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Parking Demand and Responsiveness to Supply, Pricing and Location in the Sydney Central Business District

by

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Introduction

There is a dearth of information, locally, nationally and internationally, on the sensitivity of potential and actual parkers in the CBD to pricing regimes, the location of parking relative to the final activity destination, the security of parking and the supply of such parking in terms of permissible access by time of day (ie short vs long stay parking). In addition we know so little about the influence of parking location on which destinations (eg retail centre) are chosen. A review of the published literature such as papers by Higgins (1992), Lennie and Smith (1986), Bianco, Dueker and Strathman (1997), Nathan and Welsh (1997), Verhoeff, Nijkamp and Rietveld (1995) and Young, Thompson and Taylor (1991) support this position. Without exception, all papers cite the absence of demand studies that can reveal the appropriate behavioural responsiveness to prices, location and supply restrictions.

Key questions on how individuals respond to the supply and pricing of parking are:

- do individual parkers relocate to other available parking within the CBD while maintaining or relocating their final destination (eg retail outlets) within the CBD?
- do they relocate to parking outside of the CBD while maintaining their final destination within the CBD?
- do they relocate to parking outside of the CBD while relocating their final destination outside of the CBD?
- do they switch to public transport and continue to travel to their final destination within the CBD?
- do they accept higher parking prices if they are imposed and continue to use the current parking facility?
- do they retime their current activities to limit the amount of time spent parking while still undertaking the same activity?

The responses will be dependent on many influences, in particular the ‘parking market segment’ that an individual is a member of. The main parking market segments are:

- individuals *not provided* with guaranteed parking using a privately registered vehicle with no tax benefits and paying the cost of parking themselves. These are typically the majority of non-commuters (ie shoppers, social-recreational trips) and are classified as casual parkers.
- individuals who are *not provided* with guaranteed parking using a vehicle with tax benefits but paying the cost of parking themselves. These are typically individuals on company business including those who travel as part of work (eg salespersons), and are classified as casual parkers.
- individuals who are *provided* with a guaranteed parking place through an employer or by direct arrangements with a parking station, but who pay for the parking themselves as a non-tax deductible expense. They are typically commuters and are classified as permanent parkers.
- individuals who are *provided* with a guaranteed parking place through an employer or by direct arrangements with a parking station, who can claim the cost as a tax deduction. They are typically commuters and are classified as permanent parkers.

For each parking market segment, one is interested in identifying the role played in their parking decision by parking price, parking location relative to final destination (defined by walking time), supply of parking by time of day and duration, and the nature of guarantee on a parking space. Who pays, the tax deductibility and the overall use of parking during a year (the total financial commitment) will be important influences.

This paper concentrates on casual car parkers during weekdays (ie the first two categories above) and current weekday public transport users. Permanent parkers and weekend users of car parks and public transport are excluded from the study. We investigate the role of parking pricing and supply by time of day in whether to drive and park in the central business district (CBD). A stated preference survey of car drivers and public transport users was undertaken at a number of parking locations, public transit interchanges, and shopping centres in Sydney CBD during 1998. In the context of a current trip to the CBD, respondents were asked to consider six alternatives, including three parking locations in the CBD, park outside of the CBD with public transport connection to the CBD, switch to public transport, or forego that trip to the CBD. The three parking locations were defined by hours of operation, a tariff schedule, and access time to the final destination from the parking station. Data from the survey were then used to estimate a nested logit model of mode and parking choices, which was then used to simulate the impacts of supply-pricing scenarios on CBD parking share.

Identifying Responsiveness to Parking Supply and Tariffs

There are many ways in which one can identify the influences that determine whether a trip to the CBD will involve driving and parking at specific locations in contrast to taking public transport. However, when we recognise that influencing attributes are many and varied, and interact with each other in potentially complex ways, we need methods capable of integrating these attributes in arriving at a choice outcome while also having the ability to isolate the contribution of each attribute to the overall choice. In particular, we need a method to evaluate the responsiveness of a traveller to changes in one or more conditions of casual parking; for example hours of operation and tariff schedules.

SP Experiment

Over the last 15 years, one method has come to dominate the literature. Known as stated preference (SP) analysis, it presents a choice setting in exactly the same way that an individual sees the current set of trip alternatives, but enriches the context under which we observe actual choices by enriching the combinations of observed levels of attributes. Through this enrichment strategy we can identify how individuals evaluate and hence trade-off levels of attributes such as parking prices and hours of operation at various locations in the CBD. The provision in the SP experiment of greater variation in prices and hours of operation than we observe in real markets is critical to understanding the preferences of a sample of individuals in circumstances which currently exist and those which do not, with the latter being situations that may exist in the future.

While an extensive range of parking prices and hours of operation may already exist throughout the entire CBD, existing car travellers to the CBD would only be observed parking at a particular time of day and at an existing tariff structure in the chosen parking station. For public transport users and those parking outside of the CBD and accessing it by public transport or walking we have no idea about how they would react to a range of parking prices and hours of operation – all we observe is that they reject car parking in the CBD. Our task is to uncover the preference map for parking prices and hours of operation of a sample of individuals whose final destination is the CBD. This will provide evidence on how curfews and parking prices might be used to facilitate the preservation or enhancement of public transport use (and hence modal share) to the CBD.

With an enriched knowledge of preferences we can be much more confident about our ability to understand how individuals might respond when parking tariffs and hours of operation are modified to levels which are currently not on offer but which have been captured by the SP experiment.

We are very much aware of the potential for SP methods to be misused, since we require individuals to think beyond the space of current experience (Hensher 1994, Louviere, Hensher and Swait in press). However, a carefully designed SP experiment in which the attributes such as pricing and hours of operation are varied around levels observed in real markets, does make sense to respondents and can provide meaningful information on the role of such attributes in making choices between drive and park, public transport and no travel to the CBD. We investigated (and estimated) a joint revealed preference (RP)-SP model but rejected it because the information for each individual on all four parking locations was extremely unreliable for all but the chosen parking location for car drivers and the preferred parking location for public transport users. We formed the view that respondents have enormous difficulty in being able to provide attribute data on the non-chosen parking locations. Furthermore since we are not using the model to predict demand but to identify the variability in market share between a range of policy scenarios, defined on mixtures of parking tariff and curfew hours, the stand-alone SP approach provides the necessary behavioural richness. We are essentially imposing a Bayesian rule of placing all the value weight on the SP information (Keane 1997). If the stand-alone SP model were to be implemented in a prediction mode, we would export (and fix) the SP parameters for each attribute into an RP model, estimating the RP model to establish the appropriate market share constants and parameters of other variables such as income (see Louviere et al in press).

