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THE IMPACTS OF HOUSEHOLD STRUCTURE TO THE INDIVIDUAL STOCHASTIC TRAVEL AND OUT OF-HOME ACTIVITY TIME BUDGETS

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Abstract

The amount of travel time made by households and individuals can be seen as a result of complex daily interactions between household members, influenced by opportunities and constraints which vary from day-to-day. Using Stochastic Frontier Model and dataset from the 2004 UK National Travel Survey, this study examines the unseen stochastic limit and the variations of the individual and household travel time overtime. The results show that most of individuals may have not reach their limit yet to travel and may still be able to spend further time in travel activity. The model and distribution tests show that only full-time workers' out-of-home time expenditure which is actually have reached it limit and the existence of dependent children will reduce the unseen constraints of their out-of-home time thus reduce their ability to engage further at out-of-home activities. Even after the out-of-home trips taken into account in the analysis, the model shows that the dependent children's in-home responsibility will still reduce the unseen boundary of individual ability to travel and engage at out-of-home activities. The analysis also reveals that some groups of population (e.g. high income households, younger people etc.) have a larger needs of spending minimum travel time and also more bigger time constraints in doing their out-of-home travel and activities, whilst others (e.g. male full-time workers) need less travel time to satisfy their minimum travel needs. This study also suggests that the individual out-of-home time expenditure may be a better budget indicator in drawing the constraints in individual space-time prisms than individual time travel budget.

1. INTRODUCTION

The amount of time people spend on routine activities has been explored by social scientists in different contexts. A striking empirical evidence about the amount of time people spend in travelling is that it approximately the same (on average) for people of different characteristics, and that in many countries and societies it has remained constant, or at least stable, over many years. Ever since the work of Zahavi and his colleagues at the late 70s, it is common to interpret the constancy of travel time as signifying the existence of "*travel time budget*" (TTB) - a fixed and stable amount of time that an individual make available for travel. There have been number of studies that observed the constancy and stability of travel time (Tanner, 1961; Robinson and Converse, 1972; Goodwin, 1973; Zahavi and Talvitie, 1980; Zahavi and Ryan, 1980; Roth and Zahavi, 1981; Newman and Kenworthy, 1999; Schafer and Victor, 2000). Most of these studies came to a robust empirical evidence to support the idea of a stable amount of daily travel time, which on average, individual would spend about 1 to 1.5 hours per day for travelling.

Gunn (1981) reviewed TTB approaches and argued that many of them have been based on the assumption that details of an individual's travel behaviour are affected by the total amounts of the travel he or she performs, implying that TTBs in some sense are determined prior to actual travel (and therefore can be used to predict it). It might be also argued that the idea of constant travel budgets is in conflict with rational economic behaviour (Tanner, 1979). Goodwin (1973), cited by in Gunn, (1981), constructed simplified models of travel to demonstrate that stable travel times could arise even when travel behaviour is not explicitly constrained to reproduce them.

Interestingly, despite of this concept has been examined for more than 40 years and most of the studies demonstrated the existence of TTB stability at aggregate level and used as fix constraints at various transport models, the reason underlies this phenomenon is still unknown (Moktharian and Chen, 2004). Some studies at disaggregate level (Kirby, 1981; Kitamura et al., 2006) show that routines and TTBs are not constant but rather a function of several different variables. Therefore, it might be argued that there may be an *unseen limited amount of time budget,* which have been spent

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and constrained on various '*common*' daily travel-activity trade-off engagements and left a small variance on the observed individual total travel time which may seems stable at aggregate level.

