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Incorporating intra-household interactions into a tour-based model of public transport use in car-negotiating households

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Abstract

Intra-household interactions in travel constitute a fundamental aspect in understanding activity-travel behaviour, as reflected by the substantial percentage of regional travel which is made by joint household travel. The development of travel demand models incorporating intra-household interactions are crucial to providing a more credible analysis of travellers' response to policies and this paper contributes to this goal by examining intra-household interactions in travel mode choice with a particular focus on public transport use in households with different levels of car availability using a tour-based modelling framework. An important distinction is made between car-sufficient households (where there are at least as many cars in the household as licence holders) and car-negotiating households (households with fewer cars than licence holders). Intra-household interactions and temporal-spatial constraints are explicitly represented by different patterns of joint household tours, using home-based tours as the unit of analysis. A nested logit model is developed to integrate intra-household interactions with tour-based mode choices, using three years pooled data of the Sydney Household Travel Survey. The results offer a typology of joint household travel that can be embedded in the activity-based modelling framework to provide a better behavioural understanding of household travel and barriers to public transport use. The results show that joint household travel account for more than half of weekday home-based tours in Sydney, and that the mode choice associated with different joint tour patterns are influenced by household and individual characteristics, tour attributes, and transport-related fringe benefits.

Keywords Public transport, Activity-based modelling, Intra-household interactions, Joint travel, Mode choice, Group decisions

1. Introduction

Intra-household interactions mean the travel decisions of a household member are sometimes contingent on the travel behaviour of other household members. The existence of intra-household interactions giving rise to joint activity participation and shared rides is widely acknowledged and increasingly receiving attention; however, quantitative investigations of this phenomena are still limited. The limited evidence is partly due to the absence of information on participating household members in many activity based travel surveys; the difficulty of extracting such information where it exists, detecting and correcting data inconsistencies reported by participating household members from travel diary surveys and the difficulty in defining and analysing all possible joint household travel patterns. As a result, traditional travel demand models accommodate interdependencies among household members only indirectly, through the use of household characteristics as explanatory variables for individuals' travel behaviour.

Although more advanced models developed are beginning to explicitly incorporate intra-household interactions, most of the analytical approaches have been limited to household heads only, due to methodological difficulties (Golob and McNally, 1997; Gliebe and

Koppelman, 2005; Zhang et al., 2009). This limitation has to be overcome if other household members are to be considered as agents in the household decision-making. Also, previous studies on household decisions have mostly focused on time allocation, activity participation, location choice, and car ownership, purchases, disposes and have paid little attention to travel mode choice, despite the way in which mode choice is an important research element of operational travel demand models.

This paper introduces an analytical approach to modelling the weekday joint household decision – individual mode choices. The model simultaneously determines the travel mode for each tour of all household members using home-based tours as the unit of analysis where a home based tour captures the scheduling of trips in sequence, starting and ending at the individual's home. Household decisions are identified as patterns of intra-tour cooperation between/among household members that reflect different ways of arranging household travel and activities into a home-based tour. Joint household activities and shared rides are recognised as part of the joint decision making process that influence the travel patterns of each household member as these joint activities imply household members have agreed upon time and space constraints for the journey.

The paper starts with a review of the studies on intra-household interactions in transport research. The section that follows describes a typology of joint household tours. This is followed by supporting statistical evidence of intra-household interactions in household travel arrangements. The following section discusses the structure of the joint household decision – individual mode choice model and presents the estimation results. The paper concludes with a discussion and directions for further research.

2. Intra-household interactions in transport research

Recognition that individuals do not make their travel decisions in isolation of the household context has recently produced a growing body of research, as seen by special issues of Transportation (Bhat and Pendyala, 2005) and Transportation Research (Timmermans and Zhang, 2009) as well as studies found elsewhere. Research of intra-household interactions in transport-related fields have covered a number of inter-related topics including car purchases, car ownership and mode choice, residential location choice, household task and time allocation, and activity generation and scheduling. This section reviews activity based studies which have focussed on household interactions in short-term activity-travel decisions and methodologies for modelling discrete units of travel as these provide a context for this paper.

Miller et al. (2005) and Roorda et al. (2006), using a simulation technique, developed a tour-based mode choice model for the Greater Toronto Area, Canada to generate travel mode for each trip of an individual's home-based tour. The model explicitly recognised household interactions through vehicle allocation and joint household travel arrangement within the following processes. First, mode choice for individual and fully joint tours are determined without regard for the availability of household cars; then it is decided which household member uses the car if conflicts occur in which more than one household members who want to use the same car at the same time; finally, whether ridesharing opportunities exist within the household is evaluated in terms of total household utility. Implicit in the model is the assumption that an individual's mode choice decisions come first, then joint household travel decisions. However, it might be that the decision hierarchy is the other way around: household members choose their travel modes conditional on the joint household travel decisions. Another concern to the mirco-simulation approach is the computational burden and onerous tasks associated with the estimation of parameters.