The Design

The stated preference experiment has three parking alternatives each described by three attributes:

- Hours of operation
- Tariff schedule, and
- Walk time from parking to main destination

The three alternatives are 'parking close in the CBD', 'parking elsewhere in the CBD' and 'parking at the fringe of the CBD'. The three locations are identified on a map (Figure 1). Each parking alternative has three tariff schedules, the latter described by rates for each of seven parking durations (0-1 hrs, 1-2 hrs, 2-3 hrs, 3-4 hrs, 4-5 hrs, 5-6 hrs and more than 6 hours per day). A respondent is asked to evaluate each of the three parking alternatives in addition to using public transport, parking outside of the CBD and not undertaking the trip to the CBD. Regardless of which alternative was chosen, the parking rate for each parking option was sought. The SP design specifications are summarised in Table 1. The three alternatives – 'drive/park beyond the CBD', public transport' and 'not travel to CBD' are choices in the SP experiment but are not described by the attributes of parking. In the case of 'drive/park beyond the CBD', typically parking is free and unconstrained, often being on-street.

An example of an SP scenario is given in Figure 2, with the following accompanying questions:

If parking option 1 was available today, which alternative would you choose for your current trip (tick only one)**?**

1 **Drive/park close in CBD**
2 **Drive/park elsewhere in CBD**
3 **Drive/park outside CBD**
4 **Drive/park for free beyond the fringe of CBD and travel by public transport to CBD**
5 **Travel by public transport to CBD**
6 **Not Travel to CBD**

Which parking rate did you consider when making your choice? (TICK ONE RATE IN EACH OF THE 3 BOXES ABOVE).

If parking option 1 was available today, would you still park for the same duration as today?

1 Yes
2 No ➡ **How many hours would you have parked?** [ ] hours

Table 1. Sydney CBD Parking Study SP Design Specifications

Attribute	Drive/park close in CBD (Pc)	Drive/park elsewhere in CBD (Pe)	Drive/park at fringe of CBD (Pf)	Drive/park beyond CBD (Pbf)	Public transport (PT)	Not travel to CBD (No trip)
Hours of operation	3 levels	3 levels	3 levels			
Parking tariff	3 levels	3 levels	3 levels			
Walk time	3 levels	3 levels	3 levels			

Figure 1. Location Classification of Parking

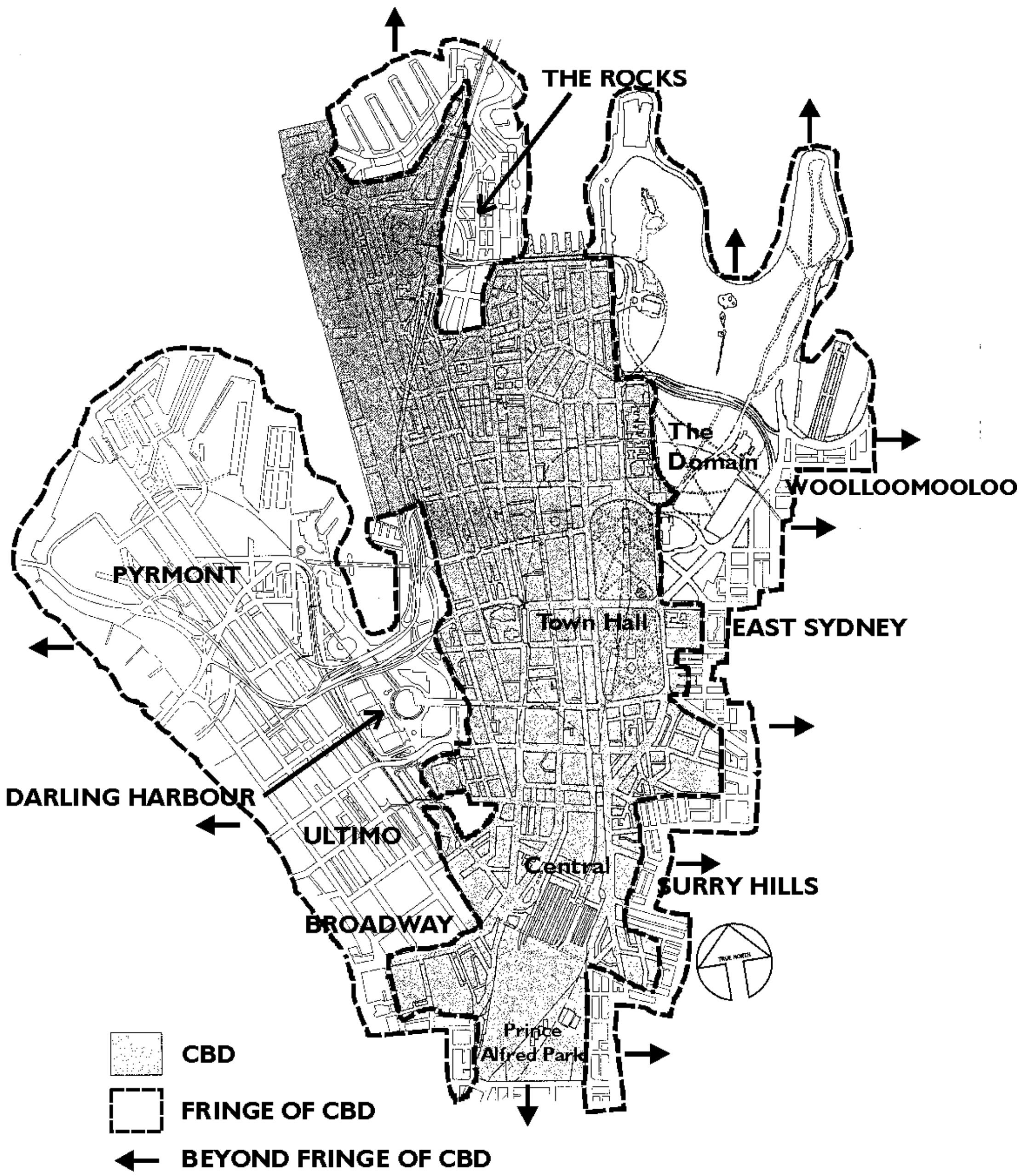


Figure 2. Example of SP Question

OPTION 1

DRIVE/PARK CLOSE IN CBD

HOURS OF OPERATION:
24 hours

PARKING TARIFF: *Casual rates*		**Please Tick rate** (refer Q32)
0-1 Hrs	$2.00	☐
1-2 Hrs	$4.00	☐
2-3 Hrs	$6.00	☐
3-4 Hrs	$8.00	☐
4-5 Hrs	$10.00	☐
5-6 Hrs	$12.00	☐
MAX	$14.00	☐

