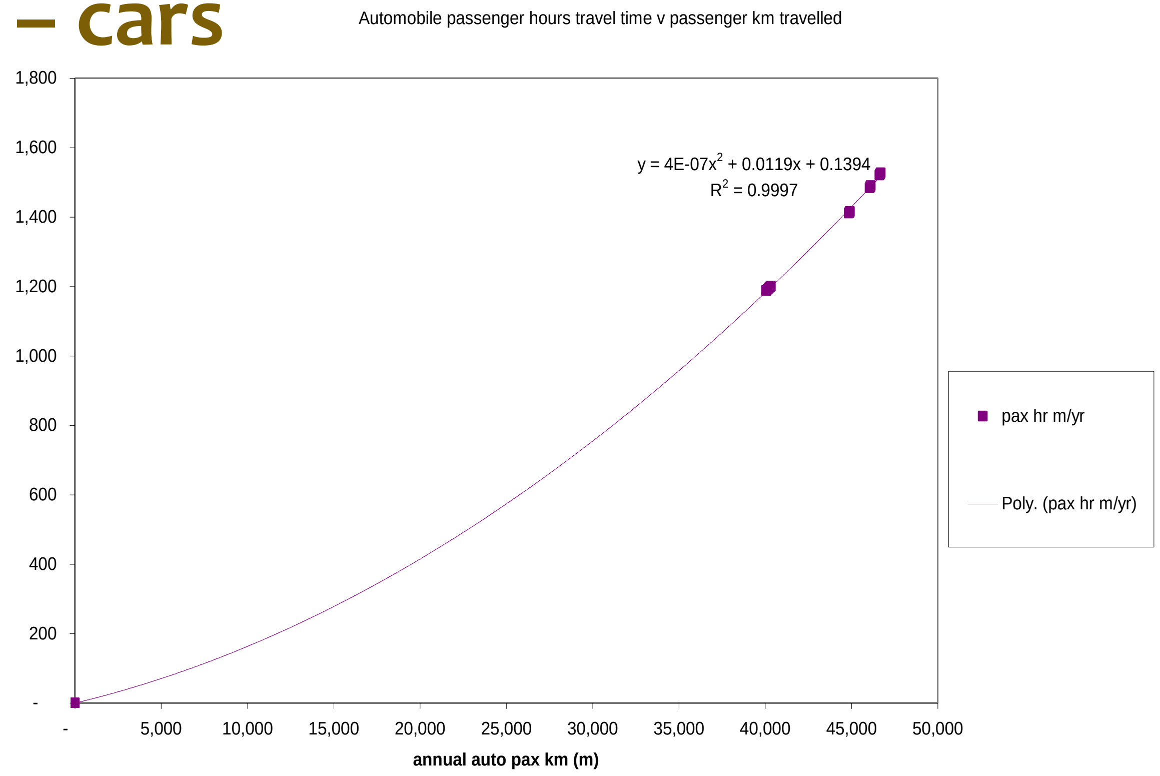
BTE OP51 provides range of study values:

- Median of commuter time VOT/wage = 35%
- Median of business travel time VOT/wage = 76%

Range adopted for rail sensitivity testing: $9.23/hr - $22.60/hr

Central case value adopted = $13.15/hr (2008 study)

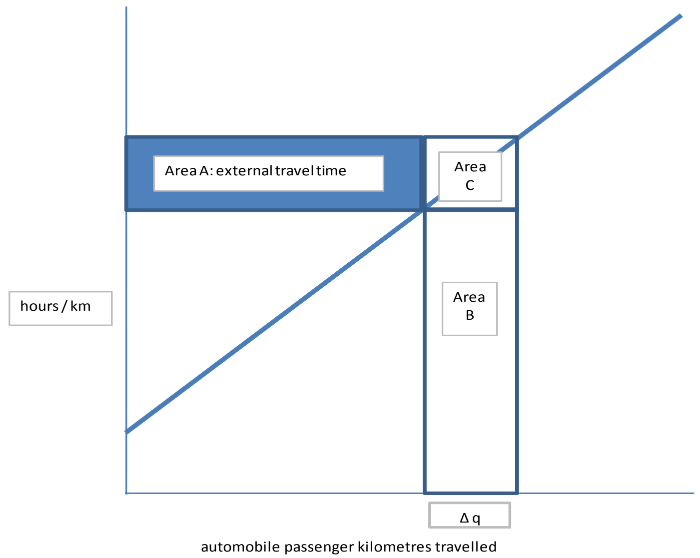
Congestion – cars



Congestion reduces average speeds, increasing the average hrs/km travelled. Longer time per journey is a cost to motorists.

