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Value of travel time savings for multiple occupant car: evidence from a group-based modelling approach

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Abstract

The value of travel time savings (VTTS) accounts for a majority of the total user benefits in economic appraisal of transport investments. This means that having an accurate estimate of VTTS for different segments of travel continues to retain currency, despite there being a rich literature on estimates of VTTS for different travel modes, travel purposes, income groups, life cycles, and distance bands. In contrast, there is a dearth of research and evidence on VTTS for car passengers and cars with multiple occupants, although joint travel by car is an important segment of travel. This paper fills this gap by developing a group-based modelling approach to quantify the VTTS for the car driver and the car passengers in a car which has multiple occupants. An online survey was conducted in Sydney in 2014 and the data used to obtain a number of new empirical estimates of VTTS. The new evidence questions the validity of various assumptions adopted in current practice for valuing the time savings of car passengers and multiple occupant cars.

Keywords: Vehicle VTTS, Passenger VTTS, Group models, Multiple occupant cars, Economic appraisals, Driver VTTS.

1. Introduction

The value of travel time savings (VTTS) is one of the key components of user benefit for transport projects. The theoretical basis for the treatment of time savings as an economic benefit is that travellers are willing to pay a higher price for a quicker travel time. As VTTS accounts for a majority of the total user benefits in economic appraisal of transport investments, it is crucial to have an accurate estimate of VTTS for different segments of travel. As a result, a very large number of empirical studies on the estimation of VTTS have been conducted in different countries. In some regions such as Europe, UK, North America and Japan, the body of research is large enough for a meta-analysis to quantify the variation of VTTS across travel segments (Abrantes and Wardman, 2011; Kato *et al.*, 2010; Shires and de Jong, 2009; Zamparini and Reggiani, 2007). The different segments explored in empirical studies of VTTS, and hence meta-analyses, are defined by travel mode (e.g., public transport vs. car), travel purpose (e.g., commuting vs. business vs. other), group of travellers (e.g., high vs. low income), and distance travelled (e.g., short vs. long journeys).

Joint travel by car constitutes an important segment of travel but the VTTS for car passengers and for the entire group are rarely investigated (Ho, 2013; Ian Wallis Associates Ltd, 2014). Most studies of car travellers' VTTS have focused on the willingness to pay (WTP) of the car drivers only. These studies assume that the VTTS of the driver is all that matters, with the influence of the passengers being ignored or implicitly accounted for by the driver of multiple occupancy cars. However, for the purposes of economic evaluation and travel demand forecasting, it is unclear how the VTTS for car passengers is evaluated. Whilst the New Zealand Transport Agency's Economic Evaluation Manual (EEM) evaluates car passenger's VTTS at 75 percent of the car driver's values, Austroads (Australian Road Transport and Traffic Agencies) and Transport for New South Wales (TfNSW) use the same VTTS for car passengers and car drivers for transport demand models and economic evaluations (Ian Wallis Associates Ltd, 2014; Austroad, 1997, TfNSW, 2013). Other national guidelines for transport management and economic evaluation, however, are silent on this issue. This may due largely to a lack of research and evidence on the VTTS for car passengers and cars with multiple occupants. Some research on the passenger's VTTS has been conducted in the UK, but the evidence is inconclusive and has led to a recommendation of non-implementation (Mackie *et al.*, 2003, p.84) subject to confirmation of the difference in the VTTS for car drivers, car passengers and larger groups with further targeted research. This paper aims to fill this challenging research gap using a new survey of car travel conducted in Sydney. In particular, the paper explores the VTTS for car passengers relative to the car drivers' values and offers a method to derive the VTTS per car with multiple occupants (i.e., group travel).

Establishing VTTS for car passengers and group travel is very important for economic evaluation and demand forecast of transport projects, especially those that involve travellers who trade travel costs for travel times and opt for high occupancy vehicle lanes and toll roads. With very limited evidence on the VTTS for car passengers and for group travel, economic evaluation and demand forecast for transport projects have to assume that the VTTS per car is the total of the driver's value and the passengers' values (i.e., VTTS are additive for multiple-occupancy car). Whether this is a valid assumption is open to question, and the answer to this research question has the potential to change the outcome of investment appraisal.

The paper is organised as follows. The next section reviews the literature on the VTTS for car passengers and car drivers of a multiple-occupant car. This is followed by a description of the car travel survey designed to address the research question. A group-based modelling approach to establishing the VTTS for car passengers, car drivers and group travel is suggested and model estimation results are then presented. The paper concludes with a discussion of the main findings and suggestions for future research.

2. Literature review

A survey of the literature on the VTTS for car travel suggests that most studies have focused on car drivers, with very few exceptions assessing the VTTS for car passengers or their influence on the driver's VTTS. Methodologically, these exceptions evaluate the VTTS for car passengers and group travel using one of two approaches. The first approach treats the car passenger as a separate mode of travel and assumes that car passengers choose the mode or route as if they are independent decision-makers. The second approach assumes that the driver of the car is the main decision-maker who may take into account the passenger's VTTS in choosing, for example, the toll road in the presence of a free road. This section examines the two approaches from the perspective of empirical findings and underlying assumptions for the evaluation of vehicle VTTS.

Hensher (1986; 1989) took the first approach to evaluate the VTTS for car passengers. The car passenger was treated as a separate mode for commuting in mode choice models from which VTTS for all travel modes were derived. The results suggest that car passengers valued in-vehicle time savings at about 75 percent of that of car drivers. This rate appears consistent with findings from other studies of mode choice for non-commuting and long distance travel (Román *et al.*, 2007; Fosgerau *et al.*, 2007; The MVA Consultancy, 1997). This result also forms the basis for New Zealand Transport Agency's evaluation practice of valuing car passenger time savings at 75 percent of the driver's values (Ian Wallis Associates, 2014).

While the passenger's VTTS relative to the driver's values has been found to be consistent across different studies and is adopted in practice in economic evaluation procedures, the assumption underlying the derivation of VTTS for car passengers is problematic. That is, the passenger's decision is assumed to be independent of the car driver's decision and the VTTS for car drivers and car passengers are assumed to be additive. There is little justification for the former assumption, and a violation of the latter assumption means that economic evaluation methods may over-estimate the benefits of time savings from multiple occupant car users. An exploratory analysis conducted by Ian Wallis Associates (2014) suggests that a violation of the additive assumption of VTTS for multiple occupant cars is very likely, as the VTTS for two adults sharing a car is not noticeably greater than the VTTS for the car driver alone. This is reinforced by the findings from other studies that undertook the second approach to assess how the VTTS of a driver varies with occupancy. These studies are discussed below.