Group decision-making is investigated by Roorda et al. (2009) where micro-simulation is used to examine the household interactions in vehicle allocation through the concept of "stress" resulting from household conflict. Conflicts are experienced when household members have concurrent but independent activities but there is limited number of

household cars. The study found that measures of activity-travel stress, signalling intra-household interactions, significantly influence vehicle purchase/dispose and vehicle type choice behaviour.

Using the mid-Ohio regional household travel survey data, Vovsha et al. (2003) identified nine joint household tour types and classified them into three joint travel categories: fully joint tour for shared non-mandatory activities, synchronised mandatory activity tour, and escorting tour. Each joint travel category, reflecting different patterns of household travel arrangement, has been modelled explicitly through a series of multinomial logit models: a joint tour frequency model, a travel party composition model, and a person participation model. Their descriptive analysis found that joint household travel accounted for almost half of the mid-Ohio tours. The influencing attributes for fully joint tours generation were person type, household car ownership, household income, household size, and the time window availability after the scheduling of mandatory activities (Vovsha et al., 2003). Although this approach provides valuable insights into interpersonal dependencies in household travel arrangement, it lacks a structural linkage between model components and relies upon simulation to ensure consistency between household members (Gliebe and Koppelman, 2005).

Another avenue of research incorporates intra-household interactions through classifying and modelling each household member's daily activity-travel patterns (DAPs). Vovsha et al. (2004) studied intra-household interactions through the coordination of DAPs between household members. They classified household members into seven types, ordered on a priority according to their occupation and age, and modelled each household member's DAP sequentially. With this framework, lower priority household members are assumed to consider choices of higher priority ones as a constraint and maximise their own utility. Consequently, only pair-wise interactions can be investigated although inter-personal linkages are incorporated more explicitly. Gliebe and Koppelman (2005) developed a parallel choice constrained logit (PCCL) model to investigate interactions between household heads. Their model is unique in its capacity to maintain separate probability expressions for each household head while modelling their joint choices simultaneously. Also, the PCCL model allows the impacts of contextual and situational factors on household interactions to be parameterised. The choice structure, however, has to be constructed in such a way that satisfies joint decision constraints imposed on the decision makers acting in parallel. Another drawback is that the number of unique individual DAPs increases with the variation in travel pattern complexity, resulting in a large number of elemental alternatives in the choice system. Bradley and Vovsha (2005) proposed a model for joint choice of DAPs, in which all household members are considered as acting agents in the household decision-making. Pair-wise and triple-wise interactions in joint choice of DAPs were explicitly incorporated in their model which can simultaneously treat all possible combinations of individual DAPs for up to five household members. The model choice structure is again very complex and sensitive to household size and the number of basic DAPs considered, to the extent that the technical management in estimation and application of the model is an issue (Bradley and Vovsha, 2005).

It is clear from the literature that the complex nature of group decisions and interpersonal interactions has led to the use of simulations as a way of avoiding addressing model tractability. Of studies adopting a random utility approach, the agents were limited to household heads only to prevent the model structures becoming very complex so that specification constraints need to be imposed to overcome the estimation and management issues.

This paper builds on previous studies and contributes to the literature in two ways. First, it contributes a typology of joint household tours that captures various patterns of intra-household interactions in daily travel under social, spatial and resources constraints. Second, the paper offers an analytical modelling approach to incorporating intra-household

interactions into an individual tour-based mode choice model of reasonable size considering all household members as acting agents.

3. Identification of joint tour patterns

This paper identifies joint household tours as patterns of intra-household interactions and spatial-temporal constraints and incorporates these patterns into the mode choice model using home-based tour as the unit of analysis. A home-based tour is a sequence of trips starting and ending at the individual's home (Shiftan, 1998). Each trip is a member of a unique home-based tour and is referred to as a trip segment. A home-based tour is considered to be joint if any trip segment is made jointly with one or more household members. Definitions and descriptions of nine joint tour patterns, representing nine different ways of arranging household activities and travel into a home-based tour, are provided in Figure 1. Separate lines are used to represent the travel paths of each household member relevant to the tours.

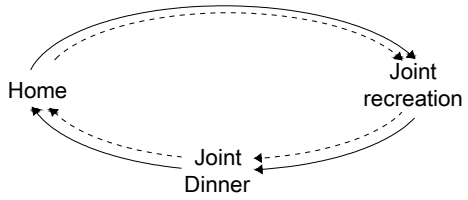
This paper identifies intra-household joint tour patterns in two stages. The first stage is to identify joint household trips from an unlinked person trip dataset, using flexibly defined matching criteria considering household identification, reported travel mode, departure and arrival times, origin and destination of trips, and the number of household members in the vehicle. In the second stage, joint tour patterns are identified by linking and matching relevant trip segments of each household member's home-based tour using a unique home-based tour identifier. This process is executed by an algorithm written in SPSS syntax.

