Transportation (2006) 33:621–639
DOI 10.1007/s11116-005-5711-x

Estimating commuter mode choice: A discrete choice analysis of the impact of road pricing and parking charges

KEVIN WASHBROOK*, WOLFGANG HAIDER & MARK JACCARD
School of Resource and Environmental Management, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia, V5A 1S6, Canada
*(*Author for correspondence, E-mail: kfwashbr@sfu.ca)*

Key words: parking charges, road pricing, stated preference

Abstract. Automobile use leads to external costs associated with emissions, congestion, noise and other impacts. One option for minimizing these costs is to introduce road pricing and parking charges to reduce demand for single occupant vehicle (SOV) use, while providing improvements to alternatives to encourage mode switching. However, the impact of these policies on urban mode choice is uncertain, and results reported from regions where charging has been introduced may not be transferable. In particular, revealed preference data associated with cost recovery tolls on single facilities may not provide a clear picture of driver response to tolls for demand management. To estimate commuter mode choice behaviour in response to such policies, 548 commuters from a Greater Vancouver suburb who presently drive alone to work completed an individually customized discrete choice experiment (DCE) in which they chose between driving alone, carpooling or taking a hypothetical express bus service when choices varied in terms of time and cost attributes. Attribute coefficients identified with the DCE were used in a predictive model to estimate commuter response to various policy oriented combinations of charges and incentives. Model results suggest that increases in drive alone costs will bring about greater reductions in SOV demand than increases in SOV travel time or improvements in the times and costs of alternatives beyond a base level of service. The methods described here provide an effective and efficient way for policy makers to develop an initial assessment of driver reactions to the introduction of pricing policies in their particular regions.

1. Background

Automobile use leads to external costs from reduced air quality, congestion delays on goods movement, and decreased urban livability. One policy option for internalizing these costs is road pricing and parking charges for intra-urban single occupant vehicle (SOV) use. Revenue from such charges could be used to improve alternative modes such as transit and carpooling, in order to encourage a shift from the SOV to those alternatives. However, the actual influence of SOV pricing policies on urban commuter mode choice is uncertain. The research described here was driven in part by concerns about the transferability of results in those few settings where road pricing for demand management has been applied.

The central feature of this study was a stated choice method known as the discrete choice experiment. This discrete choice modelling framework was used to estimate responses to time and cost attributes for drive alone, carpool and transit modes for individual commuters. These response values were then used to construct a predictive model in order to estimate the potential for two sets of policies – charging a price for single occupant vehicles (SOV's) to drive on the existing urban road system and park at work, and providing improvements to carpooling and transit services – to reduce overall SOV commuter demand by shifting drivers from single occupant vehicles to carpooling and transit.

The term road pricing is used here to mean charging for road use on an area-wide basis (for example, using multiple cordons or in-car time and distance metering and GPS tracking) at pricing levels set to reduce demand rather than recover costs. For simplicity, this study does not study commuter response to charges that vary by time of day or congestion level, though variable pricing could be used in a demand management road pricing program.

1.1. *Previous research into driver responses to road and parking pricing*

Unfortunately, there are few real-world examples of area-wide road pricing for demand management on which to generalize about driver responses to such charges. Singapore introduced an area-wide pricing scheme in the mid 1970's that has since been expanded and refined considerably, and several cities in Norway developed pricing cordons around their centres, starting with Bergen in 1986 (see Toh and Phang 1997 and Larsen and Ostmoe 2001 for a review of experiences there). Most recently, London England introduced an area licensing scheme for the centre in February 2003. Whereas the cordons in Norway present drivers with relatively low fees (equivalent of $1.50 US in 1995 or $2.10 CA)[1] and were implemented with a focus on collecting revenue for transportation system improvement, the Singapore and London pricing schemes were implemented with the goal of reducing automobile congestion in the city centre (while simultaneously generating revenue for transportation system improvements). The introduction of charges in Singapore reduced vehicle volumes in the city centre by 45% (Toh and Phang 1997). Analysis indicates that results in London have exceeded expectations, with a 25% reduction in chargeable traffic volumes (private and commercial vehicles, excluding taxis, alternate fuel vehicles and those owned by the disabled) (Transport for London 2003).

Several centres in Europe have conducted field trials to evaluate the local responses of drivers to road charges. A two month trial in Dublin in 1999 employed in-car metering of time and distance charges and focused on the effect of charging on mode choice and trip suppression for peak period commuter trips (O'Mahony et al. 2000a, b). A year long study in Stuttgart employed a cordon around the city centre and the electronic, road side deduction of charges from vehicle mounted transponders (Hug et al. 1997). Notably, the Dublin study found that a $5.75 US (1999, $8.20 CA) time and distance charge for the average peak period trip resulted in a 22% reduction in peak period traffic volumes into the city centre. Both studies used small samples and were relatively costly and complex.