Given that in the last three decades there have been enormous changes in the physical and social environments for trip making, it might be argued that the variance of the observed amount of time allocated for individual travel is becoming more complex and less predictable and so are the number of trip chains and total travel time the individual may engage and spend. Various new commodities, appliances and services have been invented to reduce the time required for domestic chores such as cleaning, cooking and yard work. Two-worker households have become a norm rather than an exception, changing the way how household tasks are carried out by its members. These entire amounts to changes in the needs for, resources available for, and constraints imposed on, travel[1] (Susilo and Kitamura, 2008). For example, many dual-earner households share their household-obligation trips, such as drop-off and pick-up children and pick up dry cleaning, with other household members. Because of this possible interaction, or even substitution, of travel time between members of the same household which unseen at individual level, some previous researchers (e.g. Downes and Morrell, 1981) tried to promote the use of household rather than individual TTBs. Moreover, recent studies on social-psychological aspects of travel behaviour, such as social interaction between household members (Bhat and Pendyala, 2005) and pro-social orientation of household members (Timmermans, 2006) demonstrate that these arrangements have a strong effect on individual travel patterns. According to social exchange theory, social behaviour can be seen as an exchange of goods (material or non-material) in a process of influence that tends to work out at equilibrium to a balance in the exchanges (Homans, 1958). Thus, patterns of time allocation of household members might be the outcome of a process in which they try to maximize utilities (or minimise costs), based on the available resources of the household. This argument is supported by recent works that explored activity time allocation of the male household head and the female household head (Zhang et al., 2005; Cao & Chai, 2007). However, the role of the household structure and the intra-household interactions between household members in generating (or reducing) travel time of individuals and households is largely unknown. It is therefore important to explore how the changes of the individual's household structure influence the unseen boundary of individual travel time expenditure. This would be the focus of this study.

It is important to understand and predict how far individuals could be expected to adapt and change their behaviour given changes in their household structure and their unseen time allocation constraints. Using Stochastic Frontier Model and a dataset from the 2004 UK National Travel Survey, this study explores the nature of the unseen TTB's boundaries of each individual and how it varies for different type of household structure. The discussions on the possible existence of the unseen stochastic TTB and how the stochastic frontier model works are explained in the next section. It is followed by the description of the datasets. Analysis on the day-to-day variability of the unseen boundaries of TTB is discussed and so is the impact of the household size and household structure on the budget boundaries. The paper finishes with a discussion of the salient findings and implications.

2. STOCHASTIC FRONTIER MODEL AND UNSEEN CONSTRAINTS

The idea of the *unseen (stochastic) time budget* introduced in this work has originated from the understanding that the amount of time for travel (and other activities) allocated by households and individuals can be seen as a result of complex daily interactions between household members, influenced by many factors which vary from day-to-day. As suggested by social exchange theory and activity-based models, such time allocations are largely shaped by opportunities and constraints. Studying individuals' spatial movement, Hägerstrand (1970) classified the individual constraints into three categories: capability constraints, coupling constraints, and authority constraints, which are unique for every household member. The *capability constraint* means that individual's activities will be limited by his ability to do the activities. It's not only a geographical boundary, but also has time-space walls on all side. And these walls might change from day to day. The *coupling constraint* means that the freedom of individual's activities will be bounded by where, when, and for how long, the individual

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[1] For discussions on changes in urban residents' activity engagement and travel in the last few decades, see, e.g., Cervero (1986), Kitamura et al. (2003), Kitamura and Susilo (2005, 2006), Susilo and Kitamura (2008).