WALK TIME TO DESTINATION:
1 minute

DRIVE/PARK ELSEWHERE IN CBD

HOURS OF OPERATION:
From 6.30 am

PARKING TARIFF: *Casual rates*		**Please Tick rate** (refer Q32)
0-1 Hrs	$2.00	☐
1-2 Hrs	$4.00	☐
2-3 Hrs	$6.00	☐
3-4 Hrs	$8.00	☐
4-5 Hrs	$10.00	☐
5-6 Hrs	$12.00	☐
MAX	$14.00	☐

WALK TIME TO DESTINATION:
7 minutes

DRIVE/PARK AT FRINGE OF CBD

HOURS OF OPERATION:
From 9.30 am

PARKING TARIFF: *Casual rates*		**Please Tick rate** (refer Q32)
0-1 Hrs	Free	☐
1-2 Hrs	$3.00	☐
2-3 Hrs	$5.00	☐
3-4 Hrs	$10.00	☐
4-5 Hrs	$10.00	☐
5-6 Hrs	$10.00	☐
MAX	$10.00	☐

PUBLIC TRANSPORT AND/OR WALK TIME TO DESTINATION:
15 minutes

This SP design has nine attributes each of three levels. A full factorial (ie all combinations) produces 19,683 possible combination (3^9). SP designs are defined as a fractional factorial in order to preserve as much of the statistical variability offered by the full factorial while recognising the need to make the exercise comprehensible to a respondent. In comparison to a random draw from the 19,683 combinations, a fractional factorial design provides statistically superior information for investigating the influence of each attribute (Louviere et al in press). We have reduced the full factorial to 27 combinations in which all main effects are independent. A main effect is a specification of an attribute as a linear or higher order term without any interaction with another attribute (see Louviere et al in press for more details). From these 27 choice sets of nine attributes (three for each car parking situation), we asked each sampled person to evaluate three of them and make a choice out of five possible alternatives. There are nine such sets of survey forms each coded to ensure that, across the entire sample, we cover all of the 27 possible choice sets of alternatives.

Table 2 summarises the levels that were assigned to each of the attributes. This experiment enables us to obtain elasticities of parking demand with respect to parking price, walking distance to main destination, as well as propensities to switch to public transport and to relocate parking inside/outside of the CBD. It also enables us to establish the extent to which an individual would relocate their CBD activity in response to a relocation of parking activity, especially the imposition of a curfew on casual parking before 9.30 am during weekdays.

Table 2. Summary of Attribute Levels Assigned to each Parking Alternative

Attribute	Dive/park close in CBD (Pc)	Drive/park elsewhere in CBD (Pe)	Drive/park at fringe of CBD (Pf)
Hours of operation	Open from 6.30am, from 930 am and 24 hrs	Open from 6.30am, from 930 am and 24 hrs	Open from 6.30am, from 930 am and 24 hrs
Parking tariff	2-14, 6-30, 10-45	2-14, 6-30,10-45,	0-10, 3-15, 5-20
Walk time	1,3,5	7,9,11	15,20,25

The Survey

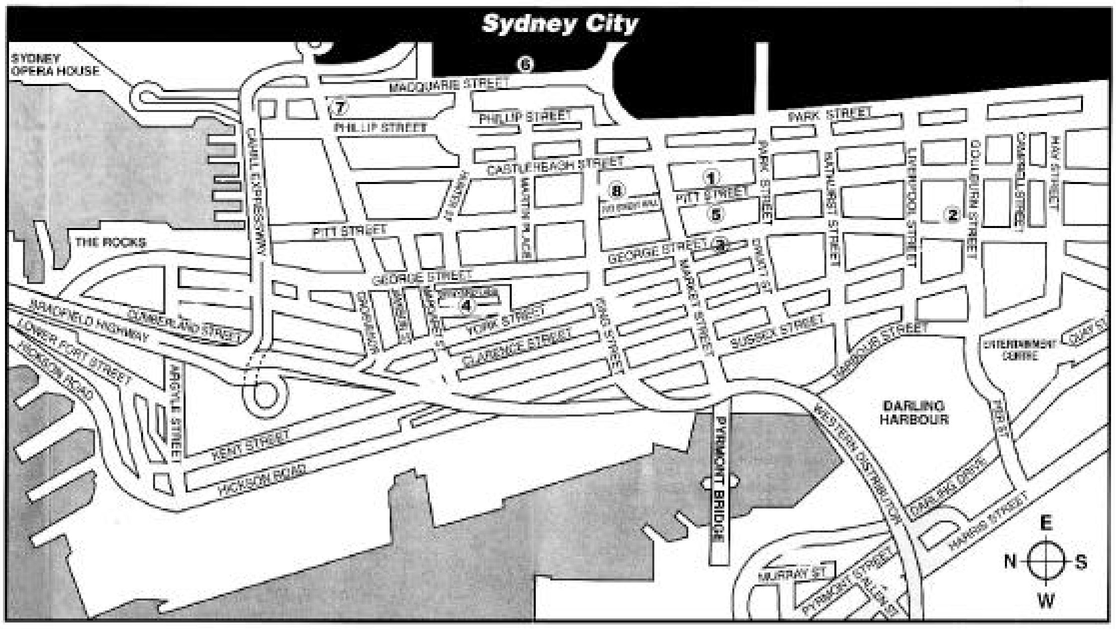
A number of survey instruments were designed to accommodate the method of data collection and the modal context. The sampling plan and the survey strategy for the market segments of car park users and public transport users are summarised in the following sections.

Car park users

A self-administered hand-out/reply paid mail-back survey instrument was used to secure the necessary data. The instrument was handed out at eight parking stations during the morning (from 9.30am to 1pm at World Square and from 7am to 1pm at the other seven parking stations) of three selected weekdays – Monday, Thursday and Friday, over a two week period in late October and early November 1998. The morning was selected because of the focus of the study on curfew hours prior to 9.30am for short stay parkers. The eight parking stations are Piccadilly, World Square, Queen Victoria

Building (QVB), Wynyard Lane, Capital Centre, Sydney Hospital, 135 King Street and 131 Macquarie Street (See Figure 3).