MVA (1987) conducted two stated preference (SP) surveys to establish the VTTS for the driver of a car in the presence of one or more passengers. One SP survey related to long distance travel and the other focused on the Tyne Tunnel crossing. The long distance travel survey found that the VTTS of the car driver increased by about 40 percent with up to three passengers, but increased by 65 percent when there were four or more passengers. By contrast, the Tyne Tunnel crossing survey found that the VTTS of a driver declined by 5 percent in the presence of a passenger on commuting trips, but was unchanged for non-commuting trips. This evidence led the authors to conclude that the VTTS of car passengers was discounted by the driver who is typically making the choice. However, the extent to which the VTTS of car passengers is discounted and the VTTS for car passengers relative to the driver's values is not clear as no surveys of car passengers were undertaken by MVA. This issue was addressed in a subsequent work for the UK Department of Transport by Accent Marketing and Research and the Hague Consulting Group (1999), which is referred to as the Accent and HCG study hereafter.

The Accent and HCG study used an SP survey to examine the VTTS for car drivers and car passengers. Each respondent was asked to play three games: two of which involved a trade-off between travel time and travel cost, and one randomly-assigned game involved a trade-off between travel time and one of the following attributes: road characteristics (number of lanes, heavy vehicle access, and hard shoulder), departure time and expected delay. A sample of 4,000 car drivers and 400 car passengers was obtained. With respect to the VTTS of the driver, the presence of a passenger was found to increase the car driver's VTTS by 9 percent for commuting trips and 15 percent for non-commuting trips, but had no influence when travel was for business. By contrast, their analysis of the car passenger surveys found that the VTTS for the car passengers was the same as for the car driver value for commuting trips, about 11 percent less for non-commuting trips and 36 percent more for business travel. The conclusion was that drivers seem to take little account of the VTTS of passengers when making their choices.

Hensher (2008) also used an SP survey to investigate the impact of car occupancy on the driver's VTTS for non-commuting travel in Sydney. Each respondent was asked to play 16 games which involved a trade-off between travel times and travel costs among alternative routes. A sample of 222 interviews was obtained, giving $16 \times 222 = 3{,}552$ observations for model estimation. Using a mixed logit model, Hensher found the average VTTS of the driver varied across the number of passengers and decreased as the number of passengers increased. This result is consistent with Ramjerdi et al. (1997) who found that the VTTS for a driver slightly reduced in the presence of one or two passengers for non-commuting trips. However, the lower VTTS for the driver of multiple occupant cars, as compared to the values for driver alone, runs entirely counter to the results of the Accent and HCG study discussed above. Hensher acknowledged this difference and explained that "the driver's marginal disutility of travel time might be lessened in the presence of passengers who they can chat to or even share some of the monetary costs" (p.69). If the car passengers share some of the travel costs with the car driver, then the questions of interest are what is the VTTS of the car passengers and how is the group VTTS compared to that of the driver travelling alone?

Hensher (2008) acknowledges that his approach of treating the car driver as the main decision maker is not able to establish the VTTS for passengers or a vehicle VTTS.

This brief review indicates that the international evidence on VTTS for passengers and drivers of multiple occupant cars is very limited and inconclusive. In addition, all studies undertaken to date have examined the VTTS for multiple occupant cars from the perspective of either the driver or the passenger separately without recognising that the decision may be jointly made as a group. More explicitly, the SP surveys used in previous studies asked either the driver or the passengers to trade-off their own travel times and costs and to indicate the alternative they most preferred. Although it is recognised that co-travellers (either the driver or passengers) may share travel costs such as parking, toll and fuel costs, the attributes that describe the co-traveller's (dis)utility are not explicitly included in the choice scenarios that the respondents were asked to trade-off when revealing their preferences. The utility of co-travellers may be accounted for by the decision-makers (the respondents) when making choices, but this is entirely implicit and up to each respondent. This is one area that the current paper addresses.

Another gap in the literature on the estimation of a vehicle VTTS is that all models to date are for individual decisions with interactions between co-travellers being dealt with in a black-box. Further, these models are not able to distinguish social effects (e.g., income, age) from situational effects (e.g., travel purpose, travel as a passenger or a driver) in order to explain the range of VTTS for passengers relative to the drivers. This paper extends the literature by examining the car VTTS as well as the driver and passenger values using a group-based modelling approach which allows the utility of all car occupants to influence the travel decision. The empirical setting and modelling approach are described in the next section.

3. Methodology

An individual power weight modelling approach is proposed to capture the influence that each travel party member may have on the joint decision. To this end, a customised survey was designed to collect data for model estimation and the derivation of the VTTS for car drivers, car passengers and cars with multiple occupants. This section describes the survey instrument, the data and the modelling approach.

3.1 The survey

The centrepiece of the empirical study is a stated choice experiment designed to understand how the (dis)utility of the co-travellers is taken into account by the decision-maker, be they the car driver or car passengers, when making a choice of route to travel for work/education, business-related and non-work activities. The choice experiment consisted of three alternatives: the current route and two unlabelled alternatives, called Route 1 and Route 2. Each route was described by attributes representing the total travel cost the respondent pays, the total cost the co-travellers pay, and the travel time for a round trip, defined and visually illustrated in the survey instrument as a trip starting and ending at the same place with one or more destinations in between (also known as a tour in the activity-based travel literature). All segments of car users including driver alone, driver with passenger(s), and passengers, were sought.

Two D-efficient designs were implemented for the experiment: one design for cases where travel costs (including toll, parking and fuel costs) are split amongst co-travellers and the other for cases where all costs are paid by one travel party member. The latter design was also applied for respondents whose last round trip by car was as a driver only. Both designs were generated in such a way that the total travel costs paid by the respondents and their co-travellers (if relevant) and the round trip travel time for the current route were first acquired from respondents over the questions related to their last round trip by car, while the attribute levels for the two unlabelled routes were pivoted off of these values as minus or plus percentage shifts to represent a decrease or an increase in travel time and travel costs incurred by each travel party member. Table 1 shows the pivot levels for the two unlabelled alternatives in the cases where the travel costs are split or not split across the travel party members.

Table 1: Pivot levels of the experimental designs with costs split and costs not split between travellers

Attributes	When costs are split	When costs are not split
Total costs you pay	±5%, ±20%, ±40%	±10%, ±20%, ±30%
Total costs other party members pay	0%, ±20%	±10%, ±20%, ±30%
Travel time (round journey)	±10%,±20%	±20%

Priors for the experimental designs were obtained from a pilot survey of 135 respondents spread evenly across the 9 segments of car travel (3 purposes $\times$ 3 types of car users). The experiments were designed with conditions such that each choice made by the respondent required trade-offs between travel time and travel cost for themselves or for their co-travellers. Specifically, one set of conditions required that, if the current route costs more than Route 1 or Route 2, then the hypothetical routes must take longer than the current route, and vice versa. This condition was applied for all possible pairs of alternatives. Another set of conditions required that, if the total costs paid by the respondents (i.e., attribute 'total costs you pay' in Table 1) on one route are higher than what they have to pay on an alternative route, then the total costs incurred by their co-travellers (i.e., attribute 'total costs other party members pay') on this alternative route must not be lower, and vice versa. This is to ensure that respondents always faced a trade-off between time and cost or between cost paid by themselves and cost paid by their co-travellers. These designed conditions were tested with *NGene* (Choice Metrics, 2012) using three segments of car use for short, medium and long travel, with the reference levels selected for short travel [$2, $0, 30 mins] for medium travel [$6, $4, 60 mins], and for long travel [$15, $10, 120 mins], with the first number in the brackets the cost paid by the decision-maker, the second number the cost paid by co-travellers, and the last value the round trip travel time.