Finally, there are a few studies which have surveyed driver responses to road charges for demand management in hypothetical or experimental settings, as proposed in this study. A 1991 stated preference study of driver responses to a potential variable pricing cordon around Trondheim Norway found that, at toll levels high enough to induce a change in travel behaviour in half the survey sample, (generally above $1.60 US, 1991 or $1.85 CA), trip retiming was a more likely response than switching to the bus (Polak et al. 1991). The Trondheim study did not test charging exemptions for carpools or incentives for their use.

It is difficult to generalize results from Singapore to particular North American settings given different public expectations about the role of government in daily life. The London experience would appear more comparable, but the transport environment there is substantially different from that in most North American metropolitan areas: London's city centre is severely congested; automobile mode share in the centre was only 12% before the introduction of charges; parking charges were already extremely high; and an array of frequent and efficient transit, subway, rail and taxi services are available to and within the centre. In contrast, most North American metropolitan areas are characterized by low density employment sites with abundant free parking. In addition, declining transit system investment in real terms and population and employment dispersion into suburbs has led to decreased transit system efficiency and continued high SOV mode shares for the trip to work. However, while Canadians and Americans both associate driving with mobility and independence, Canadian acceptance of a broad government role in redistributive programs may make for easier implementation of road charges for demand management there.

The attempt to extrapolate the results of field trials and stated preference surveys from European settings to particular North American commuting environments brings with it a high degree of uncertainty. Congestion levels, the quality of alternative modes, the political climate and level of public engagement in transportation planning, and pricing levels all play a role in determining the way commuters will respond to charges. All these variables argue for the evaluation of driver responses to the introduction of road charges at the local level.

There is a larger body of North American research on the use of parking charges to manage demand and influence mode choice. Of note here, Flannelly et al. (1991), Hunt et al. (1997) and Kuppam et al. (1998) found that increased SOV parking costs had a greater influence on mode choice than incentives to carpool or take transit. Finally, there is extensive research into commuters' opinions of charging for vehicle use (see Higgins 1997 for a useful summary). Such research is essential for documenting concerns about fairness, effectiveness and use of charging revenue, all of which need to be addressed to gain public support for pricing. However, opinion research does not tell policy makers how drivers will respond to charges on the road.

1.2. *Greater vancouver context*

Growth in Greater Vancouver has led to a steady increase in vehicle traffic, resulting in a decrease in average travel speeds; in addition, a shift away from periphery – core commuting to inter-suburban commuting has led to longer average travel distances, often between areas poorly connected by transit. The region has invested in transit system expansion, most notably in light rail systems from suburbs to the core, but also in more flexible express bus systems. Despite this, transit's overall share of total trips in the region has increased only slightly in the past 10 years. Ongoing discussion of the need to recover a greater proportion of transportation system costs from users has led to numerous calls for introduction of road pricing; however, an attempt to introduce an annual per-vehicle levy collapsed in response to opposition. Senior levels of government have recently called for an expansion of automobile infrastructure to alleviate congestion, with the application of tolls for cost recovery. While public opinion on the benefits of highway expansion is mixed, there is widespread recognition of need for improvement to the transportation system.

2. Survey methodology

2.1. *Designing the discrete choice experiment*

Researchers can measure actual travel choice behaviour in order to collect information on commuters revealed preferences, or test responses to hypothetical choice scenarios to collect information on stated preferences. While revealed preference data has obvious appeal, such information is not always easily interpreted, because of covariance between choice attributes, small variance in attribute levels, and difficulty identifying the range of choices available to individuals in the real world. In addition, in many cases – such as this study's investigation of area wide tolling for demand management – relevant revealed commuter preferences are not available for analysis. A stated preference method called the alternative-specific discrete choice experiment (DCE) (Louviere et al. 2000) was used in this study to overcome these constraints and collect preference data in a quick, inexpensive way.

The DCE measured suburban drive alone commuters' preferences for driving alone, carpooling or express bus services when drive alone costs were increased and travel times for the three choices were longer or shorter than reported drive alone times. Information on respondents' home and work locations and travel time to work was collected in telephone screening interviews and used to customize the DCE to respondents' particular commuting situations. The customized DCE was mailed out to 650 people for completion and return. Survey customization methods were adapted from Ewing and Sarigollu (1998). In the DCE each mode choice was represented by three attributes varying between four levels in each choice question.[2] The attributes are listed in Table 1 and described below.