4. Joint household travel arrangement: statistical evidence

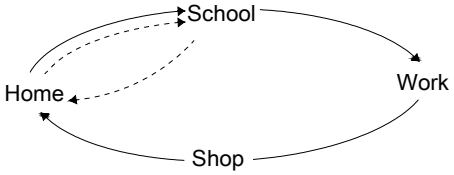
Figure 2 shows a distribution of home-based tours by the joint tour types for an average weekday in Sydney, using the Sydney household travel survey data pooling from three years: 2007/08, 2008/09, and 2009/10. After restructuring and cleaning the data, and excluding weekend travel, the three years pooled data provided 16,545 home-based tours for analysis. Segmentation analysis by tour main purpose is also provided where a tour's main purpose is assigned on a hierarchical basis with work activities as the highest priority, followed by education, maintenance and discretionary activities, adapting Stopher et al. (1996).

Joint household tours accounted for more than half of the total weekday tours in Sydney with fully joint tours representing the most important joint tour type, equal to all partially joint and mixed tours taken together. Vovsha et al. (2003) reported a similar percentage of joint tours in the two metropolitan regions of mid-Ohio and New York in the USA. Figure 2 shows that joint household tours are frequent for the three combined purposes of *education* (school and childcare), *maintenance* (shopping, personal business and serving passenger), and *discretionary* (social and recreational). In contrast, tours to work or work-related business are mostly individual. While maintenance and discretionary tours have a substantial share of fully joint travel, education tours are characterised by a high share of partially joint travel. The latter can be explained by the fact that joint travel to education is not normally followed by a joint activity, and that school and other activities such as work and serving passenger can be synchronised only for one direction (Vovsha et al., 2003). Furthermore, the jointly drop-off and pick-up pattern (J7) accounts for a high portion of education tours indicating the existence of interpersonal constraints and interactions in daily activity and travel. An example for interpersonal constraints is that an infant, who would not be left at home alone, accompanies their mother as she is driving their sibling to school. Another example is that two students, studying at the same school, are being dropped off and picked up on a same car tour.

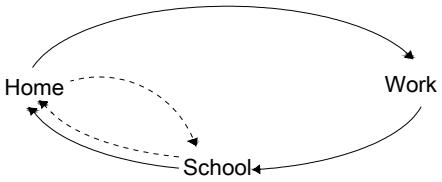
Figure 1 Typology of joint home-based tours



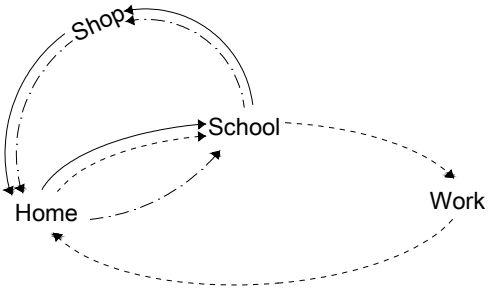
Fully joint tour (J1): a tour pattern in which two or more household members travel together on all trip segments.



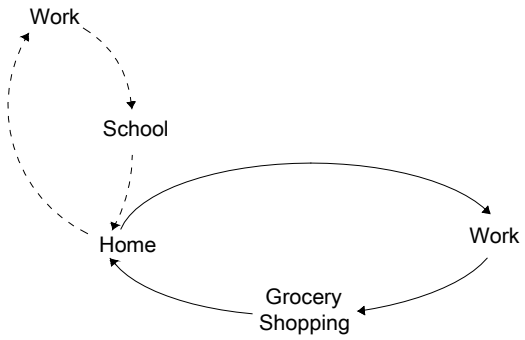
Drop-off tour (J2): a tour pattern in which two household members share rides to an activity location, then go their separate ways and return home separately.



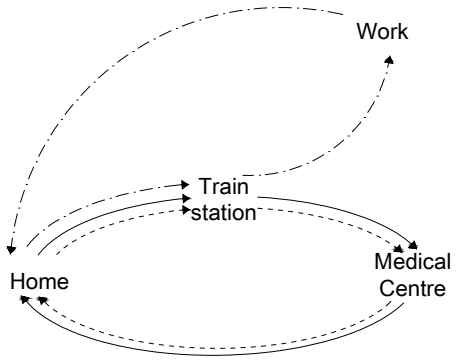
Pick-up tour (J3): a tour pattern in which two household members meet at an out-of-home activity location and return home together.



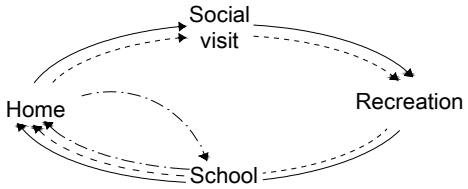
Shared rides tour (J4): a combination of J2 and J3 patterns. At least one participant to this tour pattern shares both rides (to and from home) in the same tour with the same or different household members.



