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The influence of parents' travel patterns, perceptions and residential self-selectivity to their children travel mode shares

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Abstract Using the UK National Travel Survey from 2002 to 2006, this paper investigates the influence of households' residential self-selectivity, parents' perceptions on accessibilities and their travel patterns on their children daily travel mode share. In doing this, this study introduces a model structure that represents the complex interactions between the parents' travel patterns, their perceptions on public transport services and their reported residential self-selectivity reasons and the children travel mode shares. This structure is analysed with structural equation modelling. The model estimation results show that parents' residential self-selectivity, parents' perceptions and satisfactions on accessibilities and their daily travel patterns significantly influence the children's daily travel mode shares. However, the effects are not uniform across household members. This study has revealed that households' residential self-selectivity behaviours have more correlations with the children's non-motorised mode shares, whilst the parents' perceptions and satisfactions on transport infrastructure and public transport service qualities have more correlations with parents' mode shares. The results also confirm that parents' non-motorised modes use in travelling is highly correlated with the children's physically active travel mode shares. However, at the same time, the results also show that the effects of mothers' car use to the children travel mode shares is more apparent than fathers'.

Keywords Children travel behaviours · Physically active travel mode participations · Parents' perceptions · Household's residential self-selectivity · Household interactions · United Kingdom National Travel Survey

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Introduction

Recently there has been an emerging body of research into children travel behaviour, including active transport to school (such as walking and bicycling), which shows that physically active children are healthier and more socially connected than children who have more sedentary lifestyle (US Department of Health and Human Service 2008; World Health Organization (WHO) 2008). Previous studies have shown that active travel is positively associated with higher daily levels of physical activity (Rosenberg et al. 2006) and higher cardiorespiratory fitness (Andersen et al. 2009). Given that healthy habits developed during adolescence may have a significant impact on the life-long health of individuals (Millstein and Litt 1990) it is very important to introduce a healthy and independent lifestyle as early as possible. Lanzendorf (2003) argued that how we grow up will influence the way we travel, including our perspectives on travel modes and our habits and Simma and Axhausen (2003) found that the use of a particular travel mode positively influences the usage of the same mode for the rest of an individual's life course, and the usage of other modes negatively.

Despite the importance of the introduction of active and independent travel[1] to an individual during their earlier life period, the rates of active transportation to school have declined dramatically over the past 30 years in many countries. Using data from the 2001 US National Household Travel Survey (NHTS) McDonald (2007) showed that 36 % of children's trips of less than one mile to school were by private car (an increase from 7 % in 1969) with the percentage of walking and bicycle trips being 55 % within that same distance (a decrease from 87 % in 1969). Similar trends have been found in Australia (van der Ploeg et al. 2008), Canada (Buliung et al. 2009) and Japan (Susilo and Waygood 2012).

In order to understand this problem, there have been studies that explored the relationships between children travel behaviours and their built environment conditions. McDonald (2008) reported that children living in neighbourhoods with higher residential density and mixed land use were more likely to walk for school travel purposes. Mitra and Buliung (2012) found that factors like travel distance, block density, signalised intersections, walking density, and schools in low-income neighbourhoods were associated with active travel. These findings are also supported by other studies, such as Lin and Chang (2010) in Taiwan, which showed that high shade-tree density and high sidewalk coverage encouraged children to walk to school independently, while large city block sizes and increased numbers of intersections discouraged children from walking to school independently.

However, whilst the built environment factors found to be important, at the same time, the previous studies (e.g. Di Guiseppi et al. 1998; Chillón et al. 2011) also highlighted the importance of including parents' perceptions in analysing children's travel pattern. Waygood and Susilo (2011) found that, despite similarity in gross domestic product (GDP) output, after socio-demographic, travel and built environment variables have been controlled, the UK and Japan have significantly different participation rates of children's active travel modes. Presumably this is due to differences in the culture and parenting system, especially the social norm and parents' responsibility in allowing children to travel independently to their school. Based on California data, Hsu and Saphores (2013) found

[1] Independent travel here means that the traveller is able to make decisions, solve the problems and develop a good judgement in relation to their travel activity, by his/her self, without being accompanied by an adult. A trip with friends and siblings is independent if no adult was indicated as a companion (e.g. World Health Organization (WHO) 2008; Waygood and Kitamura 2009).

that, among the parents who are holding equal concerns and attitudes on chauffeuring behaviours, mothers are still more likely than fathers to chauffeur their children to school. Moreover, if we put it into a household's perspective, children's transport mode to school is an integral part of the household decision-making process (Black et al. 2001) and includes many factors such as the possibility of linking the school journey with the journey to work, convenience, parental concerns about road safety, social and cultural norms (Yarlagadda and Srinivasan 2008; Grize et al. 2010). Therefore, it is important to understand the influence of parents' perceptions and their activity-travel constraints to their children travel mode choice and analyse it under one integrated decision structure. This would be the aim of this research.

Using the UK National Travel Survey (NTS), this study examines the influence of parents' and children's socio-demographic and their built environment characteristics on their daily travel mode shares and how these interact with each other in one integrated model structure. Parents' perceptions of public transport qualities and reported residential self-selectivity behaviours are also included in the analysis. Although there has been a general consensus that the denser the urban structure, particularly when locating a mix of uses in close proximity to each other, the less dependence there is on the car, Handy et al. (2005) and Moktharian and Cao (2008) argue that there is a lack of understanding of to what extent the observed behaviours are the result of the prior self-selection of residents into built environment conditions that is consistent with their predispositions towards certain travel modes and land use configurations. In-line with this, despite all the sustainable features available within the studied neighbourhoods, Susilo et al. (2012) found that the residents' reasons for moving into the newly built sustainable developments are a crucial factor that influence whether the residents will travel in a more sustainable manner than the rest of the population.

The next section describes the dataset used in this study and the profiles of the samples. Then, a descriptive analysis on the relationships of parents' perceptions and household's residential self-selection with the household members' travel patterns and mode shares are provided. An integrated model structure that includes all mentioned aspects above then is introduced and the estimation results are described. The paper is closed with a conclusion section.