Figure 3. Map of Parking Survey Locations



Legend:

(1) Piccadilly
(2) World Square
(3) QVB
(4) Wynyard Lane
(5) Capital Centre
(6) Sydney Hospital
(7) 131 Macquarie Street
(8) 135 King Street

The target number of effective surveys was determined for each parking station by the number of parking spaces and the turnover per day of cars parked. For example, Piccadilly has a small number of casual spaces but the turnover is very high, in contrast to QVB where the turnover is low for a larger number of spaces. A total of 2,860 forms were handed out at the eight parking stations. The breakdown by station of the target, the number handed out and the response rate is given in Table 3. The survey instrument was a six page A4 form distributed to every driver entering the car park during the survey hours. We requested a mail return by November 6, or the option to hand the form to the parking attendant when departing the parking station.

Table 3. Summary of Targets, Forms Distributed and Effective Response Rate

Sites	Casual Spaces	Target	Total Handed Out	Total Returned	Response Rate
Piccadilly	80	200	750	54	7.2 %
World Square	400	250	800	120	15.0 %
QVB	450	75	400	90	22.5 %
Wynyard Lane	300	50	200	43	21.5 %
Capital Centre	300	50	200	28	14.0 %
Sydney Hospital	20	50	270	74	27.4 %
131 Macquarie Street	20	50	200	43	21.5 %
135 King Street	20	50	50	9	18.0 %
Parking stations	1590	800	2860	461	16.1 %
Piccadilly retail		75	75	75	100%

Public transport users

To investigate the extent to which existing public transport users might switch to driving under a particular parking regime, we sampled public transport users who travel to the CBD. In addition to be able to generalise the findings, it is essential to study the behavioural choices of all travellers going to and from the CBD of Sydney. Excluding current public transport users would bias the results and make it difficult to defend the scientific value of the study. The inclusion of public transport users enables us to estimate a stated preference model for the full set of travellers to and from the CBD of Sydney.

The sample sizes for the combined public transport survey was 200, with half bus and half train, as per the following geographical distribution:

- Piccadilly retail outlets 50
- Sites in CBD 150

Over two weeks, face to face interviews were conducted with a sample of individuals alighting from the trains and buses in the CBD and at the Piccadilly Retail complex. The questions were identical to those in the car survey form but with different wording and order given the different data collection strategy. A total of 50 face to face interviews were undertaken at the Piccadilly retail complex and 150 at major bus and train stations in the CBD including Town Hall, Bus Interchange at York Street, Wynyard Station and Circular Quay. To achieve the effective sample size 2,000 individuals were approached (hence a response rate of 10%). The selection of the Piccadilly retail complex enabled us to establish the extent to which visitors to a retail complex come by public transport or park in the CBD, either at the Piccadilly parking station or elsewhere. Such information is useful in establishing the role of parking in attracting business to a retail centre. The ownership of a driver’s licence was used in screening to ensure that we had approximately equal numbers of public transport users with/without a licence.

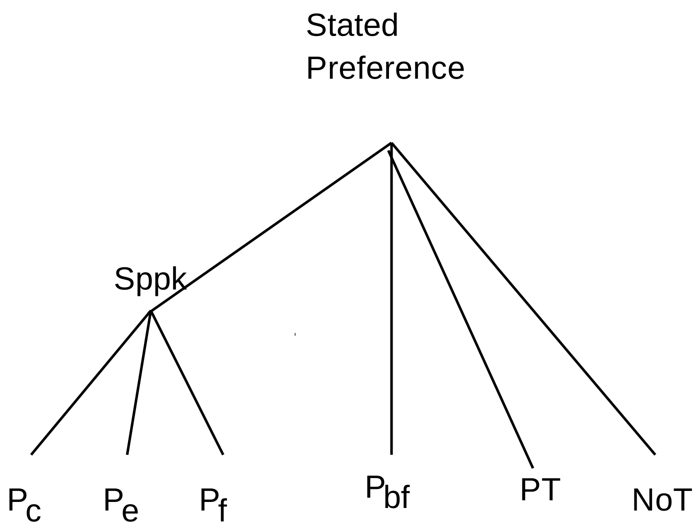
The SP and Parking Choice Model

Model Specification

The modelling task is to estimate a model for choice of mode and parking using stated preference data. Figure 4 summarises the overall choice setting, with six SP alternatives. An individual traveller is represented by up to three SP observations for three parking alternatives (Pc, Pe and Pf). Thus we have a maximum of three SP observations per sampled trip maker (assumed herein to be independent).

In presenting the choice context in Figure 4 as a hierarchical structure, we are not suggesting that an individual actually evaluate the alternatives in this hierarchical way. They may do so; that is, the upper level choice is between driving a car, using public transport and not undertaking a trip to the CBD. Conditional on choosing a car, a parking alternative is then chosen. There are clearly many possible hierarchical structures, of which Figure 4 is an intuitively appealing example (and the one selected herein after evaluating a number of tree structures).

Figure 4. The Choice Set of SP Alternatives



Pc = drive and park close to the CBD, Pe = drive and park elsewhere in the CBD, Pf = drive and park at fringe of CBD, Pbf =drive and park for free beyond the fringe of the CBD and travel by public transport to CBD, PT = travel by public transport to CBD, NoT = not travel to CBD, Sppk is the upper branch representing the composite parking locations in the CBD.

The reason for suggesting a hierarchical or tree structure for linking the alternatives in the complete choice set is a recognition that there may be information defining the sources of utility (or satisfaction) associated with each alternative which is not measured by the set of observed explanatory variables, which consequently is represented by the error structure assigned to each alternative. It is well known that the utility of the i*th* alternative is represented by two components: the set of observed influences (denoted V_i) and the set of unobserved influences (denoted by ε_i) (McFadden 1981, Ben Akiva and Lerman 1985). An individual is assumed to compare the alternatives in terms of a set of attributes and choose that alternative which yields the highest level of utility.