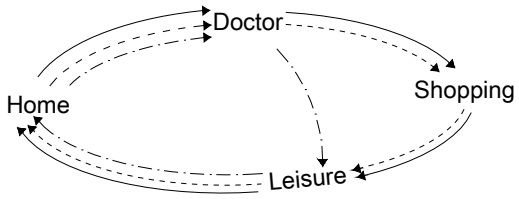
Individual tour (J9): a tour pattern without any full or partial joint travel with any other household members.



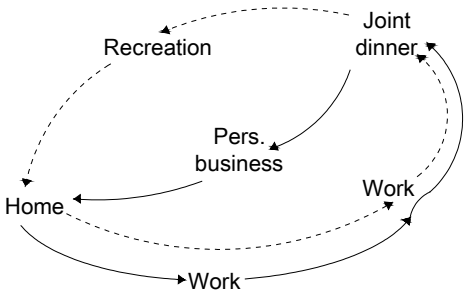
Jointly drop-off tour (J5): a combination of J1 and J2 patterns. A travel arrangement in which two household members jointly drop-off a third household member at an activity site or a train station.



Jointly pick-up tour (J6): a combination of J1 and J3 patterns. A travel arrangement where two persons make a fully joint tour and the third person joins in with them at an out-of-home activity location and shares the ride to home. All participants to this tour pattern end their home-based tours together, but not all participants start the tour jointly.



Jointly drop-off & pick-up tour (J7): a combination of J1 and J4 patterns. A joint tour pattern in which a household member is dropped off and picked up by other household members.



Joint in middle tour (J8): a joint tour pattern in which the participants travel together on some middle part of their home-based tours but leave and return home alone.

Figure 2 Distribution of home-based tours by joint tour type and tour main purpose

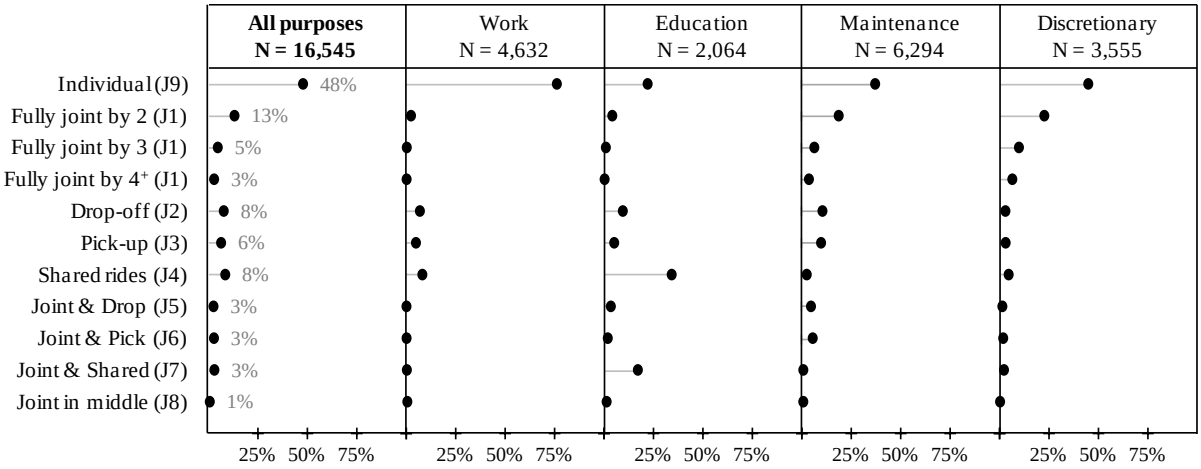
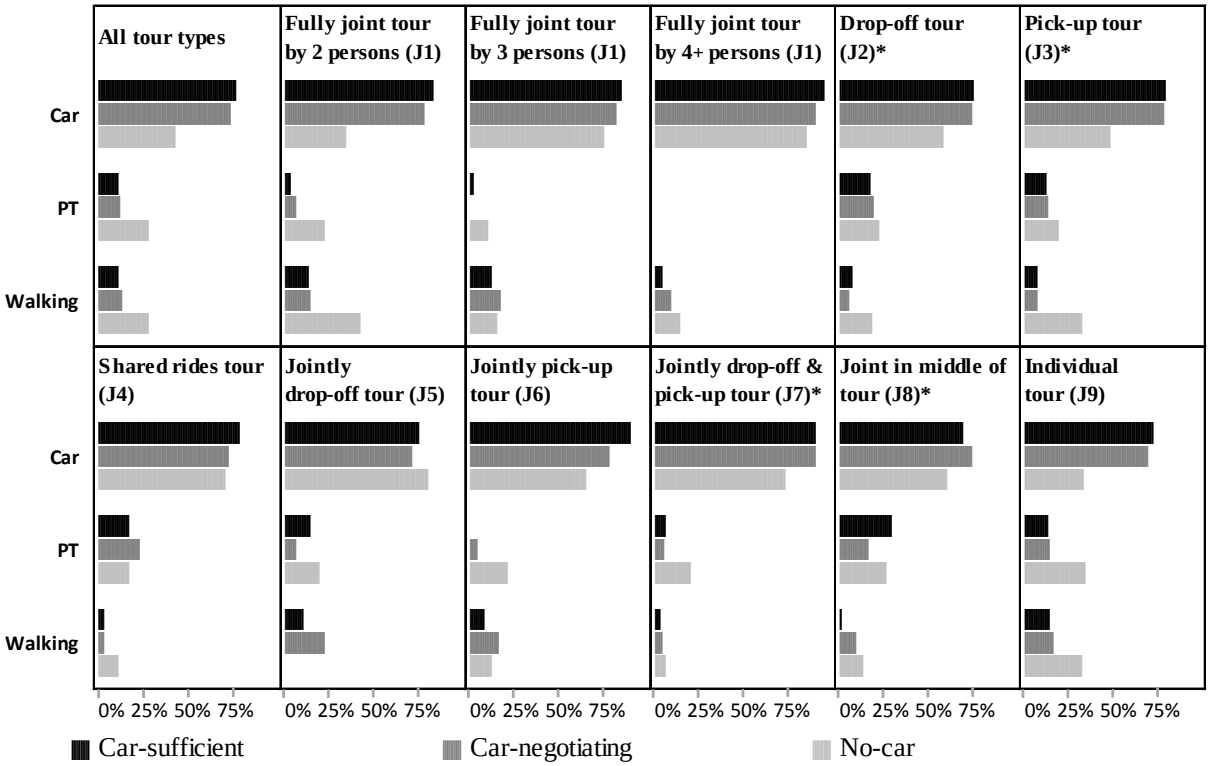