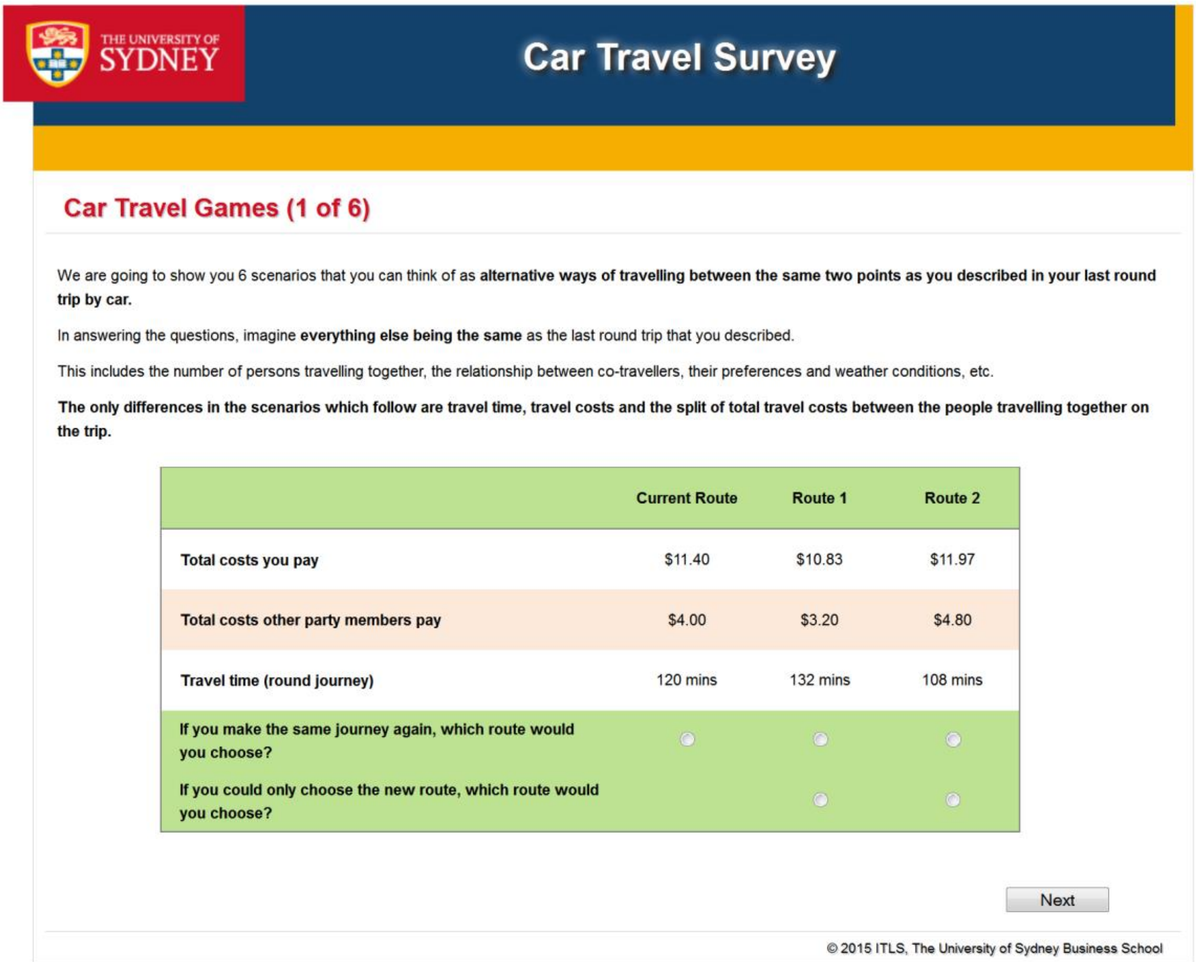
The design for cases with no cost-sharing consisted of six choice tasks. The design for cases with cost sharing amongst co-travellers consisted of 12 choice tasks which were blocked into two sets of six choice tasks. One randomly selected block of the latter design was assigned to respondents if they reported a sharing of costs on their last car trip. However, if the respondents reported that the travel costs were fully paid by themselves or by their co-travellers, the former design was assigned to them. In both cases, each respondent was shown sequentially six scenarios, each with three alternatives, and asked to select one route if they made the same journey again. They were also asked to select one of the new routes in a subsequent question where the current route is not available for choice. Figure 1 presents illustrative choice screens for both cases with costs split and costs not split.

Apart from the information that was acquired for the design of the stated choice experiment, other details were also collected. These included the main purpose of the respondent's last round trip by car, the way they travelled (as a driver only, as a passenger or as a driver with passengers), origin and main destination of the round trip, the presence of any stop on the outward and return journeys, auto body type, fuel consumption and year of manufacture of the vehicle used for the last round trip, the number of people travelling together, the relationship between the travelling party, the approximate distance all travel party members travelled together as well as age, income, travel purpose (detailed classification), relationship to the driver (for all passengers), and licence status of all travel party members. The respondents were also asked to indicate whether they had a joint bank account or shared income with any co-travellers, and the proportion of tolls, parking and fuel costs covered by their contribution in their last car trip. After playing the games, respondents were asked to describe themselves and their households, with questions relating to age, gender, access to car as a driver, work status, occupation, household size and structure, number of cars own by the household, personal and household income.

The SSI panel (www.surveysampling.com) was used to obtain the sample and Sydney was chosen as the study area where SSI has many thousands of participants. Ethics approval (approval no: 2014/242) was obtained for the experiment, and each respondent received a small incentive for a completed survey (be it cash, points redeemable for a gift card or equivalent money that they can donate to a charity depending on their preference). Respondents were recruited from 14th March to 2nd April 2014 via an email directing them to a customised online survey. In total, 2,061 invitation emails were sent and a sample of 765 qualified respondents was obtained, resulting in a response rate of 37 percent. This is reasonably low compared to other online surveys we have previously undertaken with SSI, and the reason for this was twofold. First, quotas were applied to screen out respondents when the segments to which the respondents belong were full. Second, it was difficult to find respondents in some segments of car use such as drivers with passenger(s) for business-related travel. This screened out more respondents at the end of the survey period when some easy-finding-respondent segments of the survey were closed while more difficult segments were still open for recruitment.

Figure 1: Illustrative choice screens

(a) Travel costs split amongst co-travellers



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Car Travel Survey

Car Travel Games (1 of 6)

We are going to show you 6 scenarios that you can think of as **alternative ways of travelling between the same two points as you described in your last round trip by car.**

In answering the questions, imagine **everything else being the same** as the last round trip that you described.

This includes the number of persons travelling together, the relationship between co-travellers, their preferences and weather conditions, etc.

The only differences in the scenarios which follow are travel time, travel costs and the split of total travel costs between the people travelling together on the trip.