2.1.1. *Travel time for the drive alone, carpool and express bus choices*

The travel time ranges for the carpool and bus choices were set slightly lower than for driving alone to reflect improvements in travel time for those modes resulting from government investment in infrastructure (queue jumpers, HOV/bus lanes, etc).

2.1.2. *Drive alone road charge*

Values were presented as a daily round trip charge in order to make them comparable with other costs in the DCE. Values were spaced unevenly assuming that the mode switching threshold was at the low end of the price range.[3]

2.1.3. *Parking costs for driving alone and carpooling*

The highest drive alone parking charge corresponds to the daily portion of average monthly parking rates (April 2001) in the downtown core of Vancouver. Carpool parking charges were set at a lower price range to reflect their use as an incentive to switch modes.

2.1.4. *Time spent picking up other carpoolers*

Door-to-door pick up of carpoolers was included as an attribute as regional residents have consistently identified this as an attractive feature of carpooling (TransLink 2000).

Table 1. Attributes and attribute levels used in the discrete choice experiment.

Driving alone	Carpooling	Taking express bus	
In-vehicle travel time	*In-vehicle travel time*	*In-express bus travel time*	
1. +30% revealed time	1. +15% revealed time	1. +15% revealed time	
2. +15% revealed time	2. revealed time	2. revealed time	
3. revealed time	3. −15% revealed time	3. −15% revealed time	
4. −15% revealed time	4. −30% revealed time	4. −30% revealed time	
Road charge	*Time spent picking up other carpoolers*	*Total time waiting for all buses*	
		walk to exchange	bus to exchange
1. $0	1. 3 min	1. 3 min	1. 5 min
2. $1	2. 6 min	2. 6 min	2. 10 min
3. $4	3. 9 min	3. 9 min	3. 15 min
4. $9	4. 12 min	4. 12 min	4. 20 min
Parking cost	*Parking cost*	*Travel time from express bus stop to work*	
1. $1	1. $0	1. 3 min walk	
2. $3	2. $1	2. 6 min walk	
3. $6	3. $2	3. 5 min local bus ride and 3 min walk	
4. $9	4. $3	4. 10 min local bus ride and 3 min walk	

2.1.5. *Travel time from an express bus stop to work*

This attribute was included as it is unlikely many respondents would have express bus service available directly from their community transit exchange to their workplace.

2.1.6. *Total time waiting for buses*

Respondents living within 10 min walk of the local transit exchange were assumed to wait for, at most, two buses in any given choice scenario, whereas respondents who live further away could face up to three wait time periods in a scenario (local bus to the exchange, express bus near to work, and local bus from an express stop to their workplace).

2.2. *Respondent-specific fixed values included in their choice questions*

Estimated travel time from each respondent's home to their existing local transit exchange was included as a fixed value in the description of the express bus option in their customized survey. The return trip daily bus fare between home and work was also included as a fixed value in this option, based on the cost (April, 2001) of a discounted monthly pass for the appropriate distance. Figure 1 shows a sample choice question.

CHOICE QUESTION 1

Choice ❶: DRIVE ALONE	Choice ❷: CARPOOL	Choice ❸: EXPRESS BUS
Travel time in vehicle:	**Time for pick-ups:**	**Time from home to exchange:**
26 minutes	9 minutes	1 min. walk + 4 min. local bus ride
Road charge:	**Travel time to work:**	**Travel time on express bus:**
$1 return	21 minutes	34 minutes
Parking cost:	**Parking cost:**	**Time from express bus to work:**
$3 day	$3 day shared by carpoolers	6 minute walk
		Total time waiting for buses:
		15 minutes
TOTAL TIME: 26 minutes	**TOTAL TIME:** 30 minutes	**TOTAL TIME:** 60 minutes
COSTS: $4	**COSTS:** $3 shared	**COSTS:** $4

➨ **If these were the only 3 commuting choices available to you, would you:**

DRIVE ALONE ❑ CARPOOL ❑ TAKE EXPRESS BUS ❑

Figure 1. A choice question from the discrete choice experiment.

2.3. *Sample selection process*

Two suburban Vancouver communities were chosen for the study because they did not have express bus service similar to that presented in the DCE (nor were they linked to the regional light rail system). A random sample of telephone listings in the communities was contacted to select 650 respondents. For inclusion, respondents had to commute to work alone at least three days per week with travel times of longer than 20 min.[4] The DCE and attached generic travel survey took approximately 30 min to complete. The small number of returned surveys containing incorrectly completed DCE's (15 out of 584) indicates that the experiment was comprehensible. Further details on design of the DCE, sample selection and response rate are found in Washbrook (2002).