Figure 3 compares modal shares by joint tour type across households with different levels of car availability, defined in this paper as car-sufficient, car-negotiating, and no-car households. Car-negotiating households are households with fewer cars than licence holders (drivers) and car-sufficient households are households with at least as many cars in the household as licence holders. Overall, households with a lower level of car availability use PT more and walk more. Modal shares are different significantly between no-car households and car-owning households but less so between car-negotiating households and car-sufficient households.

Figure 3 Modal shares by joint tour type by household car ownership



* differences in modal share between car-negotiating and car-sufficient households are not significant at the 5% level

Holding household car ownership constant, fully joint tours are less likely than partially joint tours to be made by PT although this is less true for no-car households who are captive users. This finding suggests that PT is not as suitable for fully joint household travel and requires drop-offs and/or pick-ups at either end of the tour. This would be to some extent

explained by the role of intra-household interactions under household resource constraints (e.g., the household car needs to be back home for a housekeeper running household errands) as well as time and space constraints (e.g., train stations are too far to walk, locations of passengers' activities are too far to serve directly) in household travel mode choice.

Intra-household interactions in PT use are explored by comparing individual tours (J9) with tours involving joint travel at either end (J2, J3, and J4) in terms of access mode and access distance. In terms of terminology, for convenience those individual PT tours which have car access at each end are referred to as park and ride (P&R) to contrast PT tours with drop-off/pick-up being made by car being referred to as kiss and ride (K&R). Table 1 shows that three-quarters of individual PT tours are accessed by walk while 64 percent of PT tours are K&R. Also, the differences in median walking access distance between PT tours with and without drop-offs/pick-ups are insignificant, suggesting that the spatial separation between home and PT nodes is not a factor motivating intra-household interactions in PT use with walk access and that the motivation could be companionship. For PT tours with car access, P&R had a far longer access distance than K&R. This may be a result of inter-personal constraints which lead to a shorter access distance for K&R (e.g., a car commuter en route to work drops off his partner at a train station closer to home than her most desired station which otherwise detours to his journey). Similarly, temporal and spatial constraints may make K&R less attractive economically than P&R, resulting in a longer access distance for P&R.

Table 1 Access distance (in km) by access mode and joint tour type

Access distance in km	Individual PT tours, accessed by		PT tours with drop-offs/pick-ups by	
	Walking	Car (P&R)	Walking	Car (K&R)
Median	0.65	4.75	0.64	2.95
75 percentiles	1.03	9.12	1.07	5.91
Sample	1,136	245	230	461
Access mode share [a]	*74.7%*	*16.1%*	*32.1%*	*64.4%*

[a] *Total shares do not equal 100% because access trips shorter than 100m are not recorded by the Sydney HTS.*

The efficient use of limited household resources is another factor which could motivate intra-household interactions in PT use as *ceteris paribus,* car-negotiating households are more likely than car-sufficient households to make K&R (77% vs. 58%) given a PT tour with car access. This is further reinforced when licence status of K&R users is taken into account. K&R users from car-negotiating households are more likely than those from car-sufficient households to be licence holders (65% vs. 42%), suggesting that car availability plays an important role in travel arrangement of car-negotiating households. It should be noted that there are clear differences between car-negotiating households and car-sufficient households in the use of PT. The use of K&R among licensed members of car-negotiating households may be motivated by household resource constraints and economic factors while the motivation for the use of K&R among licensed members of car-sufficient households must be mainly economic factors. For K&R users without a licence, intra-household interactions are motivated by time and space constraints as well as altruism.