	Current Route	Route 1	Route 2
Total costs you pay	$11.40	$10.83	$11.97
Total costs other party members pay	$4.00	$3.20	$4.80
Travel time (round journey)	120 mins	132 mins	108 mins
If you make the same journey again, which route would you choose?	○	○	○
If you could only choose the new route, which route would you choose?		○	○

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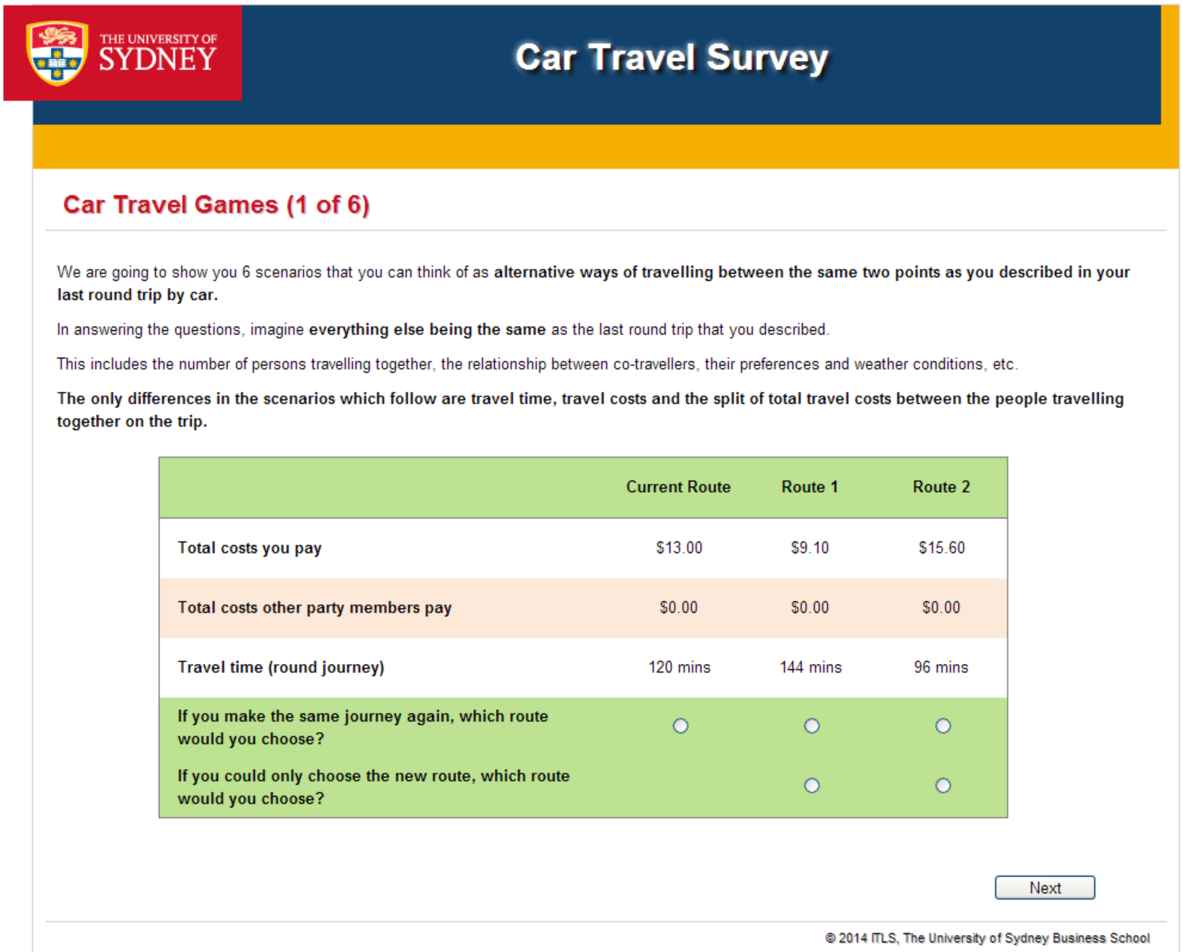
© 2015 ITLS, The University of Sydney Business School *(b) Travel costs fully paid by one travel party member*



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This includes the number of persons travelling together, the relationship between co-travellers, their preferences and weather conditions, etc.

The only differences in the scenarios which follow are travel time, travel costs and the split of total travel costs between the people travelling together on the trip.

	Current Route	Route 1	Route 2
Total costs you pay	$13.00	$9.10	$15.60
Total costs other party members pay	$0.00	$0.00	$0.00
Travel time (round journey)	120 mins	144 mins	96 mins
If you make the same journey again, which route would you choose?	○	○	○
If you could only choose the new route, which route would you choose?		○	○

Next

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3.2 The data

A process of cleaning and validating the data identified 46 respondents who reported inconsistent trip details and 73 respondents whose last car tours were too short (less than 10 minutes) or too long (longer than 5 hours). These respondents were removed from the analysis, reducing the sample to 645 usable respondents. Very short journeys were excluded as the difference between alternative routes is too small to reveal the respondent's VTTS (i.e., a 20 percent pivot off of a 10-minute journey creates only a 2-minute difference in travel time between alternative routes). By contrast, very long journeys were not included because of the potential of long distance travel contaminating the dataset. Table 2 provides the summary statistics of the final sample, distinguishing driving alone and shared ride respondents.

Table 2 shows a clear distinction between the two segments of car users in terms of socio-demographics and travel-related characteristics. Single-occupancy-vehicle (SOV) users appear to be older, have a higher personal income, pay standing fees (e.g., registration fee, insurance and maintenance) more often, and have greater access to car than high-occupancy-vehicle (HOV) users. In addition, drivers of SOVs on average have a slightly shorter journey (68 vs. 84 minutes) but incur a substantially higher cost than HOV users do ($5 vs. $2). The differences in travel cost between SOV users and HOV users are likely to be due to differences in travel purpose and the way in which travel costs are split amongst co-travellers of HOV users. With an average occupancy of 2.27 per vehicle, on average HOV users pay about 2.5 times less than SOV drivers. The distribution of travel purposes of SOV and HOV users is another possible explanation for a large difference in travel cost. The sample of HOV users have more non-work and commuting journeys but fewer business-related trips than the drive alone sample. As non-work travellers have more opportunity than commuters and business travellers to avoid parking costs (by the choices of destination and parking zones such as 2-hour free parking), the average travel cost per person is lower for HOV users than for SOV users.

Table 2: Summary statistics of the sample

	Drive alone		**Shared ride**	
	Mean	std. dev	Mean	std. dev
Main purpose is business-related (1/0)	.27	–	.10	–
Main purpose is commute/education (1/0)	.34	–	.40	–
Main purpose is non-work (1/0)	.39	–	.50	–
Presence of stop on tour (1/0)	.30	–	.22	–
Travel party size for most of the journey	1.0	.0	2.27	.60
Travel time of round trip (mins)	68	52	84	54
Total cost the respondent pays for round trip	5.00	7.26	2.03	5.92
Respondent pays standing fee (1/0)	.88	–	.47	–
Respondent's age (year)	46.57	15.09	42.86	16.64
Respondent is man (1/0)	.41	–	.39	–
Number of household cars	1.77	.96	1.58	.95
Respondent's income in $1000	57.60	29.29	45.28	28.35
Sample size (number of respondents)	*271*		*374*	

Note:– standard deviation is not meaningful for a dummy variable.