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has to join other individuals, tools or materials. The *authority constraint* relates to the time-space aspects of authority – a time-space entity within which things and event are under the control of a given individual or a given group[2]. These constraints define time-space prisms in which the individual's trajectory in time and space must be contained. Under the assumption that each individual has his own home base, and needs a certain minimum number of hours a day for sleep and for maintenance activities at the home base, there exist boundary walls in time and space beyond which he or she cannot encroach. The walls shape a prism in time and space, and also shape the amount of the daily TTB that an individual can spend. At the same time, an individual also has the desire to travel and explore (Smith, 1978; Hay and Johnston, 1979) to spread their choice risk, find a better opportunity and reduce uncertainty by learning all viable options. Some recent studies (e.g. Moktharian and Solomon, 2001) also show that travel may not necessarily a derived demand but can be constitute as an activity itself which has positive utility components. Therefore, whilst the individual may have walls of prism that represent the amount of travel time that individual would like to spend, at the same time there may also another wall of prisms that represents the amount of minimal travel time that same individual would need to spend as this time is competing with other activities that carry larger benefits to the individual (see Figure 1). The time allocated for individual's travel activities would be therefore inside the prism, in between those two boundaries. As lifestyles, constraints and personal preferences vary among individuals, it is likely that heterogeneity will be exhibited in TTB's boundary conditions.
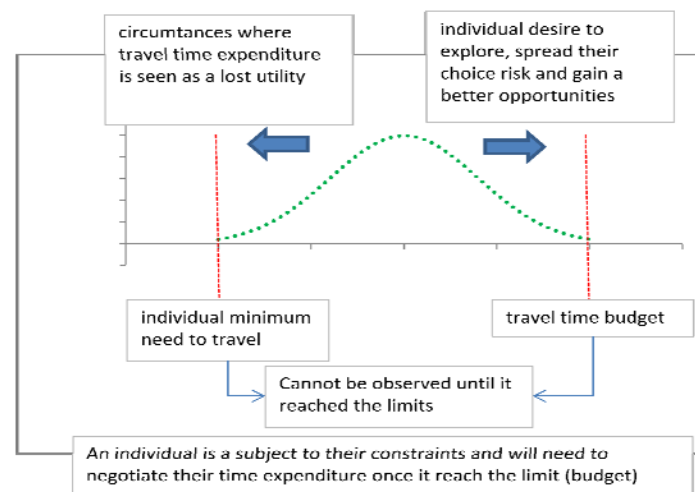

Figure 1. Push and pull in individual daily time expenditure

The concept of prism is extremely useful, both as a conceptual framework and as a construct for the analysis and prediction of travel behaviour. The prism itself, however, is difficult to be observed directly. Mostly, we only observe time-space paths that represent the individual's movement inside a prism, from which only a sub-region of the prism can be identified. In addition to the above, there are always unobserved conditions and events that may cause individual not to spend their travel time as much as they want.

In order to explore the unseen TTB's boundary conditions, stochastic frontier modelling is used in this study. Stochastic frontier model is an econometric modelling that used to explore the maximum or minimum limit of outputs that unachieved, therefore is unobserved, due to various internal and external conditions (such as imperfect knowledge of choices as a part of decision making processes or unexpected disruption due to random weather conditions). The stochastic frontier model was first proposed (Aigner et al., 1977) in the context of production function estimation to account for the effect of technical inefficiency. The inefficiency causes actual output to fall below the potential level (that is, the production frontier) and also raises production cost above the minimum level (that is, the cost frontier). The illustrations of cost and production frontiers are shown at Figure 2.

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[2] This perspective views the person in space and time as the centre of social and economic phenomena. The three aggregations of constraints interact in many ways (direct and in-direct ways). For more descriptions of these concepts and their applications to travel behaviour analysis, see Burns, (1979), Kitamura et al. (1981), Jones et al., (1983), Damm (1983), Jones et al, (1990), Axhausen and Gärling (1992), and Ettema and Timmermans (1997).