3. Analysis

3.1. *Model estimation*

The statistical model used for analysis is the conditional logit, often referred to as a discrete choice model (McFadden 1974). All analysis was done using LIMDEP 7.0 (Greene 1998). Attributes were estimated first with categorical coding for all attributes, and then with continuous coding for numerical attributes and categorical coding only for the non-continuous attribute "time from express bus to work." Statistical comparison showed that continuous coding provided a better overall prediction of responses. The results for the continuous model are shown in Table 2. The first model showed two quadratic coefficients with insignificant effect at the 90% level, indicating linear effects only for these variables. A second model was estimated with these insignificant quadratic coefficients removed. All further analysis was conducted on this restricted model.

Table 2. Coefficient and constant estimates for continuous attribute model of mode choice.

Attribute/constant	Full model coefficient	*t*-stat.	Restricted model coefficient	S.E.	*t*-stat.
Drive alone choice attributes:					
In-vehicle time – linear effect	−0.037	−4.770	−0.037	0.008	−4.770
In-vehicle time – quadratic effect	0.001	1.769	0.001	0.001	1.762
Road charge – linear	−0.206	−15.176	−0.206	0.014	−15.150
Road charge – quadratic	0.016	3.731	0.016	0.004	3.678
Parking cost – linear	−0.182	−15.087	−0.179	0.012	−15.270
Parking cost – quadratic	0.003	0.666	–	–	–
Carpool choice attributes:					
Carpool in-vehicle time – linear	−0.052	−6.498	−0.052	0.008	−6.452
Carpool in-vehicle time – quad.	−0.003	−3.533	−0.003	0.001	−3.518
Pickup time – linear	−0.070	−4.595	−0.069	0.015	−4.553
Pickup time – quadratic	−0.067	−1.976	−0.065	0.034	−1.913
Carpool parking cost – linear	−0.052	−3.349	−0.051	0.015	−3.317
Carpool parking cost – quad.	−0.037	−1.093	–	–	–
Express bus choice attributes:					
In express bus time – linear	−0.037	−2.567	−0.037	0.015	−2.560
In express bus time – quadratic	0.002	1.707	0.002	0.001	1.725
Total wait time for buses – linear	−0.175	−3.026	−0.174	0.058	−3.001
Total wait time for buses – quad.	0.004	1.807	0.004	0.002	1.794
Time from express bus to work:					
3 min walk	reference	–	reference	–	–
6 min walk	−0.245	−1.446	−0.242	0.169	−1.426
5 min local bus ride + 3 min walk	−0.315	−1.864	−0.307	0.168	−1.824
10 min local bus ride + 3 min walk	−0.853	−4.488	−0.842	0.190	−4.436
Drive alone constant	0.496	1.633	0.512	0.303	1.689
Carpool constant	0.531	1.745	0.548	0.303	1.809
Express bus constant	reference	–	reference	–	–
$L(0)$	−4438.394		−4438.394		
$L(a)$	−3642.476		−3642.476		
$L(\beta)$	−3276.681		−3277.494		
Likelihood ratio index:					
ρ^2 (adjusted) = $1-(L(\beta)-k)/L(0)$	0.258		0.258		
Likelihood ratio test: $-2^*(L(\beta)\text{restricted} + L(\beta)\text{ Full})$			$\chi^2 = -1.626$ with 2 d.f.		

$n = 529$ surveys (the number on which all eight choice questions were completed)

3.2. *Interpreting model coefficients*

As one would expect, an increase in any of the mode time or cost attributes reduced the chances of that mode being chosen for the commute to work. SOV parking and road charges had the largest effect of the cost attributes on mode choice. The non-linear effect of the road charge, shown by the significant positive coefficient for the quadratic estimation of this attribute, indicates that at higher road charges the negative impact of an increase in cost declines. While this may initially appear counter intuitive, it is likely that some respondents associate higher road charges with less congested travel routes and are willing to pay for the associated reduction in travel time. In fact, when re-estimated for sample income segments, the road pricing quadratic was significant only for respondents with incomes above $40,000 ($25,430 US). A similar income effect was noted in a stated preference study conducted prior to the implementation of road pricing in Trondheim, Norway (Polak et al. 1991). Carpool parking charges had a relatively small effect on the likelihood of carpool mode choice.