5. Estimation results

5.1. Structure of joint household decision – individual mode choice model

The construction of the choice structure for modelling proceeds from the identification of joint household tour patterns and tour main travel modes. Consistent with the literature, this study assumes that for tours with multiple modes, not all modes are the main ones for the tour. Rather, a hierarchy is adopted to identify the main mode which is the one most likely to form the longest part of the home-based tour as this is assumed to be a controlling factor for the

person arranging his or her travel. Public transport (PT) is highest in this adopted hierarchy, followed by car and walking.

The choice structure considers all possible combinations of joint household tour types and tour main modes where coordination of household members' activities and travel is considered as intra-household interactions. Conditional upon the chosen joint household tours, each household member chooses the travel mode to maximise their own utility. This paper incorporates intra-household interactions into a tour-based mode choice model by the specification of a nested logit model with the upper-level capturing joint household decisions and the lower level representing individual's choice of travel mode among PT, car, and walking. The observed choice of travel mode for each home-based tour is the dependent variable in this model. Thus, this is not a group decision model *per se,* but rather an individual decision model with household decisions being explicitly incorporated.

The model formally includes 30 alternatives that correspond to three tour main modes by ten joint tour types with the fully joint tour pattern (J1) being further split into two separate types: fully joint tour by two household members and by 3^+ household members. Considering three household members as a maximum number in modelling is justified by reference to the empirical data as Figure 2 shows only small joint household tour patterns with 4+ participants. It should be noted that not all joint household tour types are available to each household. Lone-person households only have three alternatives of travel mode corresponding to the individual tour pattern (J9) in their choice set and two-person households have 18 alternatives corresponding to six joint travel patterns (those with a maximum of two participants) to choose from. Households with 3^+ members have all alternatives in their choice set.

The model specification examines the effects of household and individual characteristics alongside their interaction terms, tour attributes, and transport-related fringe benefits on the utility of joint tour patterns and travel mode alternatives. The model is estimated using NLOGIT 5.0 and the estimation results are shown in Tables 2 – 4. The following sections highlight the more important and interesting results.

5.2. Model fit statistics and inclusive value parameters

Table 2 shows the model fit statistics and inclusive value parameters for the joint tour pattern nests. The final model, including 111 parameters for 30 alternatives, compares well with other models dealing with intra-household interactions (e.g., Bradley and Vovsha, 2005; Gliebe and Koppelman, 2005). McFadden's Rho-squared is 0.403 indicating a relative good fit to the data. The model found the correlation in the unobserved component of the mode choice alternatives within five joint tour pattern nests whose inclusive value parameters are significantly smaller than one and so the inclusive value parameters for the remaining nests which were not significantly smaller than one are fixed to one, so as to keep the model consistent with random utility theory.

Table 2 Summary statistics and inclusive value parameters

Summary statistics		
Number of observations	16,545	
Number of parameters	111	
Log likelihood at convergence	-33,614	
Log likelihood at market shares	-38,932	
Log likelihood at zeros	-56,273	
Mc-Fadden R-squared (vs. zeros)	0.403	
Mc-Fadden R-squared (vs. constants)	0.137	
Inclusive value parameters	**Coefficient**	**t-ratio**
Individual tour (J9)	0.188	2.93
Drop-off tour (J2)	1	fixed
Pick-up tour (J3)	0.606	7.66
Shared ride tour (J4)	1	fixed
Fully joint tour by 2 members (J1)	0.528	5.34
Fully joint tour by 3+ members (J1)	0.285	3.43
Jointly drop-off tour (J5)	1	fixed
Jointly pick-up tour (J6)	0.134	2.62
Jointly drop-off & pick-up tour (J7)	1	fixed
Joint in the middle tour (J8)	1	fixed

5.3. Generation of joint household tours

Table 3 shows the parameter estimates for variables affecting the propensity for household members to incorporate joint activities and travel into home-based tours. As expected, maintenance and discretionary activities are significantly more likely than subsistence activities to be made jointly by household members. Education tours have a greater propensity to be served by other household members and individuals making education tours are more likely to be dropped off than to be picked up.