The importance of the underlying assumption of the form of the random components is crucial to the specification of the choice model and is the main feature that differentiates the family of discrete choice models. The simplest model assumes that the ε_i are the same across all alternatives. 'Sameness' refers to the distributional properties. If the random component of each alternative is identically distributed and they are all independent (ie no correlation between the alternatives) then we have a model known as the multinomial logit (MNL). Behaviourally this assumption implies that any unobserved attributes that are important influences on choice influence the ε_i terms for each alternative in exactly the same way. We cannot separate out the role of each component of these unobserved effects. Under this condition (known as independently and identically distributed - IID), we can drop the subscript giving an identical ε for each and every alternative.

If we believe that this IID assumption is unrealistic because the behavioural influences not accounted for by observed attributes may indeed impact on the random components differentially, then the IID assumption and hence the MNL model is not a valid representation of choice behaviour and will result in larger errors in predictions and elasticities than are likely under a set of more realistic (ie less restrictive) assumptions. The task ahead is to establish a more flexible set of assumptions and to test for their appropriateness. Ideally one would like to allow for total flexibility by treating all alternatives as being correlated in their random components and having unique distributions (ie variances) around their own means. This is possible; however in practice, estimation becomes complex and often impossible without very extensive data sets, to permit isolation of all the possible sources of differences in the random components. These differences can be due to correlation between pairs of alternatives, inter-choice set correlation (ie serial correlation), and presence of random effects (ie individual-specific idiosyncracies) (Bhat 1997, Hensher 1998). We have selected what is now regarded as the best progressive step beyond the MNL model, namely relaxing the constant variance assumption between subsets of alternatives while preserving the condition within partitions. This can be achieved by selectively allowing differential variances between subsets of alternatives while preserving the constant variance assumption amongst other alternatives. The approach produces the nested logit (NL) model. While the NL model has the potential disadvantage of imposing IID on specific pairs of alternatives, it accounts for correlation between alternatives conditioned on a specific upper level alternative. We estimate MNL, and NL models (see Hensher and Louviere (1999) for another application comparing these methods).

The SP model is a joint modal and parking choice model. The emphasis is on both the entire door-to-door modal trip and the specific parking choice made if a car were used. The integration of the parking choice SP experiment enables us to enrich existing modal choice models by identifying the probability of choosing a particular parking location (given hours of operation, tariff structure and egress time to final destination) conditional on choosing to drive a car and park at a specific location inside or at the fringe of the CBD or beyond the CBD.

Unlike a modal choice model that can provide modal elasticities with respect to parking attributes, we are able to provide parking (and modal) choice elasticities with respect to parking attributes. This is a very important distinction, enabling us to evaluate the consequences on parking of a number of parking regimes. The regimes of particular interest are:

- The introduction of a curfew which prevents casual parking before 9.30am during weekdays at all parking stations in the CBD while maintaining existing tariffs.
- The removal of all curfews prior to 9.30am and the introduction of increasing parking charges.

After the final mode and parking choice model is estimated, we can apply it under these two regimes to evaluate the implications on modal response and parking location choice.

Model Estimation

The final model, a nested logit model is summarised in Table 4 and the distribution of levels of attributes influencing choice are given in Table 5. Maximum likelihood estimation was used to obtain the parameter estimates. Overall we have a very good statistical fit for the nested logit model, with a log-likelihood of –1759.76 compared to the value of –3901.68 when we assume no information about market shares and the influencing attributes. The nomenclature in Table 4 referencing Sppk refers to the utility expression in the upper level of the nested logit model. This utility expression includes the inclusive value and two socioeconomic characteristics (no. of adults in a car, age of driver), with different parameter estimates for the three parking locations (Pc, Pe, Pf) in the CBD compared to parking beyond the fringe (Pbf).

The nested structure, selected from a number of tree structures, displays a parameter of the inclusive value variable of 0.7017 with a t-value of 6.11, suggesting that the NL model is preferred over the (not reported) MNL model. A condition for consistency with utility maximisation is that the NL model must have its inclusive value parameter(s) lying in the 0-1 range. Values equal to or not statistically significant from unity suggest an MNL form in which the error variances (and hence scale parameters) are identical. 0.7017 is statistically significant from 1.0 on a t-test. Each of the three branches of the tree with only one alternative (ie Pbf, PT and No trip) is referred to as a degenerate branch and does not produce inclusive value parameters.

Table 4. Final Mode and Parking Choice Model: Nested Logit .

Attribute	*Alternatives*	*Parameter Estimate (t-values)*
6.30 am curfew	Pc,Pe,Pf	-.0497 (-.4)
9.30 am curfew	Pc,Pe,Pf	-.2308 (-2.1)
Parking price per hr	Pc	-.2064 (-12.7)
Parking price per hr	Pe	-.2501 (-11.2)
Parking price per hr	Pf	-.1400 (-3.1)
Linehaul time	Pc,Pe,Pf,Pbf	-.0108 (-2.5)
Linehaul time	PT	-.01473 (-3.8)
Invehicle cost	Pc,Pe,Pf,Pbf	-.0118 (-.53)
Invehicle cost	PT	-.0056 (-.33)
Access time	PT	-.05472 (-4.9)
Egress time	All excl No trip	-.0387 (-4.9)
Park only	Pc	1.9799 (4.8)
Park only	Pe	1.983 (4.6)
Park only	Pf	1.984 (4.4)
Park only	Pbf	.7147 (2.3)
You pay	Pc	-1.899 (-4.3)
You pay	Pe	-1.918 (-4.2)
You pay	Pf	-1.130 (-2.3)
You pay	Pbf	.8155 (1.4)
Household business pays	Pc	-1.011 (-1.7)
Household business pays	Pe	-1.068 (-1.5)
Personal income	Pc	.0205 (4.1)
Personal income	Pe	.0185 (3.5)
Personal income	Pf	.0138 (2.5)
Personal income	No trip	.02654 (4.2)
Social trip	Pc	-.3382 (-1.6)
Social trip	Pf	-.4834 (-1.4)
Commuting trip	Pc	-2.046 (-4.9)
Commuting trip	Pe	-1.488 (-3.4)
Commuting trip	Pf	-1.428 (-3.0)
Business meeting	Pc	.9287 (3.4)
Business meeting	Pe	.6651 (2.1)
Personal business	Pbf	-2.248 (-3.0)
Shopping trip	Pe	.4103 (1.7)
Piccadilly centre	Pe	-.5158 (1.9)
No. of adults in car	Sppk(Pc,Pe,Pf,)	-.5812 (-2.6)
No. of adults in car	Pbf	-.0039 (-.02)
Age of driver	Sppk(Pc,Pe,Pf,)	.2735 (2.9)
Age of driver	Pbf	.3387 (3.8)
constant	Pc	1.280 (2.4)
constant	Pe	.3514 (.6)
constant	Pf	-1.401 (-2.3)
constant	Pbf	-4.217 (-6.2)
constant	No trip	-6.065 (-11.4)
Inclusive value	Sppk(Pc,Pe,Pf)	.7017 (6.1)
Log-likelihood at zero		-3901.68
Log-likelihood constants		-2089.21
Log-likelihood at convergence		-1759.77
Adjusted Pseudo-R^2		0.547
MNL Log-likelihood at convergence		-1777.43
MNL Adjusted Pseudo-R^2		0.542
Sample size		1789