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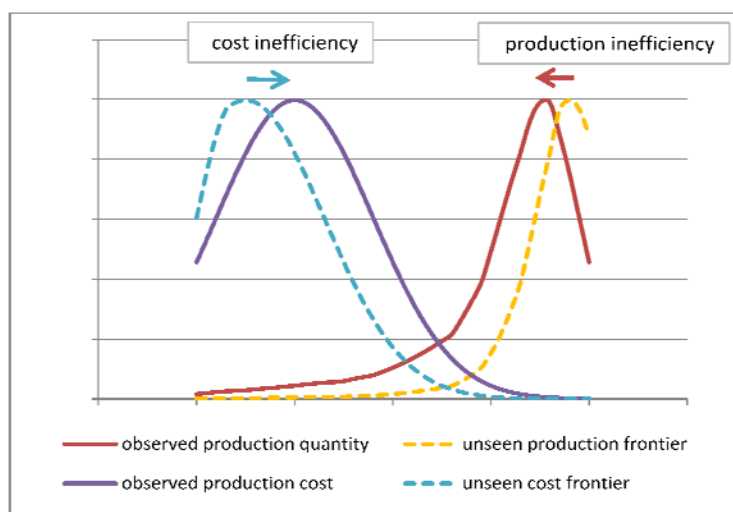*Open University,*
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Figure 2. The concept of unseen boundary at Stochastic Frontier Model

The general form of stochastic frontier models is:

$$Y_{it} = \beta'X_{it} + \varepsilon_{it} \qquad \text{where } \varepsilon_{it} = v_{it} + u_{it} \text{ ; for production frontier} \qquad (1a)$$

$$\varepsilon_{it} = v_{it} - u_{it} \text{ ; for cost frontier} \qquad (1b)$$

with i = observation case; t = observation time; Y_{it} = observed dependent variable; β'= vector of coefficients; and X_{it} = explanatory variables.

v_{it} = pure random error terms, varies across individual and time. Assumed have normal distribution, $-\infty < v_{it} < +\infty$.

u_{it} = random error terms that represent the inefficiencies of the output/choice which still below its frontier limitation, assumed to be half truncated normal distribution, $u_{it} > 0$.

The equation is subject to:

$$E[v_{it}] = 0, \; E[u_{it}] \geq 0; \; E[\alpha_i v_{it}] = E[\alpha_i u_{it}] = E[v_{it} u_{it}] = 0 \qquad (2)$$

$$E[\alpha_i \alpha_j] = E[v_{it} v_{iq}] = E[v_{it} v_{jt}] = E[u_{it} u_{iq}] = E[u_{it} u_{jt}] = 0$$

Where: $i \neq j, \; t \neq q, \; i,j = 1, 2, 3, \dots , N$ behavioural unit (individual), t,q = 1, 2, 3, …, T observed time

v_{it} assumed to have a normal distribution, u_{it} assumed to have half truncated normal distribution and α_i solved with mass-point model, a non-parametric approach which assumes a discrete distribution for the error component with unspecified probability masses at unspecified location.

This model assumed the following distribution of the error term (Aigner et al., 1977):

$$h(\varepsilon_{it}) = \frac{2}{\sigma_t} \phi\left(\frac{\varepsilon_{it}}{\sigma_t}\right) \left\{ 1 - \Phi\left(\frac{\varepsilon_{it}\lambda_t}{\sigma_t}\right) \right\}, \; -\infty < \varepsilon_{i\tau} < \infty \qquad (3)$$

where $\sigma_t^2 = \sigma_{u_t}^2 + \sigma_{v_t}^2$, $\lambda_t = \sigma_{u_t}/\sigma_{v_t}$, ϕ and Φ are the standard normal density and cumulative distribution functions, , respectively, $v_{it} \sim N(0, \sigma_{v_t}^2)$, and u_{it} is the density function,

$$g(u_{it}) = \frac{2}{\sqrt{2\pi}\sigma_{u_t}} \exp\left[-\frac{u_{it}^2}{2\sigma_{u_t}^2} \right], \quad u_{it} \geq 0, \; t = o, t. \qquad (4)$$

The expected value and the variance of u_i are evaluated for the half normal models as

$$E[u_i] = \sqrt{\frac{2}{\pi}}\hat{\sigma}_u, \; Var[u_i] = \left(1 - \frac{2}{\pi}\right)\hat{\sigma}_u^2, \qquad (5)$$

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Stochastic Frontier in predicting the limit of travel spent