Carpool travel time had a slightly greater effect on mode choice than either drive alone or bus travel time. Carpool pickup time had an even larger effect, and, not surprisingly, bus wait time had the greatest effect on mode choice of any time attribute. All time attributes also showed non-linear responses, significant at the 90% level (carpool travel time significant at the 95% level). For drive alone travel time as well as bus travel and wait times, this non-linearity suggests a threshold after which additional increases in time have a declining effect on the likelihood of mode choice. For drive alone travel time, the threshold is gradual, and the flattening out of the curve likely reflects the response of a core group of drive alone commuters who are highly resistant to mode switching regardless of the increase in drive alone travel time. For bus travel and wait times the effect is quite dramatic: the likelihood of respondents choosing to take the bus decreases quite rapidly as bus travel time approaches revealed drive alone travel time, and as bus wait times approach 10 min.

In the case of carpool travel and pickup times, the non-linearity in the mode choice response indicates that additional increases in these attributes have an increasingly negative effect on the likelihood of carpooling as travel and wait time increase. The sharpness of these curves also suggests a threshold response: at travel times greater than 85% of revealed travel time, and pick up times greater than 6 to 8 min, further increases in these times result in a much greater decrease in the likelihood of choosing to carpool. This result may reflect respondent concerns about the safety of travelling with other drivers in a carpool, or a lack of tolerance for spending large amounts of time travelling with others.

Response to the bus attribute "time from express bus to work" showed that respondents' likelihood of choosing the express bus to work decreased considerably with a transfer to a local bus to continue to work after travelling on the express service. Finally, the constant values indicate that unmeasured mode attributes contribute an underlying preference for driving alone and carpooling over transit, independent of time and cost values.

3.3. *Predicting mode choice probabilities for a base case scenario*

In order to estimate the effect of policy driven changes to cost and time attributes on the probability of mode choice, it will be useful to define a base case for comparison. Ideally, a base case is equivalent to the status quo; for the sample population this would mean a drive alone market share of 100% and poor mode choice alternatives. However, the DCE presented respondents only with improved hypothetical carpool and transit choices, so the closest the model can come to recreating the status quo is to set drive alone travel time attributes at their revealed levels, road and parking charges to zero, and carpool and transit travel time attributes at the least competitive levels offered in the choice questions. Attribute levels for this base case, using the median reported commuting time of 35 min, are described in Table 3. Given these attribute levels, the baseline mode choice probabilities (or, more broadly, market shares) among the sample population of commuters would be 0.83 for driving alone, 0.15 for carpooling, and 0.02 for transit.

The 15% base case market share for carpooling is somewhat surprising, and suggests that some respondents would consider this mode if it were available as presented. Responses to two survey questions support this argument. First, a majority of respondents indicated they are currently unable to find carpool partners, and most also indicated that carpooling infrastructure is limited or absent on their route to work; the instructions to the DCE

Table 3. Attribute levels for base case market shares.

Driving alone	Carpooling	Taking express bus
35 min in vehicle	40 min in vehicle	40 min in vehicle
(median revealed time)	(15% above revealed time)	(15% above revealed time)
no road charge	7.5 min pick up time	10 min wait time
(as at present)	(study mean value)	(study mean value)
no parking charge	no parking charge	3 min walk from express bus to work
(as at present)	(as at present)	(base categorical value)
market share: 83%	market share: 15%	market share: 2%

asked them to assume that improved infrastructure was in place and that ride matching services were available. Second, most respondents reported that they had never previously carpooled to work, suggesting that for some, participation in the survey may have been the first time they actively considered the possible benefits (such as reduced costs and door to door pickups) associated with carpooling. In addition, it is important to note that carpool market share in the base case results from a carpool member pickup time of 7.5 min; when pickup time increases above this level, carpool market share declines rapidly. In any case, real world carpool market shares would likely be somewhat lower than those predicted by the model because of the difficulty of matching all potential carpoolers together.

3.4. *Estimating the effect of economic instruments on demand for driving alone*

Table 4a below shows the separate and combined effect of road and parking charges on drive alone choice base case probability. All other attributes are held at the base case levels described in Table 3. The table shows that a $1.00 ($0.64 US) parking charge and $1.00 return road charge together reduce the probability of driving alone from 83 to 75%. At the other extreme, introduction of a $9.00 ($5.72 US) road charge and a $9.00 parking charge together reduce the drive alone market share to 17%, which equals a total reduction in drive alone demand of 80%. Overall market shares given this $18.00 ($11.44 US) return trip cost are 17% drive alone, 74% carpool

Table 4. (a) Effect of road and parking charges on the probability of choosing to drive alone to work. (b) Effect of SOV road charges and forced SOV travel time increases on the probability of choosing to drive alone to work.