Data and sample profiles

This paper draws on data from the UK NTS which provides detailed information about individuals, households and their 7-days trip engagements. The UK NTS is a series of household surveys designed to provide regular, up-to-date data on personal travel and monitor changes in travel behaviour over time. It was designed to provide a representative sample of households in Great Britain for each survey year. The sampling process was based on a stratified two-stage random probability sample of private households in Great Britain. It was first collected in 1965/1966, and it was repeated on an ad-hoc basis in 1972/1973, 1975/1976, 1978/1979, and 1985/1986. In July 1988, the NTS became a continuous survey (i.e. fieldwork was conducted on a monthly basis) with an annual set sample size of 5,040 addresses which had increased to 5,796 by 2001. In 2002 the annual set sample size increased to 15,048 addresses (Cronberg et al. 2007). In the analysis, we used data from 2002 to 2006 and focused on the traditional households with two adult members, who are assumed to be taking 'parent' roles within the household, and which also had at least with one child member. The general samples' socio-demographic profiles

and travel characteristics of the used dataset are summarized in Table 1. The total number of travellers on NTS from 2002 to 2006 is 76,362 households, whilst the number of households with two adult members and at least one child, which are the focus on the analysis, is 30,645. The fathers are dominated by the full time workers with older average age than the mothers (see Table 1 below).

As shown in Table 1, the subsamples we are focussing on (the group of households with two adults/parents member with at least one child) have children's socio-demographic profiles which are relatively similar to the rest of the NTS dataset population. On the parents' characteristics, the subsamples have a higher proportion of working parents, higher income households and parents with access to private car than the rest of the population.

Focusing only on households with two adult members and how their travel engagements vary across different sizes of cities, it is shown on Table 2 that, on average, the mothers made more trips than the fathers and their children. However, the levels of private car use between parents were comparable. Moreover, the households who live in smaller cities made more trips than those who live in bigger cities/more built up areas. Interestingly, the highest participation of cycling for children is not in the most dense areas (the biggest cities), which has the highest participation of cycling for parents, but among those who live in medium cities which have population between 25,000 and 250,000 and the highest walking proportion for children is found among children who live in cities with 10,000–25,000 residents.

Table 1 Socio-demographic profiles of the travellers from the NTS 2002–2006

	All samples	Only households with two adults member and at least one child	
The child is male	51.0 %	51.6 %	
The child is between 0 and 4 years old	30.8 %	28.0 %	
The child is between 5 and 10 years old	39.3 %	35.6 %	
The child is between 11 and 15 years old	30.0 %	36.4 %	
Number of siblings	1.1817	0.8565	
The child has access to bicycle	60.1 %	63.8 %	
		Father	Mother
The adult is less than 20 years old	1.06 %	3.3 %	0.9 %
The adult is between 20 and 29 years old	13.8 %	9.7 %	14.3 %
The adult is between 30 and 39 years old	17.1 %	43.7 %	51.7 %
The adult is between 40 and 49 years old	18.3 %	35.7 %	30.1 %
The adult is between 50 and 59 years old	16.1 %	6.8 %	2.7 %
The adult is 60 years old or above	0.37 %	0.8 %	0.3 %
The adult is a full time worker	44.0 %	87.8 %	27.9 %
The adult is a part time worker	14.5 %	3.7 %	43.4 %
The adult has full car driving license	70.7 %	90.1 %	82.4 %
Low income household (less than 25,000 GBP)	44.2 %	31.0 %	
Med income household (25,000–50,000 GBP)	37.3 %	45.6 %	
High income household (50,000 GBP or higher)	18.5 %	23.3 %	
N (number of households)	76,362	30,645	

Table 2 Household members' percentage of mode share by regional locations

Type of area	Children's average percentage of daily mode share					Father's average percentage of daily mode share					Mother's average percentage of daily mode share				
	On foot	Cycle	Car	PT	Total trips	On foot	Cycle	Car	PT	Total trips	On foot	Cycle	Car	PT	Total trips
London Boroughs	15.8	1.4	64.0	17.2	2.56	7.8	3.5	59.9	27.6	3.09	12.3	1.1	65.7	20.7	3.60
Metropolitan built-up areas	16.3	1.3	69.6	11.1	2.78	7.9	1.7	78.2	10.8	3.44	11.9	0.3	76.7	10.9	3.99
Other urban over 250,000	14.6	1.8	74.7	7.5	2.82	7.3	2.8	80.0	8.1	3.43	11.8	0.8	79.9	6.8	4.12
Urban, between 25,000 and 250,000	14.9	2.4	74.0	6.9	2.85	7.8	2.7	80.6	7.1	3.44	11.5	1.0	80.7	6.3	4.03
Urban between 10,000 and 25,000	19.0	2.2	71.4	5.2	2.87	7.6	3.0	83.4	4.4	3.52	13.3	0.8	81.8	3.8	4.08
Urban over 3,000 to 10,000	13.4	1.9	74.2	7.3	2.80	5.9	2.3	83.4	6.7	3.45	9.2	0.6	86.0	4.1	4.17
Rural	9.0	3.1	75.6	7.8	2.87	4.5	1.9	86.6	5.2	3.43	7.5	1.2	87.8	2.8	4.06
Average	14.7	2.1	72.5	8.5	2.81	7.1	2.6	79.4	9.3	3.41	11.2	0.8	80.0	7.6	4.02

PT public transport; statistical *t* test has been used to confirm that the distribution of father's number of trips is significantly different than those of mother and children

The influence of parents' perceptions and residential self-selections

The descriptive analysis on the influence of parents' perceptions on the local public transport quality and residential self-selections to the households' mode shares are shown in Tables 3 and 4, respectively. It is important to note here that every household has only one set of responses on their perception of public transport quality and residential self-selection, which is likely from a joint response from both parents. The parents' perceptions that were collected within the given NTS dataset were their perceptions on the quality of the road transport infrastructure and public transport (PT) services within their neighbourhood. The parents were asked to evaluate on a scale of 1–5 (very satisfied/very frequent to very dissatisfied/infrequent): (1) the overall satisfaction with the existing bus service, (2) the frequency of the existing bus service, (3) the reliability of the bus service, (4) the frequency of rail and other public transport services, (5) the reliability of rail and other public transport services, (6) the quality of local pavement conditions, and (7) the cycle path. Further, the parents (adult household members) were also asked the reason they moved to the neighbourhood. They were asked whether they moved to the existing location because of looking for (1) a better neighbourhood, (2) better public transport, (3) a larger or better house/flat, (4) closer to work/school, (5) closer to family/friends, (6) closer to shops/leisure facilities, (7) a smaller or cheaper house/flat, (8) change of employment, (9) moved in/split up with partner, (10) wanted to buy, (11) to live independently, or (12) any other reasons. To test the effect of households' residential self-selections (the reasons why they choose to live in a particular neighbourhood), the relationships between the options of 1–8 against their existing travel pattern and travel mode choices were examined further and special dummies were created and integrated into the model structure.