Congestion externality

External cost is the value of travel time for the inframarginal motorist. (Same approach used for prior studies.) STM used to determine change in travel time with change in car passenger km.

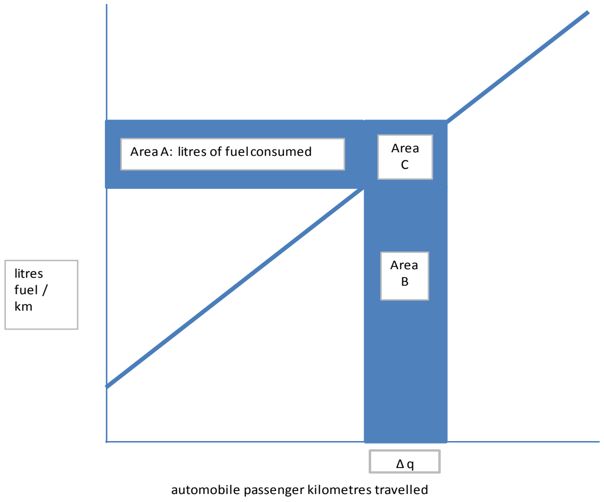


Emissions

For car, bus and ferry modes, emissions are proportional to fuel consumed.

Data from Watkiss (2002) is the basis for quantifying conventional air pollution costs per litre of fuel combusted.

A carbon price range will be assumed to value the greenhouse gas externalities per litre of fuel consumed.



Accidents – approach

Idea is that by reducing car usage, CityRail reduces the likelihood of traffic accidents.

Two complications in measuring this effect:

1. Accident costs borne by (motorist) accident victims are not external, and insurance further internalises most costs
2. Under congested conditions, there are likely to be fewer accidents per vehicle km and less severe accidents.

Therefore, marginal external accident costs are probably small, hard to measure, and possibly unfavourable to rail.

Internal accident costs are already taken into account when motorist compares rail fare with cost of driving.

Types of accident costs

Total accident costs are estimated in BTE report 102.

A suggested split between internal and external is given here.

It is the marginal external benefit from accident reduction that is relevant to the CityRail fare/subsidy split.

This information sheds no light on marginal benefit.

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

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

Accidents – conclusions

The marginal external accident benefit is small, hard to measure and possibly a disbenefit to rail.

More rail patronage means less congested roads, which means higher average car speeds.

Higher car speeds mean greater likelihood of accident per vehicle km and more severe accidents on average.

While the total number of accidents may be higher with no rail, the accident rate per passenger km will probably be lower.

Even if the accident cost per pax-km was the same, the accident benefit would not be an externality—no subsidy would be justified on the accident externality ground.

Accident externalities excluded from analysis of fares and subsidy.

Results – external costs

Comparison to prior studies - Rail

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

sapere research group

Summary of external costs - Ferries

MARGINAL EXTERNAL COSTS	car	train	bus	ferry		VOT ($/hr)	car occupancy	
congestion								
commuters ($/person-km)	0.65	0	0	0		20	1.2	
tourists ($/person-km)	0.06	0	0	0		10	1.2	
emissions						petrol	diesel	
litre unleaded petrol/veh-km	0.250	0	0	0		1.24	1.36	Beer $/litre
litre diesel/veh-km	0	0	0.278			0.46	0.58	Watkiss $/litre (band 1)
litre unleaded petrol/person-km	0.208	0	0	0		2.34	2.68	kg CO2/litre
litre diesel/person-km	0	0	0.011	0.163			25	$/tonne CO2 price
health costs (Watkiss) ($/person-km)	0.096		0.006	0.095				
GHG cost ($/person-km)	0.012		0.001	0.011				
Total emissions cost ($/person-km)	0.108	0.007	0.007	0.105		Rail figure from Karpouzis 2007, pp. 21-22		
accidents								
by argument, mec ($/person-km)	0	0	0	0				
other externalities								
by assumption, mec ($/person-km)	0	0	0	0				
Total mec ($/person-km)								
commuter	0.76	0.01	0.01	0.11				
tourist	0.17	0.01	0.01	0.11				

Road pricing

Road pricing

The marginal cost of motoring is not known. Neither is the total out-of-pocket cost of a typical motorist. Fortunately, price should equal vehicle marginal cost except for Government taxes—petrol excise, road tolls, and parking space levy. To vehicle marginal costs must be added road infrastructure marginal costs.