The generation of a particular joint tour type is found to be highly associated with person type (see also Vovsha et al., 2003). Preschool children, up to five years old, have a significantly greater propensity to accompany adult household members giving drop-offs/pick-ups to other household members. When travelling to participate in an activity, preschool children are both dropped off and picked up, if they are not fully accompanied. Similarly, elementary and secondary students are more likely to receive rides but they also join with adult household members giving rides to another household member. More interestingly, the results indicate that mothers in households with preschool children and pre-driving children have a significantly greater propensity to make jointly drop-off tours (J6) but a lower propensity to make fully joint tours by 3+ household members (J1). Thus, gender differences in household activity-travel arrangements are evident, with mothers being primary care givers for children, especially very young ones (see Gliebe and Koppelman, 2005 for a similar finding).

Table 3 Estimation results for joint tour type generation*

Variable	Indivi-dual tour (J9)	Drop off tour (J2)	Pick up tour (J3)	Shared ride tour (J4)	Fully joint tour by 2 members (J1)	Fully joint tour by 3+ members (J1)	Jointly drop off tour (J5)	Jointly pick-up tour (J6)	Jointly drop-off & pick-up (J7)	Joint in middle tour (J8)
Education tour		0.969	0.507				-1.005			
Maintenance tour		1.128	1.290		2.418	3.336				
Discretionary tour					2.504	3.844	-0.675			-0.855
Children aged up to 5	-3.422			0.730				1.338	1.297	
Children aged 6-10				1.870					3.052	
Children aged 11-15	-1.302			0.828					1.297	
Mother of mix aged children (aged 0-5 & 6-16)						-0.184		0.810		
Constant	4.513	-0.704	0.800	1.195	1.495	0.300†	-0.182†	1.478	-3.297	

**All parameters are significant at the 5% level or less unless otherwise indicated.*
† Not significant at the 10% level.

5.4. Mode choice of different joint tour types

Parameter estimates for variables affecting individuals' mode choices of all joint tour patterns are shown in Table 4. Members of no-car households use PT and walk significantly more than those of car-owning households. The coefficients related to the effect of car-negotiating households on the propensity of making PT tours involving drop-off/pick-up are significantly positive, indicating that the limited car availability is the motivation for shared ride arrangements and PT use as a substituting mode to the car. For jointly drop-off tours (J5), the negative effect of the car-negotiating household variable on the utility of PT suggests that drop-off providers are more likely to use car and walking than PT.

Members of high income households are less likely to make fully joint tours by PT but are more likely to generate PT tours with shared rides to/from home. Given that high income households will include a high proportion of dual-earner couples, these results might be expected on weekday activity-travel arrangements because working tours are more likely to be PT-based and mostly independent. Other household characteristics affecting individual's mode choice of some joint tour patterns include the number and mix of children at different ages. The results indicate that as the number of children up to 15 years old in the household increases, car use increases for the four tour patterns involving drop-off but decreases for fully joint tours by two household members.

Students aged 16^{+} years old have a significantly greater propensity to make PT tours with or without drop-off/pick-up and a lower propensity to make fully joint car tours. This might be expected due to their busy activity agenda on weekday, less involvement in childcare, and less reliance on adult household members to participate in individual activities. Having a driving licence increases the propensity of making drop-off tours and pick-up tours (J2 and J3) but decreases the propensity of undertaking both drop-off and pick-up in the same tour (J4 and J7). These results suggest that, *ceteris paribus*, licence holders are significantly less likely to undertake both drop-off and pick-up in one car tour than to return home in between the rides, forming two separate tours.

Tour complexity, represented by the number of destinations visited and the number of secondary activities (i.e., activities sharing a destination with others), significantly influences the mode choice. Generally, as the number of destinations chained into a tour increases, PT use decreases while car use increases; in contrast, the more activities sharing destinations with others is chained into a tour, the more likely PT is used. The effect of tour complexity on walking is similar to that on PT, albeit less significant.

Finally, the propensity to use PT is strongly linked to the type of transport-related fringe benefits provided to the worker. The probability of generating PT tours increases if PT fares are provided or if the worker has flexibility at work; conversely, if benefits favour the running of a car, this significantly reduces the use of PT. The effect of transport-related fringe benefits on the choice of travel mode is limited to individual tours only.

6. Conclusions and discussion

This paper has explored ways in which household members cooperate in the scheduling of joint activities and shared rides into their home-based tours. To this end, a typology of joint household tours is used that allows a modelling approach to be developed which explicitly incorporates intra-household interactions through their joint choice of tour patterns. Intra-household interactions in household activity and travel arrangements are evidenced by the prevalence of joint household travel which accounts for more than 50 percent of weekday home-based tours in Sydney. Joint household travel is found to be motivated by resource limitation (i.e., the unavailability of household cars for all household drivers) and social constraints (i.e., very young children who do not stay home alone). In addition, mode choices of different joint tour patterns are influenced by household and individual characteristics, tour attributes, and transport-related fringe benefits.