Table 3 shows that the household groups in which the parents had good bus service satisfaction and positive perceptions on bus frequency and service reliability had higher proportions of parents' non-motorised and public transport modes and their children walking trips than the ones who were dissatisfied with or had negative perceptions of the bus services. At the same time, the parents who had a positive perception of the quality of the local pavements drove private car and cycled more than their counterparts.

The household groups who had positive perceptions on rail's and other public transport modes' frequency and reliability had higher proportions of public transport use and lower private car use than their counterparts. But the effects were relatively small compared to the effects of good perceptions of bus services.

The children and their parents who come from household groups with a positive perception in cycle path quality had a higher cycling participation than their counterparts. The parents from this group also had a lower car use than the ones who did not have good appreciation of the quality of the existing cycle path, but not for the children.

Unlike the influence of parents' perceptions, the influences of residential self-selectivity reasons are less uniform across household members (see Table 4). For example, the children and the fathers of households who moved to the location because of looking for a better neighbourhood or a larger house/flat had a higher proportion of car use than their counterparts, whilst for the mothers of the household, they drove less. Presumably it is because of the *trade-off* and *decision priorities* mechanism among household members. The mothers who moved to the location because they wanted to be closer to work or school places had a lower proportion of private car use than their counterparts, but that is not necessarily the case for the children and the fathers.

Table 3 The proportions of children and parents' travel mode shares by parent perceptions

Parents' perceptions of the transport infrastructure and public transport (PT) services		Children's percentage of mode share					Father's percentage of mode share					Mother's percentage of mode share				
		On foot	Cycle	Car	PT	No. of trips	On foot	Cycle	Car	PT	No. of trips	On foot	Cycle	Car	PT	No. of trips
Has a good satisfaction level with bus service	No	14.0	2.1	73.9	7.7	2.82	6.5	2.5	80.7	8.7	3.42	10.5	0.8	81.7	6.6	4.07
	Yes	18.6	2.0	64.9	12.4	2.75	10.3	3.0	73.0	12.2	3.38	14.9	1.2	71.1	12.5	3.75
Considers there to be a very frequent or frequent bus service	No	13.8	2.1	74.3	7.5	2.81	6.3	2.3	81.4	8.6	3.41	10.3	0.8	82.3	6.2	4.07
	Yes	17.0	2.1	67.8	10.9	2.78	9.2	3.4	74.5	11.0	3.43	13.5	1.0	74.3	10.9	3.88
Considers there to be a very reliable or reliable bus service	No	13.8	2.1	74.4	7.5	2.82	6.3	2.3	81.2	8.6	3.42	10.3	0.7	82.2	6.3	4.07
	Yes	17.0	1.9	67.7	10.9	2.78	9.1	3.3	75.0	10.8	3.40	13.4	1.1	74.6	10.7	3.90
Considers there to be a very frequent or frequent rail and other PT services	No	14.6	2.1	72.6	8.4	2.80	6.7	2.5	81.0	8.0	3.42	11.1	0.8	80.5	7.1	4.00
	Yes	15.0	1.9	72.2	8.7	2.81	8.1	2.9	75.4	12.3	3.39	11.5	0.8	78.7	8.8	4.07
Considers there to be a very reliable or reliable rail and other PT service	No	14.8	2.0	72.7	8.3	2.80	6.9	2.6	80.7	8.2	3.42	11.2	0.8	80.3	7.2	4.00
	Yes	14.6	2.1	72.0	8.8	2.81	7.8	2.7	76.1	12.0	3.38	11.2	0.8	79.1	8.7	4.07
Considers there to be good local pavement conditions	No	14.8	2.0	72.2	8.6	2.80	7.2	2.5	79.4	9.3	3.41	11.4	0.8	79.7	7.6	4.01
	Yes	14.5	2.2	73.8	7.7	2.83	6.8	2.9	79.2	9.3	3.43	10.1	1.1	81.2	7.5	4.06
Considers there to be very good or good cycle paths	No	14.7	2.0	72.4	8.6	2.80	7.1	2.5	79.5	9.3	3.41	11.2	0.8	80.0	7.6	4.01
	Yes	15.1	2.4	73.5	7.6	2.87	7.3	3.3	78.3	9.3	3.46	11.4	1.0	79.7	7.8	4.10

PT public transport

Table 4 The proportions of children and parents' travel mode shares by reported residential self-selection

Household residential reported self-selection behaviour		Children's percentage of mode share					Father's percentage of mode share					Mother's percentage of mode share				
		On foot	Cycle	Car	PT	No. of trips	On foot	Cycle	Car	PT	No. of trips	On foot	Cycle	Car	PT	No. of trips
Move to location because looking a better neighbourhood	No	14.8	2.1	72.3	8.5	2.81	7.1	2.7	79.3	9.2	3.42	11.2	0.8	80.0	7.5	4.03
	Yes	13.8	1.5	75.0	8.4	2.81	7.0	1.1	80.4	10.3	3.24	11.3	0.6	78.9	8.8	3.85
Move to location because want to live closer to work or school	No	14.8	2.1	72.4	8.5	2.81	7.1	2.6	79.5	9.2	3.41	11.2	0.8	80.1	7.5	4.02
	Yes	14.0	1.8	73.9	8.7	2.81	7.3	1.4	77.5	12.7	3.32	10.9	0.9	76.8	11.4	3.88
Move to location because want to be closer to shops and leisure facilities	No	14.7	2.1	72.5	8.5	2.81	7.1	2.6	79.4	9.3	3.41	11.2	0.8	80.0	7.6	4.02
	Yes	17.7	1.4	71.2	9.2	2.78	8.4	3.3	73.4	13.0	3.33	13.6	1.0	74.2	11.3	3.46
Move to location because looking for a better public transport service	No	14.7	2.1	72.5	8.4	2.81	7.1	2.6	79.5	9.2	3.41	11.2	0.8	80.1	7.5	4.02
	Yes	19.0	0.0	62.0	17.3	2.80	10.3	0.0	58.8	31.0	3.20	15.6	0.3	55.5	28.3	3.48
Move to location because of looking for a larger/better house/flat	No	14.8	2.1	72.2	8.5	2.81	7.2	2.6	79.3	9.2	3.41	11.2	0.9	80.1	7.5	4.03
	Yes	13.9	1.3	75.6	7.9	2.82	6.5	2.1	80.0	10.0	3.42	11.2	0.5	79.3	8.8	3.89

PT public transport

Nevertheless, all household members who belong to the groups who moved to the location because of looking for a better public transport service had a lower car use and higher participation in public transport use and walking than households who moved to the location because of any other reasons.