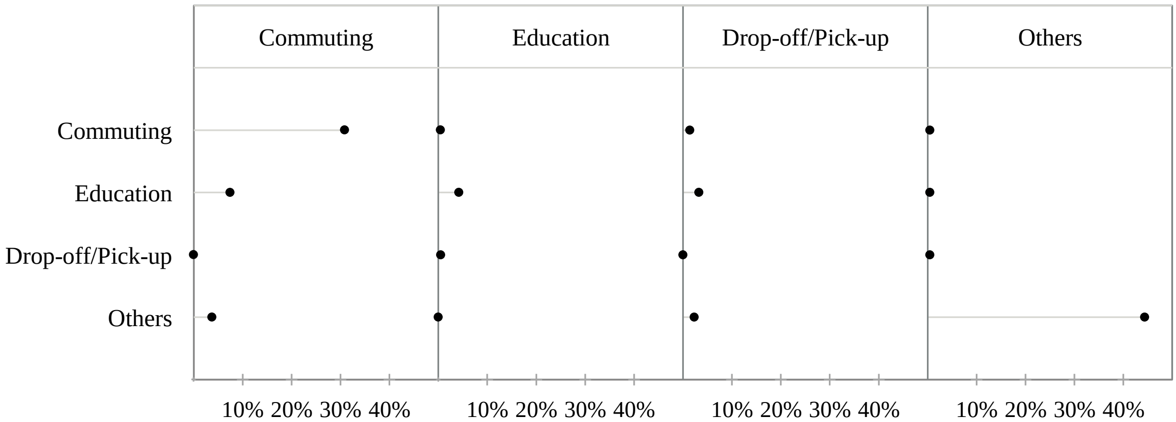
It should be noted that the sample is not meant to be representative in terms of travel purpose, as quotas were designed to obtain enough respondents in each travel segment for quantifying the variation of VTTS across travel purposes and car travellers. Nevertheless, it was difficult to obtain the quotas for business-related travel, especially in the shared ride segment, with the final sample consisting of only 10 percent of the respondents (37 persons). The small sample of business-related travel is the main reason for the exclusion of this travel segment from further analysis. Another reason is that the choice experiment approach may not be able to reveal the VTTS for business travellers when travel costs are paid by their employers (the analyst does not observe a trade-off between time and cost from respondent's choice of route when the payment is paid by the employer). In this case, the Hensher approach (Batley, 2015) for valuing the VTTS for business travel is more suitable than the approach employed in this study.

Table 3 and Figure 2 show the profile of HOV users. As can be seen from Table 3, drivers of HOVs are older, have a higher income and contribute more to for the outlays on fuel, tolls and parking costs than the passengers, as expected. About 64 percent of the passengers hold a driving licence. The joint travel sample consists of 53 percent car passengers and 47 percent car drivers. HOVs are mainly used for intra-household joint travel, with couples (29%) and parent and child relationships (27%) dominating the relationship between co-travellers. Colleagues and friends together account for a substantial percentage (35%) of HOV users. About 28 percent of the co-travellers have a joint bank account, which is about the same as the couple relationship in the sample. Compared to an average round trip journey of 84 minutes in Table 2, the average time that all travel party members travel together is 82 minutes, suggesting that most of the shared ride tours are fully joint with very few journeys being drop-off or pick-up. This is reinforced by the dominance of the same travel purposes shown in Figure 2 for joint car tours by 2 persons (80% of the shared ride sample). That is, joint travel, where the driver and passengers have the same purpose, accounts for more than three quarters of the sample, while dropping off and picking up children en route to/from work or on a dedicated tour together accounts for only 10 percent.

Table 3: Sample profile of joint travel by car

	Driver	Passenger
Average age in year	43.4	38.3
Average personal income in $1000	43	27.7
Average percent of holding driving licence (%)	100	63.7
Average contribution to pay toll cost (%)	19.1	5.1
Average contribution to pay parking cost (%)	20.4	5.1
Average contribution to pay fuel cost (%)	52.7	9.7
Percent being the respondent (%)	46.7	53.3
Percent having couple relationship (%)	29.5	
Percent having parent and child relationship (%)	27.4	
Percent having colleagues relationship (%)	18.2	
Percent having friends relationship (%)	16.7	
Percent having other relationship (%)	8.3	
Percent having joint account (%)	28.3	
Average time travel together (minutes)	82	

Figure 2. Travel purposes of the driver (column) and passenger (row) on a joint tour by 2 persons



3.3 The model

To capture the influence that each individual has on the choice of route for joint travel, a non-linear decision weight model is developed. Under random utility theory, decision-makers (i.e., the respondents) are assumed to maximise group utility when choosing a route for joint travel. The utility that a group of *g* individuals (i.e., co-travellers) derives from a route *r* is defined as the weighted sum of individual utility, and is given in equations (1) and (2).

$$U_{gr} = \sum_{i=1}^{g} \theta_i V_{ir} + \varepsilon_{gr} \tag{1}$$

$$\sum_{i=1}^{g} \theta_i = 1 \text{ and } \theta_i \geq 0 \tag{2}$$

V_{ir} is the observable utility that a group member *i* derives from an alternative *r*, θ_i is the power that a group member *i* possesses relative to the influence of other members *j* on the group decision, and ε_{gr} is the unobserved utility associated with group *g* and route *r*.

The individual power θ_i can be parameterised to be a function of personal income, travel purpose, and other factors such as driving licence status, gender and age (collectively denoted as Z_i). To ensure that the conditions (2) are met, the individual powers are formulated as a logit model (3) in which individual powers are bounded between zero and one, and sum to one.

$$\theta_i = \frac{\exp(\gamma' Z_i)}{\sum_{j=1}^{g} \exp(\gamma' Z_j)} \tag{3}$$

With this specification, the group-based decision model, represented by equations (1–3), allows the influence of group members on the joint decision to be context dependent. That is, the model allows different members of a group to have different influences on a group decision, dependent on the individual's preference intensity, experience and personal characteristics. In estimating the model, the estimator will identify the power weights to maximise group utility (i.e., no Pareto improvement can be obtained for the sample). Thus, the individual powers can be interpreted as the Pareto weights.