Notes: * indicates a degenerate branch and hence no inclusive value. Sppkin = the branch defining the four parking alternatives

Table 5. A Descriptive Profile of the Significant Influences on Modal and Parking Choice

In the last two columns we report the mean and standard deviation except for 1,0 dummy variables which only have a mean (ie proportion). The column headed 'total sample' reports the values for the entire sample; in contrast the last column reports the values for the subset of individuals who chose that alternative.

Attribute	*Alternatives*	*Units*	*Total Sample*	*Sample Choosing this Alternative*
Egress time	Pc	mins	2.97 (1.63)	2.95 (1.63)
6.30 am curfew	Pc	1=yes,0=no	0.34	0.34
9.30 am curfew	Pc	1=yes,0=no	0.34	0.33
Parking price per hr	Pc	$/hr	8.31 (4.40)	7.06 (4.30)
Linehaul time	Pc	mins	36.83 (27.8)	37.61 (30.6)
Invehicle cost	Pc	$	2.02 (3.0)	2.13 (3.4)
Park only	Pc	1=yes,0=no	.500	.635
You pay	Pc	1=yes,0=no	.679	.548
Household business pays	Pc	1=yes,0=no	.020	.022
Personal income	Pc	'000s	50.29 (39.6)	59.96 (40.3)
Social trip	Pc	1=yes,0=no	.171	.094
Commuting trip	Pc	1=yes,0=no	.144	.101
Business meeting	Pc	1=yes,0=no	.216	.323
Egress time	Pe	mins	8.96 (1.63)	8.95 (1.70)
6.30 am curfew	Pe	1=yes,0=no	.341	.386
9.30 am curfew	Pe	1=yes,0=no	.321	.265
Parking price per hr	Pe	$/hr	8.22 (4.29)	5.45 (2.93)
Linehaul time	Pe	mins	36.8 (27.8)	37.3 (26.8)
Invehicle cost	Pe	$	2.02 (3.00)	2.08 (2.61)
Piccadilly centre	Pe	1=yes,0=no	.093	.085
Park only	Pe	1=yes,0=no	.500	.603
You pay	Pe	1=yes,0=no	.679	.614
Household business pays	Pe	1=yes,0=no	.020	.022
Personal income	Pe	'000s	50.29 (39.6)	54.5 (38.4)
Shopping trip	Pe	1=yes,0=no	.144	.158
Commuting trip	Pe	1=yes,0=no	.144	.140
Business meeting	Pe	1=yes,0=no	.216	.235
Egress time	Pf	mins	20.04 (4.04)	18.55 (3.99)
6.30 am curfew	Pf	1=yes,0=no	.317	.359
9.30 am curfew	Pf	1=yes,0=no	.350	.308
Parking price per hr	Pf	$/hr	4.53 (2.16)	3.88 (1.98)
Linehaul time	Pf	mins	36.83 (27.8)	39.21 (32.1)
Invehicle cost	Pf	$	2.02 (3.00)	2.42 (4.65)
Park only	Pf	1=yes,0=no	.500	.598
You pay	Pf	1=yes,0=no	.679	.761
Personal income	Pf	'000s	50.29 (39.6)	47.42 (37.8)
Social trip	Pf	1=yes,0=no	.171	.120
Commuting trip	Pf	1=yes,0=no	.144	.145
Egress time	Pbf	mins	11.15 (11.3)	11.27 (14.7)
Parking price per hr	Pbf	$/hr	free	free
Linehaul time	Pbf	mins	21.50 (16.3)	20.32 (20.5)
Invehicle cost	Pbf	$	5.09 (6.64)	4.84 (6.86)
Park only	Pbf	1=yes,0=no	.500	.304
You pay	Pbf	1=yes,0=no	.679	.949
Personal business	Pbf	1=yes,0=no	.124	.025
Egress time	PT	mins	11.15 (11.3)	7.53 (6.78)
Linehaul time	PT	mins	40.88 (36.1)	30.95 (19.6)
Access time	PT	mins	12.05 (12.7)	7.41 (5.14)
Personal income	No trip	'000s	50.29 (39.6)	65.67 (58.21)
Sample Choosing:	Pc	905		
Sample Choosing:	Pe	272		
Sample Choosing:	Pf	117		
Sample Choosing:	Pbf	79		
Sample size	PT	404		
Sample Choosing:	No trip	12		
Total Sample Size	All	1789		

The nested structure is intuitively plausible, suggesting a choice between parking locations and conditions in the CBD conditional on parking in the CBD, and then the choice between parking in the CBD, beyond the CBD, using public transport and discontinuing to undertake the studied trip to the CBD. The attributes from the choice experiment – namely hours of operation, parking rates and egress time to final destination from the parking station, are all represented in the final model. We have transformed the parking rate to make it meaningful for scenario analysis. Each respondent indicated a particular duration of parking and hence parking rate from the tariff schedule. We have converted this information to a parking price per hour and included it in the model. Including parking price and duration separately is statistically unattractive since they are strongly correlated.

The variable 'parking price per hour' is the most statistically significant influence with t-values of –12.69, -11.19 and –3.42 respectively for parking close in the CBD, elsewhere in the CBD and at the fringe of the CBD.The other attribute of particular interest is hours of operation and hence curfews on parking. We have introduced dummy (ie 1,0) variables from the choice experiment to represent opening hours of 6.30 am and 9.30 am relative to 24 hours. We found no statistically significant difference by location in the CBD and thus have a parameter for each curfew hour that is generic across the CBD parking locations. We find that relative to 24 hours of operation, opening at 6.30 am is not statistically significant (although of the expected negative sign), but a curfew of 9.30 am for casual parking is negative and very significant. That is, imposing a 9.30 am curfew on all casual parking does have a strong downward influence on the probability of choosing to park in various locations in the CBD. However, and most importantly, the influence is considerably smaller than the imposition of higher parking rates per hour.