On a per vehicle km basis:

p – c = (excise rate/litre)(litre/vkt) – (road damage/vkt) + (toll/vkt) + (parking levy/vkt)

The excise rate is greater than the road damage rate. The difference can be estimated using budget figures on fuel levy receipts and road expenditure.

STM will be used to estimate (toll/vkt) and (parking levy/vkt).

Optimal public transport fares

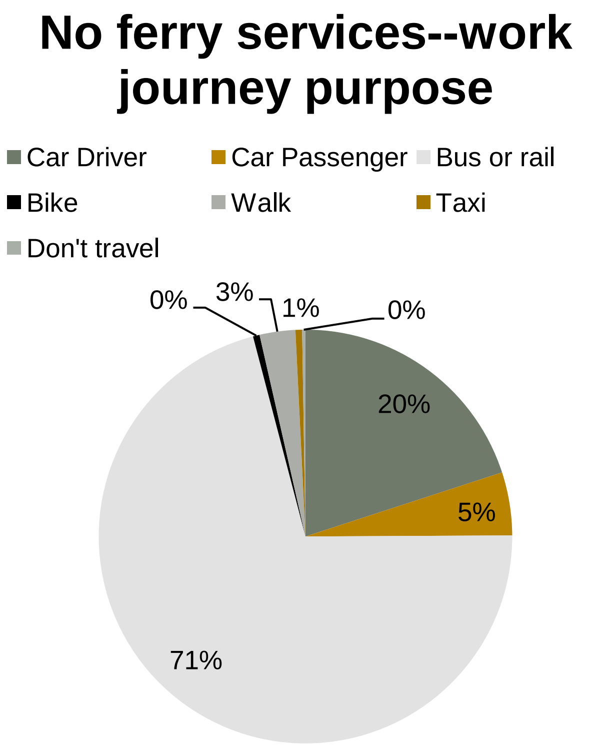
Ferry example

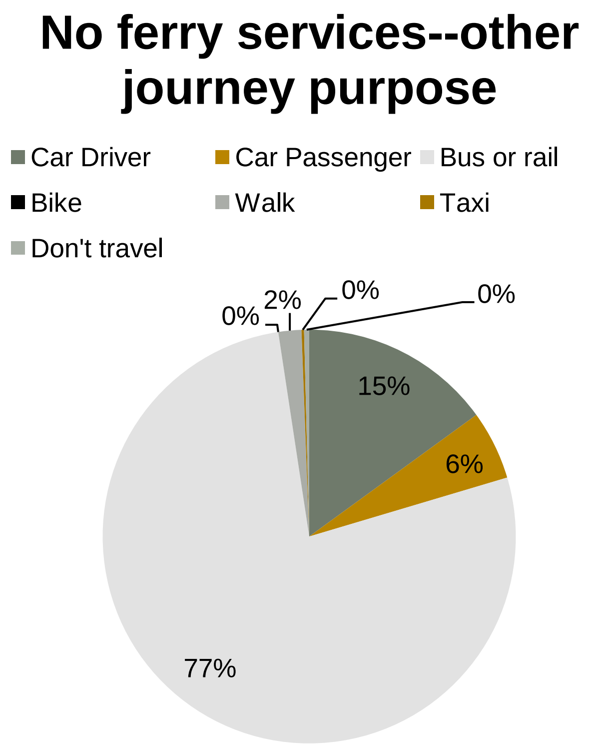
Optimal prices 1: summary of inputs

$/person-km		car	train	bus	ferry
price			0.10	0.14	0.52
marginal cost			0.27	0.22	0.88
price-marg cost			-0.17	-0.09	-0.36
	commuter/bridge/CBD park	0.53			
	commuter/no bridge/CBD park	0.37			
	tourist/bridge	0.17			
	tourist/no bridge	0.06			
mec					
	commuter	0.76	0.01	0.01	0.10
	tourist	0.17	0.01	0.01	0.10