This modelling structure lends itself to the familiar logit form. The general form of the model departs from a standard specification of linear-in-parameters for the observable utility, $V_{ir} = \beta_i' X_{ir}$. In the current context of a route choice experiment, V_{ir} is specified as a function of the travel time and travel cost that the group member *i* spends on an alternative route *r:*

$$V_{ir} = \beta_i' X_{ir} = \beta_{timei} \times Time_{ir} + \beta_{costi} \times Cost_{ir} \tag{4}$$

Assuming an iid type I extreme value distribution for the random terms ε_{gr}, the probability that group *g* choose an alternative route *r* in a choice situation of *R* routes can be expressed as equation (5). See Hensher et al. (2015, Ch 22) for more details.

$$P_{gr} = \frac{\exp(\sum_{i=1}^{g} \theta_i V_{ir})}{\sum_{r=1}^{R} \exp(\sum_{i=1}^{g} \theta_i V_{ir})} \tag{5}$$

Preference heterogeneity may be layered on top of the group-based model (5) in the form of random parameters (6) or error components (7) or both.

$$\beta_i = \bar{\beta} + \sigma_k \nu_{ik} \tag{6}$$

$$\varepsilon_{gr} = \eta_{gr} + \delta_r' E_{gr} \tag{7}$$

$\bar{\beta}$ is the population mean of the individual parameter β_i , ν_{ik} is the individual specific heterogeneity with mean zero and standard deviation one, σ_k is the standard deviation of the distribution of β_i around $\bar{\beta}$, E_{gr} are error components which are alternative specific with zero mean and standard deviation one, δ_r is the standard deviation parameter, and η_{gr} is iid extreme value.

The full model with all components is:

$$P_{gr} = \frac{\exp\left[\sum_{i=1}^{g} \theta_i (\beta_i' X_{ir}) + \delta_r' E_{gr}\right]}{\sum_{r=1}^{R} \exp\left[\sum_{i=1}^{g} \theta_i (\beta_i' X_{ir}) + \delta_r' E_{gr}\right]} \tag{8}$$

The group-based model (8) is applicable for any group size, and can be extended to reflect both group decision and individual decision. This is done by modifying the utility function (1) as:

$$U_r = d \sum_{i=1}^{g} \theta_i V_{ir} + (1-d) V_{ir} + \varepsilon_r \tag{9}$$

where *d* is a dummy variable equal to one under joint travel and zero otherwise. Combining the individual travel and joint travel models as in (9) is more efficient than using two separate models. The empirical estimation results are presented in the next section.

4. Estimation results

This section presents the empirical model results for both joint and individual travel by car. As noted in section 3.3, the model is able to reflect both individual and group decisions with multiple decision-makers. However, the empirical data consist of a small sample (68 observations) of joint travellers with three or more persons, leading to the choice of modelling individual travel and joint travel by two persons only. Different specifications for the presence of preference heterogeneity (equations 6 and 7) were explored using Nlogit pre-released version 6 (April 2015). No statistical evidence was found to support the presence of preference heterogeneity in group decision making, but the random parameters associated with travel time and travel cost are statistically significant for solo travel. Thus, the finally adopted model has a non-linear MNL form for the joint travel segment and a mixed logit form for solo travel with all random parameters assumed to follow a constrained triangular distribution. A number of distributions including normal, log-normal and constrained triangular were explored for the random parameters, and the best statistical fit was the constrained triangular distribution where the spread (not the standard deviations) is constrained to equal the mean. Table 4 shows the estimation results.

All the parameter estimates have the expected sign and the combined model fits the data reasonably well with the McFadden adjusted R^2 of 0.22. Table 4 shows that the power an individual possesses, relative to their co-traveller, is significantly influenced by the travel purpose and incomes of both travellers. The relative magnitudes of the parameters associated with the travel purpose are interesting with dropping-off/picking of passengers having the largest parameter, followed by education and work tours. These results suggest that, *ceteris paribus,* the car driver has more power than the passenger who is being served on a dedicated drop-off/pick-up tour. In contrast, if the driver drops-off or picks-up children at school as part of their commuting tour, they have less power. A possible explanation is that students are less likely to have time flexibility at school than workers have at work, and this results in a higher weight for the travel party members with education activity. Also, if they share the same travel purpose and have the same income, the passenger is found to hold a higher power than the driver, as the parameter associated with the car passenger dummy is significantly positive. This is an interesting finding which runs counter-intuitively to the common belief that the car driver is the main decision-maker, who is assumed to choose the route while taking into account the passenger's disutility. It should be noted that an interpretation of any single parameter (e.g., passenger dummy variable) must be based on a *ceteris paribus* assumption. Clearly, this assumption is not the case for the sample of respondents in which the average income of the car drivers is almost twice the car passenger's average income (see Table 3). Therefore, the power that the car passengers hold relative to the car drivers must be investigated, with differences in travel purpose and income taken into account.

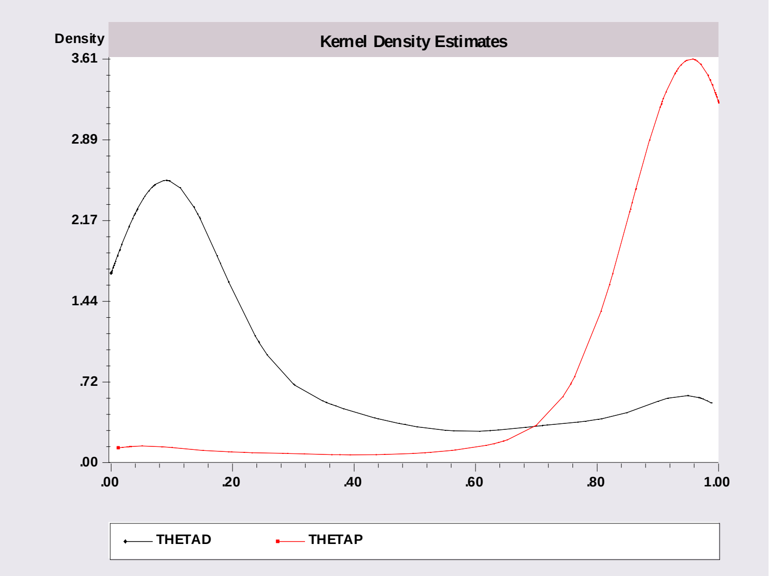
Table 4: Estimation results for joint and solo travel

Variable description	Parameter	t-value
Joint travel model		
Variables influence the individual power θ_i		
Work tour dummy (base = other travel purposes*)	1.963	3.04
Education tour dummy (base = other travel purposes)	2.889	3.73
Drop-off/pick-up tour dummy (base = other travel purposes)	3.717	2.94
Car passenger dummy (base = car driver)	1.427	4.70
Driver income in $10,000	0.558	5.63
Passenger income in $10,000	0.959	5.26
Variables influence the individual utility V_i		
Car driver travel time in minute	-0.154	-6.72
Car passenger travel time in minute	-0.006	-1.65
Travel cost incurred by car driver	-1.175	-5.90
Travel cost incurred by car passenger	-0.020	-0.97
Solo travel model		
Mean of random parameters		
Travel time in minute	-0.016	-4.70
Travel cost for work tour in dollar	-0.163	-7.98
Travel cost for non-work tour in dollar	-0.278	-14.93
Spread of random parameters		
Travel time in minute	0.016	4.70
Travel cost for work tour in dollar	0.163	7.98
Travel cost for non-work tour in dollar	0.278	14.93
Model summary statistics		
Log likelihood at convergence	-2129.8	
Log likelihood at zero	-2737.3	

*Note: *Other purposes include shopping, social, personal business and accompanying someone.*

Taking the differences in travel purpose and income of the driver and the passenger into consideration, Figure 3 shows the kernel distribution of individual power in the sample. To produce the kernel distribution shown, the parameters associated with the variables that influence the individual weights are multiplied by the values of the variables, and equation (3) is applied to compute the power weight for each individual in the sample from which the kernel distribution is estimated. It can be seen from Figure 3 that the disutility of the car passengers is weighted more heavily than that of the car drivers, with an average weight held by the passengers of 0.777, while the average power weight of the drivers was 0.223. There were very few cases where one travel party member, be it the driver or the passenger, dominated the choice. This supports the use of individual power to weight up a group member's utility in modelling joint travel, and deriving the car VTTS.