Road charge	Parking charge				
	$0	$1	$3	$6	$9
$0	0.83	0.80	0.74	0.62	0.49
$1	0.78	0.75	0.68	0.55	0.42
$3	0.68	0.65	0.56	0.43	0.30
$6	0.56	0.52	0.43	0.31	0.21
$9	0.50	0.46	0.37	0.26	0.17

Road charge	Revealed time	Percent increase above revealed time		
		10%	20%	30%
$0	0.83	0.81	0.80	0.79
$1	0.78	0.77	0.75	0.73
$3	0.68	0.66	0.64	0.62
$6	0.56	0.54	0.52	0.49
$9	0.50	0.48	0.46	0.43

and 9% transit, reducing the total private vehicle kilometres travelled to work (for both SOV and HOV modes) by approximately 50%. This reduction assumes that average carpool occupancy is two and a half persons per vehicle – an optimistic projection of the effect of carpooling incentives. A $7.00 ($4.45 US) return road charge – equivalent to the estimated subsidy for the average (14 km) trip in the Greater Vancouver region in 1993 (KPMG 1993) – reduces drive alone demand by 36% and total commuter kilometres travelled by 24%. Results assume that all those who want to carpool find rides, and commuters are not able to travel alternative untolled routes or park elsewhere for free. Also, results do not incorporate rebound demand resulting from reduced congestion, which would likely result in a somewhat higher equilibrium market share for the SOV mode.[5]

These results are similar to those reported by Kuppam et al. (1998) for a 1995 stated preference study of commuter responses to parking charges in Washington DC. That study found that a $8–$9 CA ($5.70 –$6.40 US, 1995) parking tax reduced drive alone demand by approximately 35%, compared to 36% in this study. They also found that middle income commuters were most likely to switch to carpooling in response to charges, whereas transit was first choice among those with low incomes. The present study found the same result – a $5 ($3.18 US) parking charge led to a shift in carpool market share from the base case of 15 to 36% for middle income respondents (household incomes between $60 and $80,000 per year, $38 to $51,000 US), but only increased carpool mode share to 29% for lower income respondents (household income less than $60,000 per year); transit market shares increased from 2 to 4% for middle income and to 11% for lower income respondents. One reason for this difference may be that middle income households have more opportunity to ride share in a second family car.

Governments may also consider increasing SOV travel time to encourage switching to alternatives. Travel time could be increased by allowing SOV traffic volumes to grow at a faster rate than road system capacity, or by assigning existing road capacity to exclusive use by carpools and transit. Table 4b compares the effects of forced SOV travel time increases and road charges on the probability of choosing to drive alone. The first row shows that the effect of travel time increases alone on drive alone choice probability are slight: a 30% increase in in-vehicle travel time over reported time reduces drive alone market share by just 4% – equivalent to the introduction of a $1.00 ($.64 US) road charge. These results indicate that, as well as being unpopular, forced increases in SOV travel time would be less efficient at reducing SOV demand than relatively small increases in cost.

3.5. *Estimating the combined effect of improved alternatives and pricing on SOV demand*

Model results show that a decrease in bus in-vehicle time from base case levels to 30% less than drive alone in-vehicle time reduced drive alone choice probability by only 3%. As shown in Table 4a above, this is equivalent to introducing a $1.00 ($0.64 US) road charge on the drive alone choice. In short, relatively small increases in drive alone costs have a greater effect on drive alone market share than large decreases in express bus time attributes (beyond the base level of service considered here). A comparison between drive alone costs and carpool time improvements leads to the same conclusion.

These results agree with the findings of earlier research. A 1991 study of suburban commuter responses to demand reduction measures in the Chicago area found that increases in parking cost had a greater impact on propensity to ride share than the provision of ride share service improvements (Koppelman et al. 1993). Similar results were reported in a literature review by Apogee Research (cited in Pickrell 1999) which estimated that SOV demand could be reduced 5% with road pricing (at $0.15 US per mile, $.23 CA, 1999), 3% with parking pricing (no pricing level provided), 1.4% with HOV lanes, and 1% with transit improvements. Flannelly et al. (1991) also found that improvements to travel time alone had only a small impact on carpool mode share.