The nested logit model included a large number of other attributes which were not part of the SP experiment but which are important influences on mode and parking location choice. These covariates or contextual effects include the purpose of the trip, who pays for parking, an individual's income, the number of adults in the travelling party and the age of the driver. We also included the line-haul travel time for all modes, access time for public transport (ie to the bus or train) and the in-vehicle cost for car travel and public transport. In-vehicle cost was found to be consistently statistically insignificant.

Most notable, individuals who have to pay for their own parking (in contrast to someone else's business) tend to park beyond the fringe and to a lesser extent in the CBD; those who have their parking paid by a household business (ie self employed) are also very sensitive to parking prices despite the tax deductability, preferring to park at the fringe or beyond the CBD. There is a significant influence of income, with individuals on higher incomes being more likely to park in the CBD and in particular close in. Interestingly, we find that commuters and people on social outings are much less likely to park close to the CBD. This contrasts with individuals attending a (non-personal) business meeting in the CBD. This makes good sense – the latter presumably have a stricter timetable (ie a higher value of travel time savings), are possibly on higher incomes and the trip is tax deductible. Shoppers prefer to park elsewhere in the CBD but less so at the fringe or close in – they are prepared to walk to their destination (which may well be a number of destinations in contrast to the commuter and business meeting, and even social outing) but not as far as a fringe location would entail, but further than the close in location. Personal business meetings are definitely associated with parking beyond the fringe and connecting to the CBD by walking or public transport.

Taking a closer look at the possible influence of retail trips (ie shopping) on choice of parking location, we find that if an individual is going shopping there is a much greater probability of choosing to park elsewhere in the CBD than to select any of the other alternatives. What this suggests is that the presence of a shopping trip is not a significant influence on parking close in to a particular shopping destination or parking a long way away at the fringe or beyond the CBD. This may be due to the need to visit a number of retail locations in the CBD and the relatively higher parking charges right at the close in location. However, when we specifically investigate the Piccadilly parking location, we find that for those who currently park there, they are less likely to want to choose to park elsewhere in the CBD (see Table 4). This is an important result, supporting the view that current Piccadilly parkers (parking close in to their retail activity) have a much lower probability of venturing further away than do those who currently park elsewhere or enter the CBD by other means of transport.

Policy Responsiveness to Parking Supply, Pricing and Location

What is of particular importance is the identification of traveller responsiveness to changes in the hourly rates of parking across the distribution of hours of parking. In contrast to the estimated parameters reported in Section 4, the elasticities (like marginal effects) highlight practical significance of each attribute and are much more informative from a policy perspective. The implied parking price (direct) elasticities are respectively -.541, -1.015 and -.476 for Pc, Pe and Pf (Table 6).What this suggests is that a 1% increase in hourly parking rates results in a .541% reduction in the probability of choosing to park close in, a 1.015% reduction in the probability of choosing to park elsewhere in the CBD and a .476% reduction in the probability of parking at the fringe. The greatest sensitivity is parking elsewhere in the CBD suggesting that those who choose to park as close as possible to their final destination are relatively less sensitive to parking rates as are fringe parkers compared to the other parkers in the CBD. In general there is high sensitivity to parking prices, far higher than one finds for in-vehicle cost and even travel time in modal choice (see Table 6 for the latter).

Table 6. Summary of Direct and Cross Share Elasticities

Parking price per hour

	Pc	Pe	Pf	Pbf	PT	No trip
Pc	-.541	.205 *	.035 *			
Pe	.837 *	-1.015	.043 *			
Pf	.965 *	.286 *	-.476			
Pbf	.363	.136	.029			
PT	.291	.104	.023			
No trip	.469	.150	.029			

Linehaul time:

	Pc	Pe	Pf	Pbf	PT	No trip
Pc	-.123	.056 *	.026 *	.006	.025	
Pe	.188 *	-.271	.029 *	.009	.032	
Pf	.200 *	.068 *	-.335	.011	.040	
Pbf	.099	.041	.021	-.182	.063	
PT	.069	.026	.014	.012	-.103	
No trip	.139	.052	.024	.013	.057	

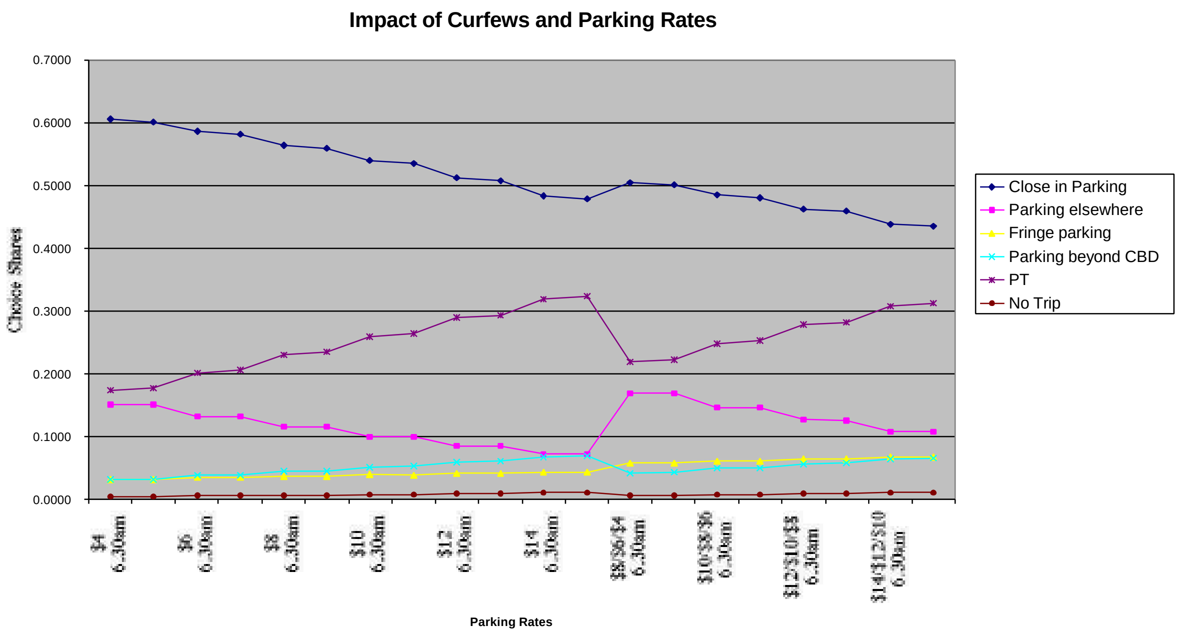
Egress time:

	Pc	Pe	Pf	Pbf	PT	No trip
Pc	-.052	.049*	.026*	.015	.068	
Pe	.057*	-.288	.042*	.013	.063	
Pf	.048*	.043*	-.718	.013	.060	
Pbf	.041	.037	.034	-.417	.052	
PT	.036	.032	.031	.014	-.363	
No trip	.010	.014	.026	.010	.032	

Note: * indicates a cross share elasticity within a partition of a nested structure where the IID condition applies and hence such elasticities are not informative. The blank blocks are not applicable because the respective attribute is not included in the utility expression of the alternative defined by the column heading. The elasticities are read by column – for example, the first column for parking price (ie Pc) tells us that a 1% increase in parking price will lead to a .541% reduction in the sample share choosing to park close in. Likewise the 1% increase in parking price for Pc will lead to a .363% increase in the share parking beyond the CBD.

In Figure 5 we have plotted the profile of changing market shares as we vary hours of operation commencing at 6.30 am and 9.30 am and parking rates (from $4 to $14) in two ways: The first 12 points on each line (from the left) represent combinations of hours of operation and average hourly parking rates throughout the entire CBD. The last eight points on each line represent a distribution of hourly parking rates between each of the three locations in the CBD (ie close in, elsewhere and at the fringe), with the average at each location maintained. Thus the last point on each line refers to a 9.30 am curfew and hourly parking rates of $14, $12 and $10 for parking close in, elsewhere and at the fringe. The full set of 20 market share predictions per alternative parking location, public transport use and curtailment of travel to the CBD, cover a very large range of parking prices and curfew hours, and thus enable us to make very reliable inferences about the role of pricing and curfews in reducing the demand for parking in the CBD and the preservation and increase in use of public transport.

Figure 5. Scenario Assessment of Curfews and Parking Rates in the CBD of Sydney



A close inspection of Figure 5 shows that a comparison of parking rates, when hours of operation are held fixed produces much higher switching between parking locations and public transport use compared to a comparison of hours of operation, when parking rates are held fixed. For example, if we look at the first 12 points on all lines we observe a decline in the share of parking close in and elsewhere in the CBD as we increase the hourly parking rate and as we introduce a more severe curfew of 9.30am. In contrast there is an increase in the share of parking at the fringe of the CBD and beyond the CBD, and a very noticeable increase in the use of public transport. However, when one compares the slopes between hours of operation for given parking tariffs with those between parking tariffs for given hours of operation, the impact of pricing is substantially greater than the curfew. *Typically if we look at the combined effect of curfews and parking pricing, the former accounts for less than 3% of the total effect.* Thus parking pricing is by far the superior instrument to achieve reductions in casual parking in the CBD.

The contribution of parking rates and hours of operation under an indicative set of operating conditions are summarised in Table 7. Overall over the range of parking rates and curfew conditions, the change in CBD parking share attributed to curfews in contrast to parking pricing is less than 3%. That is, 97% of the impact is attributable to parking prices. The curfew simply redistributes the parking around the CBD (presumably at different times) whereas the pricing diverts travel to public transport and parking beyond the CBD.

Table 7. The Contribution of Curfews and Parking Rates on Market Share of Parking by Location, use of Public Transport and Curtailment of Travel to the CBD of Sydney

	Parking in CBD	Parking in CBD	Change in parking shares	PT use	PT use	Parking Beyond the CBD	Parking Beyond the CBD	No travel	No travel
Parking rates	6.30 am curfew	9.30 am curfew	From 6.30 to 9.30 curfew	6.30 am parking curfew in CBD	9.30 am parking curfew in CBD	6.30 am parking curfew in CBD	9.30 am parking curfew in CBD	6.30 am parking curfew in CBD	9.30 am parking curfew in CBD
$4/hour	.7895	.7847	0.48%	0.1738	0.1777	0.0320	0.0328	0.0046	0.0048
$6/hour	.7545	.7493	0.52%	0.2017	0.2058	0.0382	0.0391	0.0057	0.0058
$8/hour	.7176	.7122	0.54%	0.2306	0.2348	0.0450	0.0460	0.0069	0.0071
$10/hour	.6793	.6737	0.56%	0.2601	0.2645	0.0523	0.0534	0.0082	0.0084
$12/hour	.6402	.6344	0.58%	0.2899	0.2943	0.0601	0.0612	0.0098	0.0100
$14/hour	.6005	.5947	0.58%	0.3197	0.3240	0.0683	0.0695	0.0115	0.0118
	Change from $4-$14/hr = -18.9%	Change from $4-$14/hr = -19.0%	Change from 630am to 9.30am = 0.10%	Ave. choice share =14.59%	Ave. choice share =14.63%	Ave. choice share = 3.63%	Ave. choice share = 3.67%	Ave. choice share = 0.69%	Ave. choice share = 0.7%

Note: the relative percentages in each column are the difference between the market shares at $4 and at $14 multiplied by 100.

Conclusions

In this study we provide substantive scientific evidence on the influence of (i) the introduction of a curfew which prevents casual parking before 9.30am during weekdays at all parking stations in the Sydney CBD while maintaining existing tariffs, and (ii) the removal of all curfews prior to 9.30am and the introduction of increasing parking charges.

The policy implications are profound:

> *The evidence suggests that the imposition of a curtailment of hours of operation at specific locations under existing tariffs will lead to a relocation of parking and some small switch to public transport, but essentially a continuation of driving into the CBD. Increases in tariffs however will secure significantly greater use of public transport, a noticeable switch from parking close in to parking elsewhere in the CBD, and a small increase in relocation of parking to the fringe of the CBD and parking outside of the CBD. There is virtually no loss in travel to the CBD.*

These findings are consistent with the most recent findings in the USA by Bianco et al (1997) which concluded that:

> *"Overall, the best strategies in terms of political feasibility are narrowly targeted in geographic scope but not necessarily very effective in changing mode share: parking impact fees, changing zoning ordinances, shared parking, and TDM approaches such as satellite parking-shuttle lots. The strategy with the highest level of effectiveness—increasing the price of parking, based on a tax on spaces—is a broad tool but also the least politically feasible."(page 1)*

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