Overall, the descriptive descriptions on Tables 3 and 4 show that parents' perceptions and household's residential self-selectivity behaviours play important roles in influencing parents' and children's daily travel mode shares. However, at the same time, these effects and modal shares are also the result of interactions between household members' travel patterns, constraints and commitments. It is important to detangle these complex interactions to really understand which decisions or perceptions influence particular behaviours and which ones are influencing other behaviours. This would help us to design and target a policy effective in promoting more physically active modes among children. This complexity is addressed in the next following section which analyses the influence of parents' perceptions and their activity-travel constraints on their children travel mode choice under one integrated decision structure.

The proposed model structure

To analyse the complex interactions between parents' and children travel choices, perceptions and residential self-selectivity, this study introduces a model structure that represents relationships between the parents' travel patterns, their perceptions on the existing public transport and infrastructure conditions and their reported residential self-selectivity reasons with the children travel mode shares.

In composing and estimating a complex model structure as mentioned above, several analysis methodologies can be applied. One of the most advanced approaches in modelling individual choices is a hybrid choice model (e.g. Walker 2001; Ben-Akiva et al. 2002) which has a capability in incorporating latent variables in the analyses. However, the analyses in this paper are involving several discrete choice outcomes and a considerable number of endogenous relationships. Thus, it is still computationally difficult. Since the goal of this study is to reveal the complex relationship between parents' and children's travel variables, but not forecasting, structural equations modelling (SEM) is considered sufficient and is applied where all travel variables are modelled as linear equations. SEM is a powerful method for analysis of multiple simultaneous causal relationships among endogenous variables and between endogenous and exogenous variables (Golob 2003; De Abreu e Silva et al. 2012). Compared to hybrid choice models, SEM has the advantage of being able to consider a fairly large number of endogeneity relationships as well as latent variables, although loses precision due to the assumption of linear equations.

The model structure proposed in this study can be seen on Fig. 1 below. Indeed, trends, social norms and peers' influence should also play a role in individual decision making processes and mode shares (e.g. Eriksson et al. 2013). However, due to the data limitation, these factors cannot be included here. In this study a child is defined as an individual who is less than 15 years old. For the sake of simplicity, in this paper, each child within a household is estimated separately. Combining the patterns between children within the same household would be the next step of this study.

Therefore, assuming: H is the vector of variables representing the household residential location, such as built environment density, and accessibility to public transport

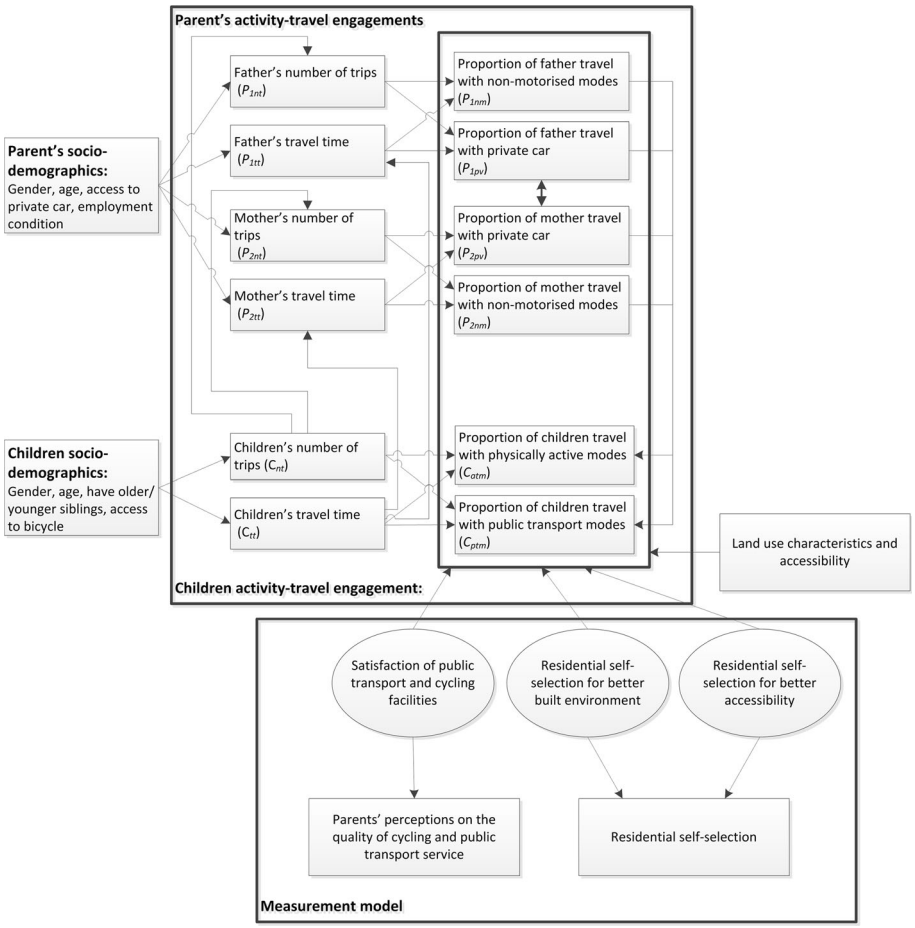

Fig. 1 The proposed model structure

and basic amenities, P is the vector of parent's socio-demographic attributes, and K is the vector of children's socio-demographic attributes, and R is the parents' perception and households' reported residential self-selectivity reasons, F is the latent variables associated with parents' perception and households' reported residential self-selectivity reasons and let P_{1nt} is the total number of father's daily trips, P_{2nt} is the total number of mother's daily trips, P_{1tt} is the father's total travel time (in min), P_{2tt} is the mother's total travel time (in min), C_{nt} is the number of children's daily trips, C_{tt} is the children's total travel time (in min), P_{1nm} is the proportion of father's non-motorised trips, P_{1pv} is the proportion of father's private car trips, P_{2nm} is the proportion of mother's non-motorised trips, P_{2pv} is the proportion of mother's private car trips, C_{atm} is the proportion of children's walking and cycling trips, and C_{ptm} is the proportion of children's public transport trips.