Optimal prices 2: modal substitution

(i.e., what travellers do when ferry is unavailable) *Source: STM*





Optimal prices 3:

fare calculation for commuter trips (other prices fixed, λ=0)

			ferry	Manly (excl Jet Cat)	Parramatta R	Taronga Zoo	Mosman	Neutral Bay	Watsons Bay	Darling H/Balmain	Woolwich /Balmain	Cockatoo Island
work purpose	mec+c-p		dXi/dXf									
car-commuter/bridge	0.23		-25%	-23%		-33%						
train	0.18		-50%	-46%	-72%	-42%			-46%	-40%		
bus	0.09		-19%	-25%	-9%	-19%			-17%	-13%		
car-commuter/no bridge	0.39				-17%				-33%	-29%		
sumproduct dXi/dXf * (mec+c-p) = Z			-0.17	-0.16	-0.20	-0.17	-0.17	-0.17	-0.23	-0.20	-0.20	-0.20
ideal fare commuter	p* = c + mec + Z		0.81	0.34	0.84	0.43	0.70	1.99	0.56	0.78	1.20	0.89
ideal fare - price			0.29	-0.09	0.61	-0.75	-0.17	0.55	0.25	-0.15	0.68	0.49
% price increase			57%	-22%	275%	-64%	-19%	39%	79%	-16%	131%	121%
ideal fare ($/pj)			6.01	3.77	18.00	1.40	3.10	5.31	6.86	3.21	8.88	8.50

sapere research group

Optimal prices 4:

fare calculation for tourist trips (other prices fixed, λ=0)

			ferry	Manly (excl Jet Cat)	Parramatta R	Taronga Zoo	Mosman	Neutral Bay	Watsons Bay	Darling H/Balmain	Woolwich /Balmain	Cockatoo Island
other purpose	mec+c-p						dXi/dXf					
car-tourist/bridge	-0.00		-20%	-26%			-24%					
train	0.18		-73%	-68%	-86%		-68%		-72%		-60%	
bus	0.09		0%	0%	0%		0%		0%		0%	
car-tourist/no bridge	0.11				-10%				-20%		-15%	
sumproduct dXi/dXf * (mec+c-p) = Z			-0.13	-0.12	-0.17	-0.12	-0.12	-0.12	-0.15	-0.13	-0.13	-0.13
ideal fare tourist	p* = c + mec + Z		0.85	0.37	0.87	0.48	0.74	2.04	0.63	0.85	1.27	0.96
ideal fare - price			0.33	-0.05	0.65	-0.70	-0.12	0.60	0.32	-0.08	0.75	0.56
% price increase			63%	-13%	291%	-59%	-14%	42%	102%	-9%	145%	139%
ideal fare ($/pj)			6.27	4.19	18.76	1.56	3.31	5.44	7.75	3.50	9.39	9.16

Justification for subsidies

Total external benefit

Total ext benefit $/day	No_Manly_Ferry	No_Parramatta_Ferry	No_Mosman_Zoo_Neutral_Bay_Ferry	No_Watsons_Bay_Ferry	No_Darling_Harbour_Blamain_Cockatoo_Ferry	Sum all routes
comm-w	4,222	1,517	1,781	3,232	1,832	12,583
comm-s	4,682	1,684	2,444	3,711	1,996	14,517
tourist-w	- 4,040	- 2,059	- 515	- 810	- 737	- 8,162
tourist-s	- 5,647	- 3,704	- 1,022	- 1,416	- 1,276	- 13,064
all-w	182	- 542	1,265	2,421	1,096	4,422
all-s	- 965	- 2,019	1,423	2,295	720	1,453
$/day	-392	-1,281	1,344	2,358	908	2,937
$/annum	-97,550	-318,919	334,655	587,178	226,074	731,437