 In travel behaviours research stochastic frontier models have been recently proposed as a means to estimate the location of an unobserved prism vertex of individual trip departure and arrival time (Kitamura et al., 2000, 2006; Pendyala et al., 2002; and Yamamoto et al., 2004). In this particular study, the observed individual's total daily travel time and the amount of out-of-home time are used as the dependent variable of the stochastic frontier models, which in turn may be used to derive the prism vertex as the location of an unobservable frontier (in this case, the unseen lower and upper limit of the spent time, depends on the cases). The daily travel time and out-of-home time are both used as dependent variables because we want to test whether the budget lies only at travel time or at out-of-home activities. Given that the individual willingness to travel is also highly influenced by the amount of the activity duration (Susilo and Dijst, 2009) and individual have to trade-off between their travel distance and activity duration in selecting their activity locations (Susilo, 2010; Susilo and Dijst, 2010), it is reasonable to expect that the prisms boundary may not lies solely on travel budget but in total out-of-home that individual have to spend.

The general form of stochastic frontier models that adopted in this study is: $Y_{it} = \beta'X_{it} + \varepsilon_{it}$, where: $\varepsilon_{it} = v_{it} + u_{it}$; for the case where individual has reached their time budget and $\varepsilon_{it} = v_{it} - u_{it}$; for the case where individual has not reached their time budget; with i = observation case; t = observation time; Y_{it} = observed dependent variable (individual travel time and out-of-home time (min)); β'= vector of coefficients; and X_{it} are explanatory variables, based on observed characteristics (heterogeneity) across individual, variant across time and individual, including their household structure.

Both cost and production frontier approaches are tested in our cases because we do not know whether the individuals actually already have reached their time budget limit or not (see Figure 3 for the illustration). Some people, like young unemployed, may have less tight time constraints and less travel needs than full-time workers. Therefore for these unemployed people they may have not used their entire travel budget yet and their time use distribution may close to the minimum amount of travel that they need to do not as a derived demand but as a positive utility. On the other hand, there may also be some full time workers who have very demanding out-of-home commitments which will use their entire out-of-home time expenditure budget and any extra time demand, such as the existence of dependent children, may force them to do some trade off and they may not actually be able to use all of their time budget.
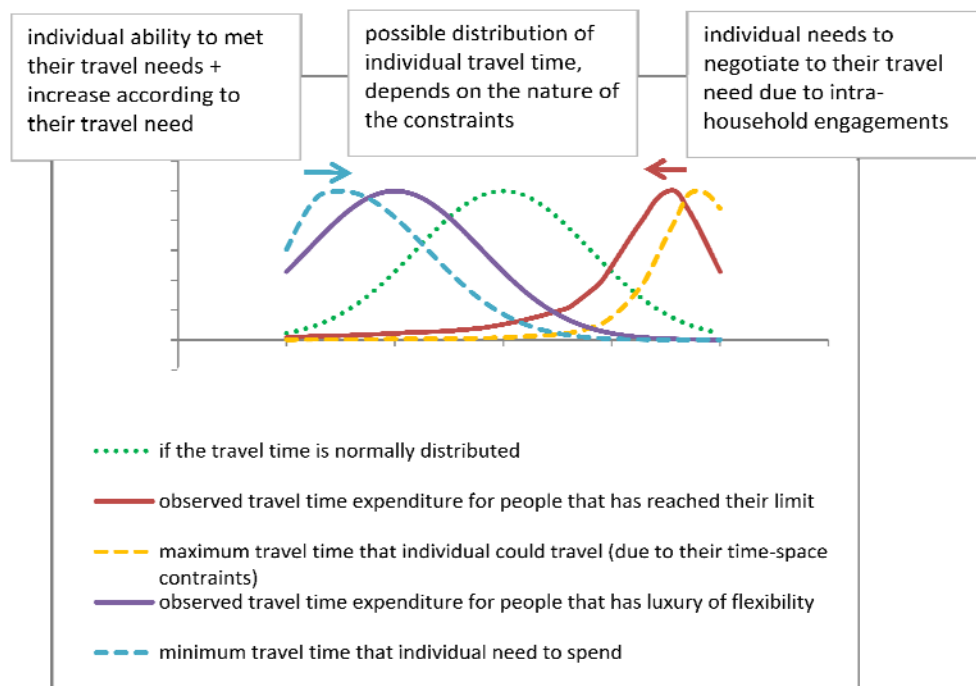