Figure 3: Sample distribution of power weight held by car driver (thetad) and car passenger (thetap)



Turning to the utility of travel party members, Table 4 shows that parameters associated with travel time and travel cost incurred by the driver are highly significant, but the parameters for the passenger are not statistically significant at the 95 percent level of confidence. While the parameter associated with the passenger time has a 90 percent level of confidence, the level of confidence is much lower (67%) for the parameter associated with the passenger cost. This is presumably due to the small sample of passengers who actually contributed to pay for the travel costs incurred in a joint tour (see Table 3). With respect to solo travel, both means and spreads of the random parameters associated with travel time and travel costs are highly significant, suggesting the presence of heterogeneity in the sample preference for travel time and travel cost. The effect of travel purpose on individual's sensitivity to travel costs is included by interaction terms between travel cost and travel purpose. The interaction parameters are statistically different from each other, with SOV commuters being found to be less sensitive to travel cost than other SOV drivers, as expected.

The driver's VTTS, both for solo and joint travel, as well as the car VTTS can be derived from the time and cost parameters. The passenger VTTS can be calculated as well but it would not be reliable, given the statistical non-significance of the corresponding parameters, especially the cost parameter. Figure 4 compares the VTTS for the driver of HOV and SOV, with the latter distinguishing work (SOVwork) and non-work (SOVother) travel. The average VTTS for the driver of a multiple occupant car is $13.65 per hour (standard deviation of $8.15 per hour) which is higher than the average VTTS for the driver of SOV ($8.30 per hour for work tours and $5.40 per hour for non-work tours). These VTTS are in line with the VTTS estimates for non-work travel and for the car driver with one passenger in Sydney (Ho and Mulley, 2013; Hensher, 2008), and in Australia in general (Litman, 2011; ATC, 2006).

Figure 4: Distribution of VTTS for driver of multiple and single occupancy car

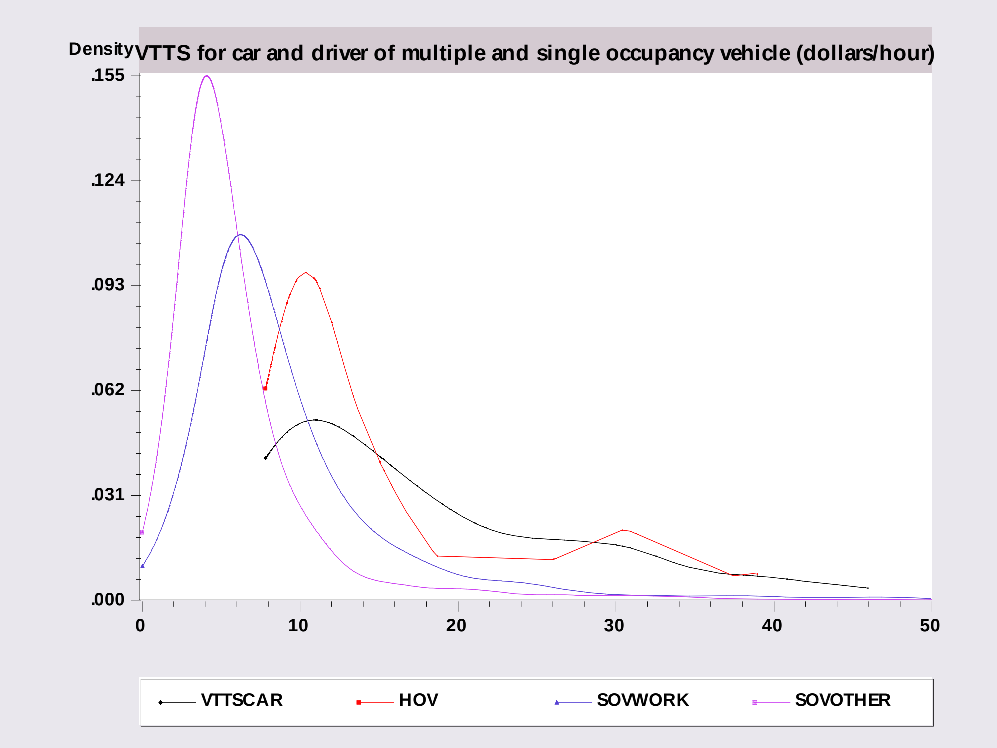


Figure 4 also shows the distribution of a vehicle VTTS for joint travel by two persons. To establish the vehicle VTTS, the marginal cost of the group (or the entire car) is calculated as the weighted average of the marginal utility of total travel cost where the weights are the costs incurred by the driver and the passenger. Specifically, the vehicle VTTS formula is expressed as follows:

$$VTTS_{car} = \frac{MU_{time}}{MU_{\cos t}} = \frac{\left(\theta_d \beta_d^{time} + \theta_p \beta_p^{time}\right) \times 60}{\dfrac{\theta_d \beta_d^{\cos t} Cost_d + \theta_p \beta_p^{\cos t} Cost_p}{Cost_d + Cost_p}} \qquad (10)$$

where $Cost_d$ and $Cost_p$ are the total costs incurred by the driver and the passenger on the chosen route in each choice task; θ_d and θ_p are individual power weight calculated using equation (3) with a reference to the annual incomes and travel purposes of the driver and the passenger in their last round trip journey by car; and $\beta_d^{time}, \beta_p^{time}, \beta_d^{\cos t}, \beta_p^{\cos t}$ are the parameters associated with time and cost of the driver and the passenger as shown in Table 4. The average vehicle VTTS is \$17.80 per hour with a standard deviation of \$9.70 per hour. The vehicle VTTS is about 30 percent higher than the driver VTTS. However, this does not mean that the passenger VTTS is 30 percent of the driver VTTS as the driver's and the passenger's VTTSs are not additive but are weighted by individual powers to form a group VTTS. Only when each co-traveller holds an equal power to the joint decision and when all of them are equally sensitive to travel time and travel cost does the additive assumption of VTTS for the car driver and for the car passenger hold. Clearly, this is not the case with this empirical dataset where the passengers appear to possess a stronger power and have different preferences to time and cost than the driver.