Then the model system on Fig. 1 may be formulated in general form as follows:

$$\begin{cases} P_{1nt} = f_{P_{1nt}}(\text{father's } P_1, C_{nt}); P_{2nt} = f_{P_{1nt}}(\text{mother's } P_2, C_{nt}) \\ P_{1tt} = f_{P_{1nt}}(\text{father's } P_1, C_{tt}); P_{2tt} = f_{P_{2tt}}(\text{mother's } P_2, C_{tt}) \\ C_{nt} = f_{C_{nt}}(\text{Child's characteristics, } K); C_{tt} = f_{C_{tt}}(\text{Child's characteristics, } K) \\ P_{1nm} = f_{P_{1nm}}(P_{1nt}, P_{1tt}, H, F); P_{2nm} = f_{P_{2nm}}(P_{2nt}, P_{2tt}, H, F) \\ P_{1pv} = f_{P_{1pv}}(P_{1nt}, P_{1tt}, H, F, P_{2pv}); P_{2pv} = f_{P_{2pv}}(P_{2nt}, P_{2tt}, H, F, P_{1pv}) \\ C_{atm} = f_{C_{ntc}}(C_{nt}, C_{tt}, P_{1nm}, P_{2nm}, P_{1pv}, P_{2pv}, H, F) \\ C_{ptm} = f_{C_{ptm}}(C_{nt}, C_{tt}, P_{1nm}, P_{2nm}, P_{1pv}, P_{2pv}, H, F) \\ R = f_R(F) \end{cases} \quad (1)$$

It is assumed in this model system that parents' daily trip parameters, like the total number of trips, P_{int}, and total travel time, P_{itt}, act as explanatory variables that influences the share of parents' walking and cycling trips, P_{inm}, and private car trips, P_{ipv}, which together with children's number of trips, C_{nt}, and their total travel time, C_{tt}, will influence the proportions of children walking and cycling trips, C_{atm}, and their public transport use, C_{ptm}. Meanwhile, children's number of trips, C_{nt}, and travel time, C_{tt}, are influencing parents' number of trips, P_{int}, and travel time, P_{itt}, to reflect the parents' travel burdens that are imposed by children's travel needs. All of these mode share variables are also influenced by the latent variables, F, that reflect parents' perception of the quality of cycling and public transport service and reported households' residential self-selection behaviours.

The latent variables are measure by ten questions that are related to parents' satisfactions on the quality of cycling and public transport service and parents' residential self-selection. Three latent variables were extracted through an exploratory factor analysis. Five variables that represent parents' perceptions of and satisfactions with transport infrastructure and public transport services are associated with one latent variable, while three residential self-selectivity variables ("Move to location because looking a better neighbourhood", "Move to location because of looking for a larger/better house/flat", "Move to location because want to live closer to work or school") are associated with a latent variable that represents the residential self-selectivity for better built environment. The other two residential self-selectivity variables ("The household moved to the neighbourhood because of looking for a better public transport service", "The household moved to the neighbourhood because they want to be closer to shops and leisure facilities") are associated with a latent variable that represents the residential self-selectivity for better accessibility. It is also assumed in this model structure that the fathers' private car use behaviour will influence the mothers' private car use and vice versa. Thus, the SEM function that used can be defined as:

$$y = By + \Gamma x + \zeta \quad (2)$$

where B is p × p matrix of coefficients, represent the direct effects of endogenous variables on other endogenous variables. Whilst, Γ is p × q matrix coefficients, represent the direct effect of exogenous variables. Then, y is p × 1 vector of endogenous variables, x is p × 1 vector of exogenous variables and ζ is p × 1 vector errors in the equations with standard assumption that ζ is uncorrelated with x. Since the data contains multiday observations from a given household, a sub dataset was drawn from the full dataset such that only one observation was randomly drawn from the observations of the given household, and the sub dataset was used for the SEM estimation.

The estimated model results

The estimation results can be seen at Table 5 below. It is also shown that the model has a good fit. The $\chi^2/df = 3.81$, The RMSEA is 0.023 and the GFI is 0.988. The final value of discrepancy function is 0.310 while the independent model is 8.173. The reference variables used in this analysis are: female, parents who are younger than 20 years old and older than 60 years old, part-timer and unemployed parents, parents who do not have driving license, children who are younger than 5 years old, low income households (which the annual income less than 25,000 GBP), urban areas in which the population is less than 10,000 people and parents and households whose preferences and residential self-selectivity reasons. An explanatory variable would be considered to significantly associate with the dependent variable at a = 10 % if the absolute t-statistic value (shown on the bracket of Table 5) equals or is larger than 1.64. The magnitude and direction of influence (e.g. positively/negatively influence the dependent variable) are shown by the value and sign of the coefficient estimates. For example, on Table 5, the estimated coefficient for the latent variable: parents 'Satisfaction of public transport and cycling facilities' variable to the proportion of father using non-motorised mode (C_{atm}) is 0.235, with t stats = 3.73. This means that the latent factor that represents the parents' satisfaction of public transport and cycling facilities is significantly and positively correlated with the proportion of father using non-motorised modes. More detailed discussions of the estimation results are described below.

The interactions of travel patterns between parents

The model results show that fathers' number of trips peaks when fathers are 50–59 years old. The differences between age groups, however, are insignificant when it comes to mothers. Both parents who work full time make a significantly smaller number of trips than their counterparts. Interestingly whereas fathers who are full-time workers also spend more time in travelling, and mothers who are working full-time spent more travel time than their counterparts but the magnitude is much less than that of the fathers. Presumably this is because mothers may have tighter time constraints in doing out-of-home activity than fathers (Susilo and Avineri 2014).

As expected, both parents who have access to private car made more trips than others and the more trips they make the higher the proportion of their private car use. Furthermore, both fathers and mothers who have the access to the private car spend longer travel time than others; whereas the magnitude is much less for mothers compared to fathers.

The model shows a positive correlation between the proportions of car use of fathers with mothers and vice versa, which indicates the habit of using private car of one of the adult household members is positively correlated with the habit of using of private car by another adult member within the household.