Figure 3. The observed travel time and the unseen boundary of individual time expenditure

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In this analysis the individual socio-demographic factors and their household structure are used as explanatory variables in exploring the stochastic frontier of their travel time use. A caveat is due here. The time constraints discussed is mainly focused on out-of-home activities. Due to the data limitation we do not have information regarding in-home constraints (e.g. house cleaning and baby sitting at home that may act as time constraints for housewives). In this study, unless individual has a production frontier distribution, it is assumed that the individual have not reached their time expenditure limit yet.

The plausible hypotheses of the analysis are:
1. The unseen boundary (budget limit) of individual travel time and out-of-home time may actually exist. However, we may not be able to observe the limits unless the individuals have been significantly 'pushed' to the boundary by their out-of-home commitments.
2. The impact of household structure (number of children, number of adult members)to the trade-off of individual time expenditure from their limits may varies, depends on individuals out-of-home commitments.

3. THE USED DATASET AND THE DISTRIBUTION OF THE TRAVEL TIME AND OUT-OF-HOME TIME

This paper draws on data from the 2004 UK National Travel Survey (NTS) which provides detailed information about individuals, households and their 7-days trip engagements (see National Statistics and DfT, 2005). 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. The first UK NTS was commissioned by the Ministry of Transport in 1965/66. Because of data availability issue, this paper only uses the UK data from 2004 datasets. The *unweighted* samples' travel characteristics in the datasets are summarized in Table 1. In the analysis, the trips were classified into three different groups based on who was the main benefactor of the journey. The *personal trips* include commuting and various personal business trips. *Mixed trips* include food and non-food shopping, visiting a friend, entertainment, sport and holiday trips. *Escorting trips* include pick up and drop off trip, shopping and all trips that was reported by the respondent as an escorting activity.

Table 1. The profiles of respondents' socio-demographic characteristics and travel engagements

(a) Characteristics of Individual Socio-demographics

Male respondents	46.8%
Respondents less than 25 years old	27.6%
Respondents between 25 & 44 years old	29.2%
Respondents between 45 & 64 years old	23.3%
Respondents 65 years old or older	19.9%
Respondents a Full-time worker	32.0%
Respondents a Part-time worker	10.5%
Respondents a student	1.1%
Respondents who have other occupation	56.3%
Respondents from low income household	35.6%
Respondents from medium income household	21.0%
Respondents from high income household	20.2%
Respondents who have access to private car	55.4%
Respondents who have children in their household	46.9%

(b) Characteristics of Individual Activity-Travel Engagements

Number of trips on the day	3.54
- Number of personal trips / day	1.57
- Number of escorting trips / day	0.42
- Number of mixed trips / day	1.55
Daily total travel time (minutes) incl. walk	69.81
- Travel time spent for personal trips (min)	25.42
- Travel time spent for escorting trips (min)	7.23
- Travel time spent for mixed trips (min)	37.16
Total daily travel distance (in tenth miles) incl walk	202.36
Total activity duration (minutes)	266.99

The amount of individual's travel time and out-of-home time spent by different combinations of household structure is shown at Tables 2 and 3, respectively. Another caveat is due in here. Because the low number of sample of households that have three or more children and three or more adults, we need to treat the values of these adult/children combinations on the Table 2 and 3 carefully.

It is shows from Table 2a that, the average amounts of individual travel time were very similar despite the different combinations of household structure - between 67-71 minutes. The time travel changes

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due to the changes in number of children or adults within the household are small and the incremental patterns do not show any clear changes patterns – except, one additional child for single parents and couples, reduced the parents' daily spent travel time about 2 minutes, whilst having a second children at such households reduced their average daily travel time at about 0.75 minutes per day.