Nonetheless, similar reductions in SOV demand can be obtained at lower pricing levels if combined with improvements to carpool and transit alternatives, which will also create less hardship for low income commuters. Modelling showed that a $2.00 ($1.28 US) road charge, a 10% travel time reduction for carpooling and transit and a 10% travel time increase for driving alone reduced total VKT by the same amount as a $5.00 ($3.18 US) road charge alone. It is also worth noting that preliminary responses to introduction of £5 ($8.24 US 2003) daily road charges in London suggest charges alone may help to reduce transit travel times; a recent six month review showed that since the introduction of charges transit travel speeds and transit travel time reliability have both increased in the centre. In effect, congestion reductions resulting from the introduction of road charges have led to substantial improvements in transit service in the city centre independent of investment in transit infrastructure (Transport for London 2003).

3.6. *Elasticities of SOV demand and total VKT in response to charges*

In this study elasticities refer to the percent change in the probability that commuters will choose to drive alone given a 1% change in road or parking charges. Elasticities were estimated with the two cost attributes first set at

$5.00 ($3.18 US) and then 1% higher at $5.05 ($3.21 US), with all other attributes held at the base level. This approach provides approximate point elasticities of demand for SOV travel in response to charges, for the median travel time commuter represented by the base case scenario.

This method is similar to calculating the shrinkage ratio of demand (Hirschman et al. 1995), which in real world settings can result in poor elasticity estimation due to overlooked explanatory variables. In the present study this is not an issue given the controlled choice situation. Oum et al. (1992) compared elasticity estimates from revealed preference discrete choice models using aggregate data and found they are consistently somewhat *lower* than those estimated from direct demand models using aggregate data. Conversely, they found elasticity estimates from discrete choice models using representative cases (as in this study) consistently estimate elasticities *higher* in absolute value than elasticities estimated with direct demand models. However, Dunne (1984) found elasticities estimated using representative cases were in agreement with weighted aggregate elasticities when the sample was relatively homogenous – as in the present study, which only includes commuters who currently drive alone, more than 20 min one way, three days per week. Table 5 shows elasticities for the whole sample and several income segments.

Table 5 shows that a 10% increase in road charges from $5.00 to $5.50 ($3.18 to $3.50 US) leads to a 3.2% decrease in drive alone demand for the sample as a whole. Similar results were obtained for parking charge elasticities; however, tighter confidence intervals indicate that respondents were more homogenous in their reaction to these charges, likely as a result of their familiarity with them.

The results show that elasticities are lowest for high income respondents, reinforcing the income effect identified for the road charge coefficient. Further, results suggest that elasticities may peak in the middle income segment and decline again with lower incomes, which reinforces the argument that lower income commuters have fewer response options – such as parking one family car and carpooling with household members in another – when faced

Table 5. Elasticities of commuter drive alone probability for $5 road and parking charges.

	Road Charge Elasticity	Parking Charge Elasticity
Overall results for study	−0.32 (−0.41, −0.23)	−0.30 (−0.33, −0.28)
Household income: greater than $80,000	−0.31 (−0.40, −0.17)	−0.23 (−0.27, −0.19)
Household income: $60,000 to $79,000[a]	−0.37 (−0.53, −0.13)	−0.46 (−0.51, −0.40)
Household income: less than $60,000[a]	−0.41 (−0.56, −0.18)	−0.42 (−0.46, −0.36)

Values for the 95% confidence interval in parentheses.

[a]Small sample size for these subgroups indicates results should be interpreted with caution.

with increased costs for driving alone.[6] These results highlight an important equity concern; not only can lower income drivers less afford to pay increased costs for travel, they would be more reliant on publicly provided transit services if charges were introduced.

Comparing results from this study to estimates of elasticities for parking costs and road charges reported in other studies shows that, broadly speaking, the results reported here fall within the upper range of parking and road charge elasticities reported elsewhere.[7] However, the usefulness of comparing elasticity values is limited, as values obtained in a given setting are dependent on the range of choices available to drivers, including alternative modes, nearby untolled routes, and, if charges are variable, untolled or discounted travel times (see Burris 2003 for a thorough discussion of this topic). For trip purposes other than commuting, the choices are even greater, and include trip abandonment and the selection of alternative destinations. Also, elasticities will likely differ depending on the length of time charges have been in place. Over the long term, drivers will have made adjustments to the charge (such as moving their home or work locations, or working more from home), and alternatives to paying the charge (such as increased frequency and quality of transit service) will probably be clearly defined and developed, so elasticities in response to increases in charges will be lower. These issues reinforce the importance of conducting region-specific studies of driver responses to the introduction of policy measures such as road pricing.