The model results also indicate that parents' numbers of trips are negatively influenced by children's numbers of trips. The magnitudes of such influences are more significant on mothers than on fathers. Meanwhile, parents' total travel time is not significantly influenced by children's total travel time. These indicate significant travel burdens introduced from children, mainly the children accompany trips, especially for mothers.

Table 5 Estimation results

	Father				Mother				Child			
	No. of trips (P_{1nt})	Total TT (min) (P_{1tt})	Prop of car use (P_{1pv})	Prop of NMT (P_{1nm})	No. of trips (P_{2nt})	Total TT (min) (P_{2tt})	Prop of car use (P_{2pv})	Prop of NMT (P_{2nm})	No. of trips (C_{nt})	Total TT (min) (C_{tt})	Prop of PT (C_{ptm})	Prop of NMT (C_{atm})
The respective parent is between 20 and 29 years old	0.038 (0.32)	1.136 (1.79)	–	–	0.081 (0.46)	1.344 (1.66)	–	–	–	–	–	–
The respective parent is between 30 and 39 years old	0.030 (0.27)	0.747 (1.66)	–	–	0.059 (0.73)	1.606 (1.91)	–	–	–	–	–	–
The respective parent is between 40 and 49 years old	0.124 (1.09)	0.481 (0.90)	–	–	0.063 (0.36)	1.399 (1.73)	–	–	–	–	–	–
The respective parent is between 50 and 59 years old	0.403 (3.05)	0.711 (1.00)	–	–	−0.016 (−0.08)	1.204 (1.35)	–	–	–	–	–	–
The respective parent is a full time worker	−0.376 (−5.61)	1.340 (2.05)	–	–	−0.198 (−4.00)	0.770 (2.35)	–	–	–	–	–	–
The respective parent has full car driving license	0.778 (9.89)	9.312 (3.57)	–	–	1.025 (16.32)	5.704 (3.15)	–	–	–	–	–	–
The child is male	–	–	–	–	–	–	–	–	0.005 (−0.32)	1.178 (1.506)	–	–
The child is between 5 and 10 years old	–	–	–	–	–	–	–	–	−0.025 (−1.69)	−4.305 (−2.52)	–	–
The child is between 11 and 15 years old	–	–	–	–	–	–	–	–	−0.025 (−1.68)	10.689 (5.80)	–	–
Number of siblings within households	–	–	–	–	–	–	–	–	−0.016 (−1.86)	−1.371 (−2.41)	–	–
The child has access to bicycle	–	–	–	–	–	–	–	–	−0.029 (−1.74)	−2.837 (−1.92)	–	–

Table 5 continued

	Father				Mother				Child			
	No. of trips (P_{1nt})	Total TT (min) (P_{1tt})	Prop of car use (P_{1pv})	Prop of NMT (P_{1nm})	No. of trips (P_{2nt})	Total TT (min) (P_{2tt})	Prop of car use (P_{2pv})	Prop of NMT (P_{2nm})	No. of trips (C_{nt})	Total TT (min) (C_{tt})	Prop of PT (C_{ptm})	Prop of NMT (C_{atm})
Medium income household (25,000–50,000 GBP)	–	–	0.011 (1.08)	−0.012 (−1.51)	–	–	0.009 (0.89)	−0.021 (−2.41)	–	–	−0.052 (−1.01)	−0.013 (−0.28)
High income household (50,000 GBP or higher)	–	–	−0.011 (−0.79)	−0.027 (−2.61)	–	–	0.021 (1.69)	−0.029 (−2.73)	–	–	−0.083 (−1.21)	−0.046 (−0.73)
Residential self-selectivity for better built environment (F1)	–	–	−0.021 (−0.44)	−0.0005 (−0.01)	–	–	−0.103 (−2.35)	0.061 (1.73)	–	–	0.023 (0.26)	0.076 (1.73)
Residential self-selectivity for better accessibility (F2)	–	–	0.057 (0.38)	−0.092 (−0.76)	–	–	−0.178 (−1.28)	−0.043 (−0.34)	–	–	−0.016 (−0.05)	0.119 (1.66)
Satisfaction of public transport and cycling facilities (F3)	–	–	−0.254 (−3.24)	0.235 (3.73)	–	–	−0.172 (−2.37)	0.107 (1.74)	–	–	0.286 (1.49)	0.080 (0.50)
The household live within the London Boroughs	–	–	−0.136 (−7.88)	−0.004 (−0.32)	–	–	−0.090 (−5.58)	−0.012 (−0.81)	–	–	−0.188 (−1.15)	−0.099 (−0.65)
The household live within metropolitan built-up area	–	–	−0.032 (−2.19)	−0.0004 (−0.04)	–	–	−0.033 (−2.44)	0.007 (0.57)	–	–	−0.037 (−0.96)	−0.003 (−0.08)
The household live within other urban areas over 250,000	–	–	−0.023 (−1.69)	0.016 (1.45)	–	–	−0.029 (−2.23)	0.011 (0.96)	–	–	−0.012 (−0.47)	0.013 (0.65)
The household live within urban areas between 25,000 and 250,000	–	–	−0.011 (−0.87)	0.018 (1.85)	–	–	−0.017 (−1.45)	0.011 (1.14)	–	–	0.002 (0.06)	0.038 (1.76)
The household live within urban areas between 10,000 and 25,000	–	–	0.003 (0.17)	0.022 (1.78)	–	–	−0.051 (−3.64)	0.060 (4.69)	–	–	0.073 (0.60)	0.102 (1.03)
The HH members knew the locations of basic amenities[a] and they can be reached within 15 min	–	–	−0.003 (−0.20)	0.001 (0.08)	–	–	0.013 (0.80)	−0.0006 (−0.04)	–	–	0.013 (0.38)	0.025 (1.78)