Sensitivity test: VOTx2; $0/tonne CO_2

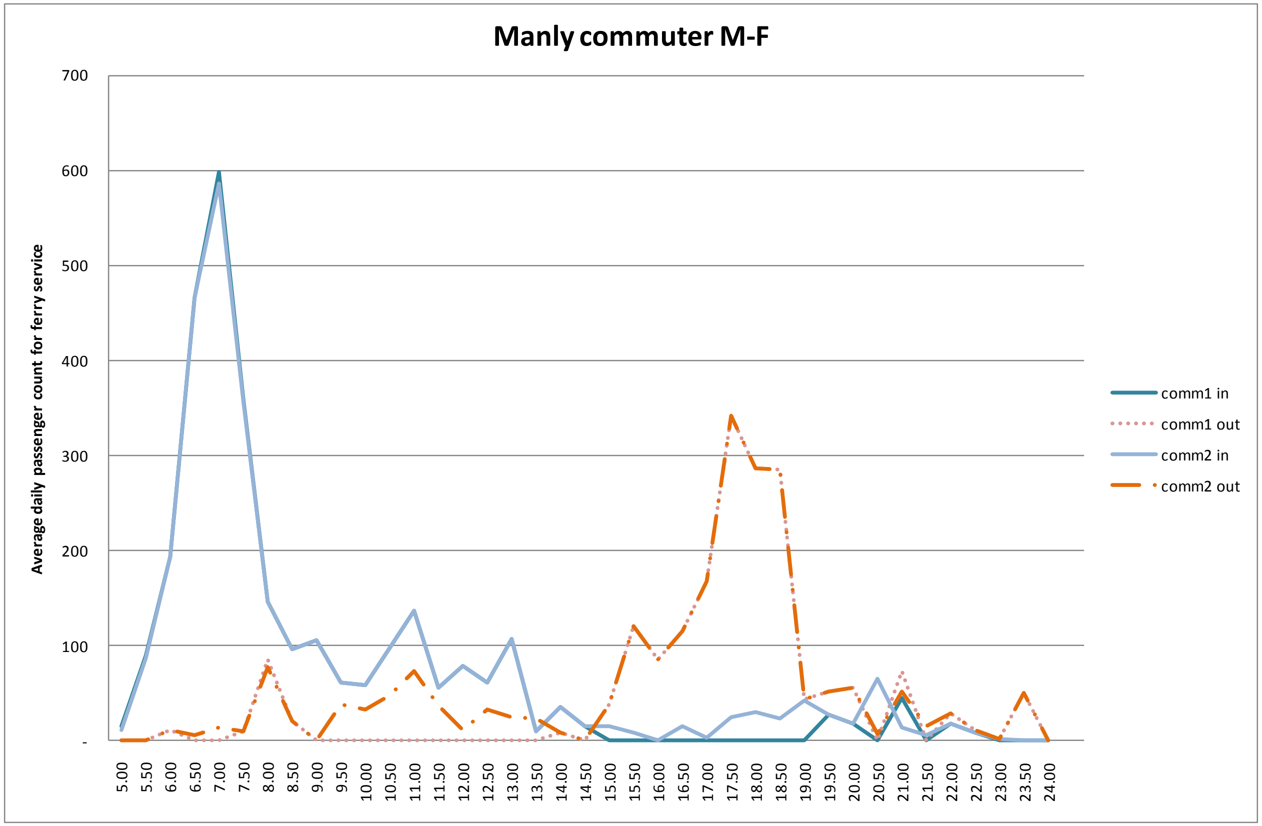
Total ext benefit $/day	No_Manly_Ferry	No_Parramatta_Ferry	No_Mosman_Zoo_Neutral_Bay_Ferry	No_Watsons_Bay_Ferry	No_Darling_Harbour_Blamain_Cockatoo_Ferry	Sum all routes
comm-w	12,580	7,494	4,283	7,847	4,573	36,778
comm-s	13,949	8,322	5,878	9,012	4,981	42,144
tourist-w	- 2,299	- 1,680	- 309	- 546	- 536	- 5,371
tourist-s	- 3,213	- 3,022	- 613	- 954	- 928	- 8,731
all-w	10,281	5,814	3,973	7,301	4,037	31,407
all-s	10,736	5,301	5,265	8,058	4,053	33,412
$/day	10,509	5,558	4,619	7,680	4,045	32,409
$/annum	2,616,663	1,383,822	1,150,156	1,912,207	1,007,112	8,069,960