4. Conclusions

The study described here demonstrates a quick, inexpensive method for estimating SOV commuter responses to policies introducing financial disincentives for driving alone and improvements to alternative modes. Results are easily presented in terms of changes in commuter market share for three modes, and elasticity of demand for any one mode, given changes in key mode choice decision making attributes. The methods described here could be modified to estimate the effect of variable pricing and a range of supply options (including paratransit, light rail, or cycling facilities) on driver mode choice responses for a variety of trip purposes, such as personal business and recreation.

Results suggest that policy makers interested in reducing demand for auto travel should place at least as much emphasis on financial disincentives for auto use as they do on improving the supply of alternative travel modes. Results indicate that improving travel time for alternative travel modes above a base level of service had only a small effect on mode choice and did little to decrease demand for SOV travel, nor did increases to SOV travel time. On the other hand, increasing the cost of SOV travel by introducing new charges had a substantial and significant effect on demand for driving alone. Among the sample, responses to road and parking charges differed most at mid range pricing levels ($5, $3.18 US), with road pricing being more effective at reducing demand. At higher or lower rates responses to the two charges were similar, and the relative ease of implementing either measure may be a more important consideration in their use. Study results also highlight an important equity issue that needs consideration in program planning: lower income respondents who are more likely members of one-vehicle households have less opportunity to carpool and may be unable to avoid paying a charge if improved transit services are not made available.

At moderate travel times, carpooling was a more attractive alternative than taking transit, suggesting governments should put additional emphasis on carpool infrastructure, ride matching services, and carpool promotion when enhancing alternatives to driving alone.

Only short travel times with few or no transfers attracted drivers to transit. Many survey respondents indicated that they see some form of road use pricing as inevitable and would make use of transit if high quality services (i.e. light rail without transfers) ran between their home and workplace. However, continuing development of suburban office parks will prove very challenging to the extension of efficient transit services in Greater Vancouver. Clearly, if road and parking charges are to play a useful role in shifting commuters from SOVs to transit, they must be accompanied not only by transit system improvements, but also by changes to land use patterns that make transit usage feasible for those travellers.

In real world settings, the ease with which existing commuting patterns could be served by expansion of carpool services and transit systems will be an important factor in the successful introduction of road and parking pricing as a demand management tool. In addition, in locations where drivers are used to paying road charges to access HOT lanes or as part of a cost recovery program for new infrastructure, there will need to be a broad public dialogue on the social and environmental benefits of charges for demand reduction.

Acknowledgements

The authors would like to acknowledge the financial support, through the Clean Air Research Fund, of the British Columbia Ministry of Environment, Land and Parks; the British Columbia Ministry of Transportation and Highways; Environment Canada; and the Canadian Petroleum Producers Institute. The authors also acknowledge the support of Don A Anderson, StatDesign, Evergreen Colorado, for his assistance with the design of the choice exercise.

Notes

1. Conversion to Canadian funds for January 1 of the year noted are based on rates from http://www.oanda.com. Conversion of current research to US funds are calculated for April 2001.
2. The design required 32 questions for estimation of attribute main effects. To avoid fatigue, each respondent was presented with only eight questions, with each block of eight having a balanced combination of attributes and levels. Measurement of the effect of attributes across the range of their values was calculated from the aggregated responses of each respondent.
3. Effects were analyzed using orthogonal polynomial coding to address uneven spacing.
4. The 20 min criteria allows a minimum 3 min variation in travel time in the DCE.
5. Rebound demand could be constrained by reassigning road capacity to alternative modes as SOV volumes decline, so that overall volume to capacity ratios are maintained.
6. Walls et al. (cited in Hagler Bailly 1999) found lower elasticities of vehicle travel with respect to fuel price for one vehicle households compared to households with two or more.
7. See Decorla-Souza and Kane (1992), Litman et al. (1998) and Burris (2003) on parking charge elasticities. Litman (2001), Burris (2003), and Hagler Bailly (1999) for revealed road charge elasticities; Decorla-Souza and Kane (1992) and Hirschman et al. (1995) present road charge elasticities based on modelled data.

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About the authors

Kevin Washbrook works as a consultant to non-governmental organizations active in policy analysis and public education on transportation, land use, energy and air quality issues.

Wolfgang Haider is a professor at SFU. He is interested in quantitative analysis and trade-off modelling as they relate to decision making in resource management, landscape evaluation and tourism.

Mark Jaccard is a professor a at SFU. He specializes in the economics of energy and the environment, particularly the design and application of models to simulate policies to induce technological change.