Table 5 continued

	Father				Mother				Child			
	No. of trips (P_{1nt})	Total TT (min) (P_{1tt})	Prop of car use (P_{1pv})	Prop of NMT (P_{1nm})	No. of trips (P_{2nt})	Total TT (min) (P_{2tt})	Prop of car use (P_{2pv})	Prop of NMT (P_{2nm})	No. of trips (C_{nt})	Total TT (min) (C_{tt})	Prop of PT (C_{ptm})	Prop of NMT (C_{atm})
The HH members know the location of bus stops and they can be reached within 30 min walk	–	–	−0.046 (−2.28)	0.015 (0.92)	–	–	−0.019 (−1.00)	0.028 (1.66)	–	–	0.036 (0.57)	−0.016 (−0.28)
The child's total number of trips on the given day	−3.295 (−1.66)	–	–	–	−8.769 (−1.80)	–	–	–	–	–	−1.153 (−1.84)	−0.869 (−1.72)
The child's total travel time (min) on the given day	–	0.005 (0.36)	–	–	–	−0.005 (−0.35)	–	–	–	–	0.007 (9.08)	0.006 (8.28)
The father's total number of trips on the given day	–	–	0.052 (1.80)	0.006 (0.27)	–	–	–	–	–	–	–	–
The father's total travel time (min) on the given day	–	–	0.044 (3.42)	−0.020 (−3.40)	–	–	–	–	–	–	–	–
The mother's total number of trips on the given day	–	–	–	–	–	–	0.058 (3.71)	−0.017 (−1.44)	–	–	–	–
The mother's total travel time (min) on the given day	–	–	–	–	–	–	0.046 (2.96)	−0.023 (−2.84)	–	–	–	–
The father's private car driving proportion on the given day	–	–	–	–	–	–	0.277 (13.74)	–	–	–	−0.304 (−0.65)	−0.099 (−0.22)
The mother's private car driving proportion on the given day	–	–	0.114 (4.18)	–	–	–	–	–	–	–	−1.467 (−1.74)	−0.577 (−0.47)
The father's non-motorised trip proportion on the given day	–	–	–	–	–	–	–	–	–	–	−1.132 (−1.45)	−0.429 (−0.58)
The mother's non-motorised trip proportion on the given day	–	–	–	–	–	–	–	–	–	–	−2.510 (−0.92)	3.463 (12.15)

Table 5 continued

Continuous	Residential self-selectivity for better built environment (F1)	Residential self-selectivity for better accessibility (F2)	Satisfaction of public transport and cycling facilities (F3)
The household moved to the neighbourhood because looking for a better neighbourhood	1 Fixed	–	–
The household moved to the neighbourhood because of looking for a larger/better house/flat	1.272 (20.36)	–	–
The household moved to the neighbourhood to be closer to work or school	0.492 (19.21)	–	–
The household moved to the neighbourhood because of looking for a better public transport service	–	1 Fixed	–
The household moved to the neighbourhood because they want to be closer to shops and leisure facilities	–	1.543 (13.12)	–
The parents belief that they have a very good or good cycle path	–	–	1 Fixed
The parents belief that they have a very frequent or frequent bus service	–	–	6.806 (15.28)
The parents belief that they have a very reliable or reliable bus service	–	–	6.950 (15.26)
The parents belief that they have a very frequent or frequent rail and other PT services	–	–	3.086 (14.36)
The parents are satisfied with the existing bus service	–	–	4.247 (14.70)

The values in the brackets are the *t* stats values of the respective coefficients

NMT non-motorised trip; *TT* travel time

[a] The basic amenities include local healthcare, chemist, shopping centre, grocery, post office

The children travel patterns

In line with some previous studies (e.g. Buliung et al. 2009; Susilo and Waygood 2012), older children make fewer number of trips compared to smaller children, whilst the teenagers (11–15 years old) spend significantly more time to travel than their younger counterparts. The presence of siblings reduces children's number of trips significantly as well as the travel time, whereas the bicycle availability decreases the number of trips and total travel time spent.

As hypothesised earlier in the paper, the more mothers' choosing non-motorised modes in travelling, the higher the proportion of children to use non-motorised mode - and it is *the most significant* variables that positively correlated with the proportion of the children non-motorised modes. However, the fathers' choosing non-motorised modes in travelling does not significantly influence children's use of non-motorised mode. At the same time, the more mothers driving, the less children would use public transport. This is in-line with a hypothesis that was outlined by Mackett et al. (2005) and Næss (2006). The model estimation results also show that the correlation of the mothers' car use proportion is much more apparent than fathers' in reducing the children public transport use and non-motorised use.

Household income and degree of urbanisation

As expected, mothers who belong to higher income households have a higher proportion of car use and a lower proportion of walking and cycling participation than others, while surprisingly fathers who belong to higher income households do not have a significant increase of car use but they have a lower slow mode share. No significant mode share differences are found between children from households of different income levels.

In general, the parents who live in more urbanised areas tend to have a lower proportion of car use than the ones who live in lower density areas, which is in-line with previous studies (e.g. Ewing and Cervero 2010; Susilo and Maat 2007). But interestingly the clear relationship between car use and degree of urbanisation is not followed by a clear relationship with corresponding non-motorised trip participation. Although the parents who live in urban areas with residences between 250,000 and 10,000 are walking and cycling significantly more than the ones who live in the rural areas with residences fewer than 10,000, the differences in the participation rate between more urbanized cities are less apparent.

Children's public transport use and slow mode shares are surprisingly not correlated with urbanization level. One possible explanation could be that such influence is absorbed by the influence of parents' travel on the children's travel mode choices which are explicitly modelled. On the other hand, the children who live in medium cities with residences between 250,000 and 25,000 have a higher proportion of walking and cycling than the ones who live in bigger metropolitan areas, including London. Presumably this is not solely because of the degree of urbanisation of the city but also because public transport service that is less available in smaller cities in the UK.

The effect of accessibility and transit supply on household members' travel mode choices

Children from households who can reach basic amenities, as expected have higher share of walking and cycling in their daily travel. However, parents' travel mode choices are not

influenced by living close to basic amenities. For households which can reach nearest bus stop within 30 min, the mothers tend to have a higher public transport travel share and the fathers tend to have a lower car travel share. Presumably, this is because parents use public transport more often, thus have more walk trips to the bus stop. However, their children's travel mode choices are not significantly affected, indicating a trend of less often using bus in children's travel in UK.

Parents' satisfactions and residential self-selectivity influencing household members' travel mode choice

The influences of latent variables representing the residential self-selectivity and self-satisfaction on the mode shares of household members are summarised in Table 6. The latent variable that represents satisfaction of public transport and cycling facilities (F3) is positively correlated with parents' proportion of walking and cycling participations while negatively correlated with parents' private car use. Such effects are more substantial for fathers than for mothers. However, it shows no significant correlation to children's mode choices. Since the actual transit supply is controlled by another exogenous variable, "*The household members know the location of bus stops and they can be reached within 30 min walk*", the positive correlation between the satisfaction latent variable and parents' public transport use reveals that parents use public transport not only because the satisfaction reflects the true transit supply but also because of the higher quality level of the public transport facilities.