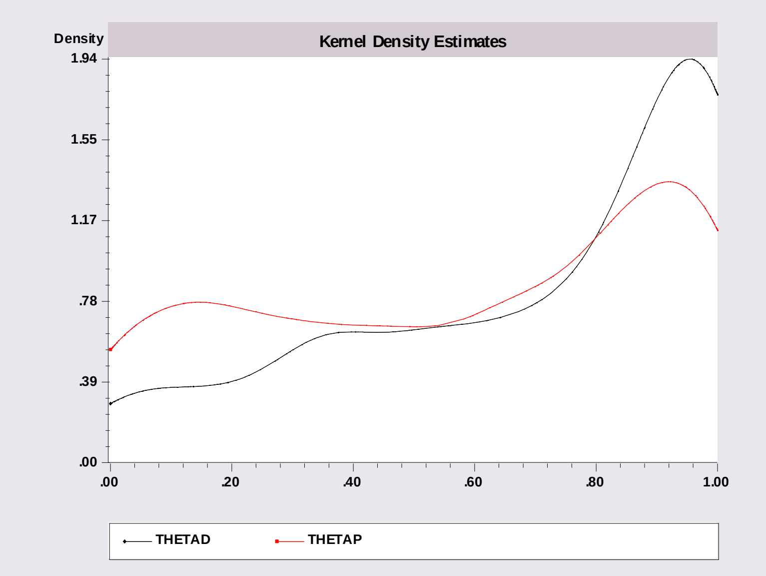
5. Conclusions and discussion

The VTTS for car passengers, and to a lesser extent vehicle VTTS, play a critical role in the economic appraisal of transport projects. Unfortunately, this is a grey area that has received very little attention in the literature. Indeed, for many economic evaluations of transport projects and travel demand forecasts, it is unclear how the VTTS for car passengers are accounted for. The New Zealand Economic Evaluation Manual, for example, uses a passengers VTTS as equivalent to 75 percent of the driver's value and assumes that these VTTS are additive for multiple occupant cars. However, the national guidelines of other countries such as the UK, and the Netherlands are silent on this issue (WebTAG, 2011; Bates, 2012) while the Transport for New South Wales and Austroads use the same VTTS for car drivers and car passengers (Austroads, 1999; TfNSW, 2013). The ambiguous role of the passenger VTTS in applications may be rooted in the lack of research and evidence on VTTS for car passengers and cars with multiple occupants. This paper has provided some initial evidence on VTTS for the car passengers, the car driver and the vehicle using an individual power weight modelling approach. The evidence has important implications for the appraisal of transport projects.

The evidence herein that car passengers have more influence than car drivers on the choice of route for joint travel questions the validity of the assumption that the car driver is the main decision-maker. From an empirical perspective, the evidence challenges the practice of approximating the passenger VTTS at a proportion of the driver VTTS or ignoring the passenger VTTS entirely for economic evaluation and travel demand forecasting. In addition, the VTTS of the driver and the passenger are found to be non-additive in this study, with the vehicle VTTS being not much higher than the driver VTTS. Although this study was unable to establish a reliable estimate of a passenger VTTS due to a small number of observations, this result suggests that a vehicle VTTS should be used instead of adding the passenger VTTS to the driver VTTS. This would at least remove the risk of double counting the benefit from HOV users where the magnitude of the risk depends on the extent to which the assumption on the additivity of VTTS is violated.

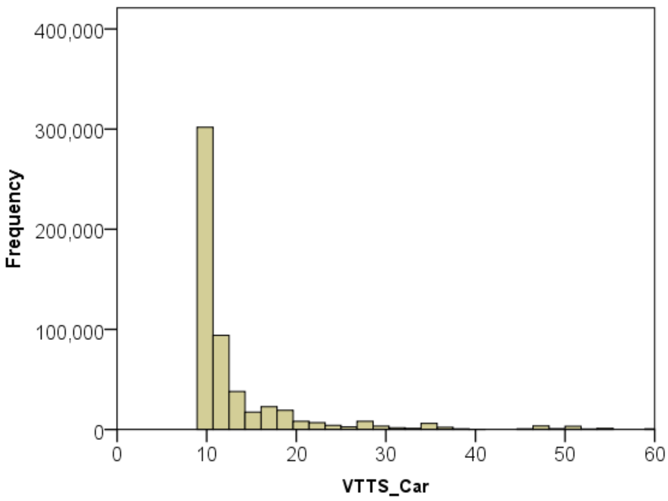
Given the parameter estimates identified in this paper, the practical question of interest relates to the VTTS that should be used for the multiple occupant cars in transport project appraisal. To answer this question, it is necessary to apply the model parameters to the population data in order to derive the vehicle VTTS for joint travel, given that the sample used for parameter estimation is not representative of the population. To this end, a joint household travel dataset constructed from the Sydney Household Travel Survey (HTS) is used (see Ho, 2013; Ho and Mulley, 2013 for a full description of how to construct such the dataset from the HTS). The power weight parameters shown in Table 4 are then applied to compute the power possessed by the car driver and the passengers, depending on their travel purpose and personal incomes, both available in the Sydney HTS. Figure 5 shows the population distribution of the power weights held by the driver and the passenger of joint car tours by two household persons. Given that intra-household joint travel accounts for more than 85 percent of total joint travel (Vovsha *et al.*, 2003), the power weights derived from the intra-household joint dataset should closely approximate the power weights for HOV regardless of the occupants being from the same or different households. Figure 5 shows that the population distribution of the individual power weights is quite different from the sample distribution shown in Figure 3, highlighting the need to apply the model to the population data for the estimation of vehicle VTTS. On average, car drivers do possess a higher power weight (0.55) than the car passengers (0.45), in contrast to the discussion of results earlier in the paper which is based on the sample data.

Figure 5: Population distribution of individual power weight held by the driver (thetad) and the passenger (thetap)



In addition, the estimation of the vehicle VTTS requires the relative contribution of the passenger and the driver to cover the travel costs. While the travel costs of a tour can be derived from the Sydney HTS, the contribution from the driver and the passenger is unknown. Thus, the average sample ratio of passenger costs to driver costs (0.33:0.67) is assumed for the population. With these assumptions, the average vehicle VTTS with two occupants (vehicle VTTS) is estimated at $13.50 per hour, with a standard deviation of $6 per hour. Figure 6 shows a histogram of the vehicle VTTS, accounting for the individual power weights of drivers and passengers.

Figure 6: Distribution of vehicle VTTS for Sydney joint travel by two persons ($/hour)



Improvements to this study can be made in many directions. An obvious enhancement would be to increase the sample size to establish more reliable estimates of the model parameters, and hence vehicle and passenger VTTS. Increasing the sample size and extending the empirical analysis to account for joint travel with three or more travel party members would be another important step forward, as joint travel involving three or more persons accounts for a substantial proportion of regional travel demand, although to a lesser extent than joint travel by two persons (Ho and Mulley, 2013). More generally, the current analysis employs a choice experiment that separately asked the car passengers and the car drivers to review and indicate that the route that they most preferred. The trade-off that this paper has to make in employing this simple experimental survey technique is the assumption that respondents will take full account of their co-travellers' preferences when making choices. However, it is possible that this assumption is not satisfied. In this case, a survey that asks all group members jointly to review the routes and indicate their joint decisions should be used. Such the survey has been used in previous studies (Beck *et al.*, 2013; Zhang and Fujiwara, 2009) but is much more expensive due to the logistical challenge of respondent recruitment (see Hensher *et al.*, 2015 Ch 22 for details on interactive choice experiments).

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