Table 4 Estimation results for mode choice of all joint tour types*

Variable	Indivi-dual tour (J9)	Drop-off tour (J2)	Pick-up tour (J3)	Shared ride tour (J4)	Fully joint tour by 2 members (J1)	Fully joint tour by 3+ members (J1)	Jointly drop-off tour (J5)	Jointly pick-up tour (J6)	Jointly drop-off & pick-up (J7)	Joint in middle tour (J8)
Public transport										
No-car household	0.350	0.350	0.350	0.350	1.078	0.721		0.350	0.350	
Car-negotiating household		0.188	0.188	0.339			-0.668§			
Household income > AS$ 67,600		0.478		0.410	-0.542	-0.542				
# Children aged 0-5				-0.722						
# Children aged 6-15					0.253					
Student aged 16+	0.105	0.720	0.736							
# Destinations visited	-0.059									
# Secondary activities	0.133			0.714						
PT fare provided	0.218									
Flexible working hours	0.067									
Free parking provided	-0.213									
Fuel cost provided	-0.436									
Constant	-0.299	0.445	-0.400	-0.839	-1.575	-1.106	0.408†	-0.492	1.638	-1.022

**All parameters are significant at the 5% level or less unless otherwise indicated.*
† Not significant at the 10% level; § Not significant at the 5% level.

Table 4 (Continued) Estimation results for mode choice of all joint tour types*

Variable	Indivi-dual tour (J9)	Drop off tour (J2)	Pick up tour (J3)	Shared ride tour (J4)	Fully joint tour by 2 members (J1)	Fully joint tour by 3+ members (J1)	Jointly drop off tour (J5)	Jointly pick up tour (J6)	Jointly drop off & pick-up (J7)	Joint in middle tour (J8)
Car										
# Children aged 0-5					-0.335		0.962		0.168§	
# Children aged 6-15		0.768					1.020			
Mixed age children household				0.332					-0.457	
Household size									0.830	
Student aged 16+					-0.228	-0.228				
Licence holder		1.982	1.299	-0.769			-0.306§		-1.044	
Preschool children (aged 0-5)							0.597			
# Destinations visited		0.199		0.666			0.199		0.522	
# Secondary activities		0.504	-0.444		-0.230					
Walking										
Car-negotiating household							0.117	0.117	0.117	
Household income > AS$ 67,600	-0.120		-0.492							
# Children aged 6-15		0.701								
Mixed children household				1.142			2.209			
Preschool children (aged 0-5)							0.597			
# Destinations visited		-0.545	-0.439		-0.262	-0.262				
# Secondary activities								0.188		
Constant	-0.222	0.209†	0.382	-2.427	-0.730	-0.262	-0.607	-0.332	1.016	-2.526

**All parameters are significant at the 5% level or less unless otherwise indicated.*
† Not significant at the 10% level; § Not significant at the 5% level.

These findings have policy implications, in particular an assessment of policies for increasing public transport use by improving the level of public transport services or encouraging public transport use through the provision of financial incentives by commuters' employers. For example, while the provision of public transport fares to workers is found to increase significantly their public transport use for individual tours, this effect is not significant for any tour pattern involving joint household travel. This means that employer-based policies aiming to increase public transport use for commuting journeys through financial incentives will not significantly move workers out of their cars if they have to drop-off/pick-up their children en route to/from work. Similarly, for a scenario with lower fares for public transport, a model incorporating joint household travel as proposed in this paper would show a lower modal shift from car to public transport than a model without joint household travel. This is because using a household car for joint household travel is still cheaper than using public transport so the effect of the lower fare policy on public transport use would accrue to individual travel only. This shows the importance of including intra-household interactions into travel demand models since without these interactions, the lower fare policy would see the car mode becoming more expensive than the public transport mode for both individual and joint travel, resulting in an unrealistic high modal shift to public transport from car for the same scenario.

The results from this study emphasize the importance of segmenting the travellers and implementing transport policies accordingly. For instance, the results indicate that education is most likely to be served in both directions, and that household chauffeurs are more likely to return home in between the rides, forming two separate home-based tours. These tours are also most likely to be made by car during peak hours, adding environmental burdens and traffic congestion. Considering that school travel is regular in terms of fixed times, days and locations and the chauffeur usually has no purpose other than serving the passengers, these findings suggest a targeted market for changing mode from car to public transport. Improved school bus services may address the need of chauffeuring children to school, although it must be acknowledged that other factors may influence the choice to escort children to school, including children characteristics and parent attitudes to child safety (Vovsha and Petersen, 2004; Wen et al., 2008; Yarlagadda and Srinivasan, 2008; Sidharthan et al., 2011).

The insights gaining from a model which incorporates intra-household interactions through joint household travel would be improved if model elasticities could be derived and compared with results from other models without intra-household interactions. In addition, if land use and public transport service level data could be incorporated, this would provide additional insight into the tradeoffs among these attributes in mode choice for different joint tour patterns.

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