Appendix – Ferry information

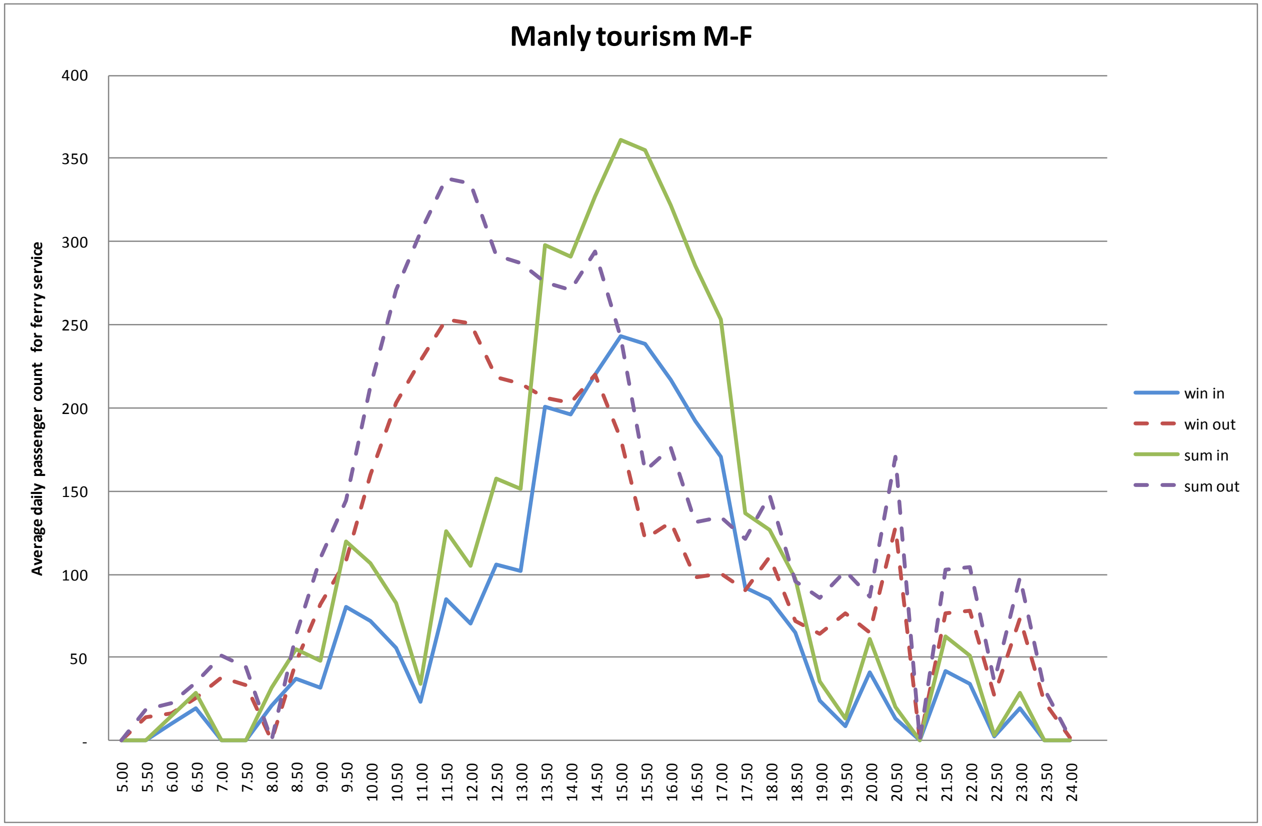
Special issues raised by ferries

1. High proportion of tourism patronage on Manly, Taronga Zoo, Watson's Bay, Parramatta/Sydney Olympic Park, and Darling Harbour routes. Likely mode-switching behaviour of tourists is unknown.
2. Two different private fast ferry services compete on Manly route. STM has difficulty modelling these. Effect is that extent of mode shift from Manly slow ferry to other modes will be overestimated by STM.
3. Most ferry passengers travel on multi-mode ticket, making it difficult to isolate the effect of changes to the ferry fare when other prices are held constant.
4. Little is known about ferry marginal costs, and the short history of service contracting limits the amount of accounting data potentially available.

Commuter travel pattern—Manly ferry



Tourist travel pattern—Manly ferry



Appendix – Optimisation formulae

Appendix 1: derivation of key equation

The function that we wish to maximise is consumer welfare+producer surplus:

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

The first-order conditions for prices can be written as follows:

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

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

Assuming marginal social utility of income = 1 for everyone, this simplifies to

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

For each individual, h,

$$(\partial Y_h/\partial p^j) = - x^j_h - \sum_i mec^i_h (\partial X^i/\partial p^j) \qquad (4)$$

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

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

$$\sum_i e^{ij} X^i [(1 + \lambda)(c^i - p^i) + \sum_h mec^i_h] = \lambda p^j X^j \qquad (5)$$

sapere research group