The latent variable that represents residential self-selectivity for better built environment is positively correlated with mothers' and children's proportion of walking and cycling participations but negatively correlated with mother's proportion of car use. However, it has no significant influence on fathers' mode choices. Surprisingly, the latent variable that represents residential self-selectivity for better accessibility shows no significant correlations with parents' proportion of private car use and walking and cycling participations. However, a good perception of accessibility encourages children's proportion of walking and cycling participations.

Table 6 The summary of the correlations of residential self-selectivity and self-satisfaction with the household members' travel modes use

Household's reported residential self-selection behaviour	Father		Mother		Children	
	Private car use	NM modes use	Private car use	NM modes use	Public transport	NM modes use
Residential self-selectivity for better built environment (F1)			−	(+)		(+)
Residential self-selectivity for better accessibility (F2)						(+)
Satisfaction of public transport and cycling facilities (F3)	−	+	−	(+)		

The ones in bracket are only significant at $\alpha = 10$ %

NM non-motorised; + significantly positively correlated; (+) marginally positively correlated (at $\alpha = 10$ %); − significantly negatively correlated; (+) marginally negatively correlated (at $\alpha = 10$ %)

These correlation relationships show that in influencing parents' travel mode choice, satisfaction of public transport and cycling facilities plays more important role than residential self-selectivity. Correspondingly residential self-selectivity has a stronger influence on children's mode choice than satisfaction of public transport and cycling facilities.

Relationship between observed satisfaction and residential self-selectivity questions and latent satisfaction and residential self-selectivity factors

From the measurement part, the statement that "*The household moved to the neighbourhood because of looking for a larger/better house/flat*" has the strongest influence on the latent variable that represents residential self-selectivity for better built environment, while "*the household moved to the neighbourhood to be closer to work or school*" contributes the least to the latent variable that represents residential self-selectivity for better built environment. The statement that "*The household moved to the neighbourhood because they want to be closer to shops and leisure facilities*" plays more important role in affecting residential self-selectivity for better accessibility than the statement that "*the household moved to the neighbourhood because of looking for a better public transport service*". This indicates "*close to basic amenities*" is more common and important than "*close to public transport supply*" as a reason of moving.

Among the satisfaction variables, the parents' satisfaction on bus services is more important than the parents' satisfaction on cycling and rail and other public transport services. This indicates bus service is more concerned and perceived by parents than other public transport modes and cycling.

Conclusions

Using data from the UK National Travel Survey (NTS) 2002/2006, this paper explores the influence of households' residential self-selectivity reasons, parents' perceptions and their travel patterns on their children daily travel mode share. The results show that, besides parents' daily activity-travel engagements, household residential self-selectivity reasons play significant roles in shaping children's daily travel mode shares. The influences of parents' perceptions and households' residential self-selectivity are not uniform across household members. This study has revealed some trade-off activities and travel implications between parents and what matters for different parents' roles. Further, it is also shows that residential self-selectivity has more correlations with children's non-motorised mode shares than parents', while parents' perception and satisfaction on transport infrastructure and public transport service qualities play more significant roles on parents' travel mode shares than children's.

Overall, the results highlight the importance of policies and interventions that are targeting and involving parents in promoting active travel among children, especially the mother. It is important for the parents to set the example for their children even from a young age as the results show that children are imitating parents' behaviours, including their daily mode choice. At the same time, different infrastructure and public transport service characteristics have different influences to the parents' travel mode shares. For example, the satisfaction on transport infrastructure and public transport service qualities has a stronger influence on fathers' travel mode choices than mothers'. Although the results confirm the hypothesis that the parents' non-motorised modes use in travelling is highly correlated with the children's daily travel mode shares, at the same time, the results also

show that the influence of mothers' car use proportion to the children travel mode shares is more apparent than fathers'.

Furthermore, the result indicates that "*close to basic amenities*" is more common and important than "*close to public transport supply*" as for a household to choose their residential areas. This highlights the importance of promoting a better mixed sustainable neighbourhood, with a good quality of house and good amenities access, as/more than providing them accessible public transport stops. The most common housing removal reasons, *moving to the location because of looking a larger/better house/flat* and/or *moving for a better neighbourhood for being closer to shops and leisure facilities*, are the most important variables that associated with the households' residential self-selectivity factors which contribute to the children's slow mode share.

A concrete example of plausible direct policy implication of this study is re-targeting the policies which aim to promote active travel among children towards parents, especially the mother. So far, most of the previous policies that were aimed to promote walking and cycling among children were focused on the school and the children themselves. The results reveal that one of the critical keys which tend to be left aside is the role of the parents, especially the mother, which is supported with Japanese case study which was laid by Waygood (2009). And both parents' attitudes towards slow modes are influenced by public transport and the build environment qualities within the neighbourhood. This, again, highlights the importance of a well-designed neighbourhood in influencing the children travel modes, directly and indirectly.

It is important to note here some caveats that may relevant in interpreting the study's results. The analysis was executed based on one observation which was randomly drawn from the 7-day observations of the given household. Thus, there will be some variability of behaviour interactions between parents and children across different days. Moreover, it is likely that during the survey period, both household's attitudes and small children's travel diaries were reported by the same parent. Thus, it would not be a surprise if there were correlations between parents' perceptions and the children's travel mode share, as parents responses would be proxies for their children's assumed responses. Furthermore, for the sake of simplicity, in this paper, each child within a household is estimated separately, which is in reality, the travel that was generated by a child may impose a constraint to another child. Nevertheless, this would be one of plausible future directions of our study. Additionally, this study is based on data from 2002 to 2006, and since then socio-demographic characteristics of the society and the urban structure have been continuously changing and so has the behaviour of the population. Recently there has been a sign of 'peak car' phenomenon (e.g. Metz 2013) and emerging Y-generation's unique mobility patterns (e.g. IFMO 2013) in various developed countries, where the younger generation consciously starts to prioritise other travel modes than private car. The impacts of this constitute another of the possible the future directions of this study. Lastly, this study is based on cross-sectional datasets at national level. It is difficult to use such datasets to reveal the real reasons underlying the interactions between households' activity-travel parameters. A deeper investigation with travel diaries, mixed with interviews with parents and children, would further reveal the reasons and intra-household trade-off mechanisms that underlie the whole decision making processes. This would form another possible future direction of this research.

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