Table 2b shows that the higher number of adults within household is, the more time an individual would spent on their daily out-of-home time expenditure. Presumably, they spent this additional time to engage in various shared activities (because the average spent travel time did not significantly different, see Table 2a). One adult increase in household with children increases the average of household member's out-of-home time expenditure at about 23 minutes/day. There is not any clear pattern of such increase towards the increase of number of children within household.

The patterns of time expenditure increases are much clearer when household become the unit of analysis (see Table 3). One additional child to the household increases the household's travel time expenditure at about 52 minutes, whilst the second and the third children to the household increase the average household's travel time expenditure at about 50 and 44 minutes, respectively. On the other hand, one and two adults increase in household with up to one child increase the average household's travel time expenditure at about 50 and 41 minutes, respectively.

The patterns are less clear at household's out-of-home time expenditure level (Table 3b). Though, it still can be seen that an initial increase because of an additional number of children would increase the household's out-of-home time expenditure higher than an initial increase in number of adult within household. Later on, an increase in the number of adult would increase the household's out-of-home time expenditure more than an increase in the number of children.

The distribution of individuals' travel time and their out-of-home time expenditure, by various combinations of household structures, were tested and shown at Figure 4 and 5, respectively. At most cases the distribution of individuals' travel time expenditure (see Figure 4) are skewed to the left, which shows that most of the individuals may not have reached their upper time limit yet to travel (similar as case cost-production at Figure 3) and may still be able to spend further time in travel activity. Further tests with Stochastic Frontier distributions against the observed travel time distribution shows that the observed travel time distribution did not have a production frontier (upper limit) but have a cost frontier (lower limit) (see Figure 6a and 6b).

However, the distribution of out-of-home time expenditure shows a different pattern, it has two peaks – which show there are, at least, two different populations in the samples. Presumably this is caused by the different level out-of-home individual commitments which provide different flexibility in time allocation arrangement among different group of individual (this was confirmed by results of Susilo and Kitamura, 2005 and Susilo and Axhausen, 2007). Further tests with Stochastic Frontier distributions against the observed travel time distribution shows that the distribution of the full time workers' out-of-home time expenditure has a production frontier (upper limit) (Figure 6c) whilst that is not the case with non-full time workers (Figure 6d). Interestingly, Figure 6d show not only one cost frontier, but two. Presumably this is due to the differences between unemployed respondents and part-time workers. However, due to the limit of the paper length, at this particular conference paper, we decided to put the unemployed respondents and part-time workers are one group.

4. HOW SIGNIFICANT THE HOUSEHOLD STRUCTURE IN PULLING AND PUSHING US TO THE LIMIT?

The Stochastic Frontier analysis results of the full time and non full time workers' daily travel time and out-of-home time expenditures can be seen at Table 4 and Table 5, respectively. The models were tested with and without the amount of trips engaged on the given day. Whilst we understand that trips is a function of individual socio-demographic and household structure as well, given that we do not enough information on in-home constraints, we think it is important to test whether, after the out-of-home engagements taken into account, the household structure still matter in defining individuals' unseen time constraints.

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Table 2. Individuals' daily travel time and out-of-home time expenditures

(a) Individual Daily Travel Time (min)

No of adults in the household	No of children in the household				
	0	1	2	3	4 or more
1	71.34	69.33	67.19	71.50	68.99
2	70.30	69.50	68.80	69.52	69.44
3	69.40	67.70	68.75	67.14	80.12
4 or more	70.81	70.46	70.92	65.48	60.28

Incremental travel time changes:

No of adults in the household	No of children in the household				
	0	1	2	3	4 or more
1	0.00	-2.01	-4.14	0.17	-2.35
2	0.00	-0.80	-1.50	-0.78	-0.86
3	0.00	-1.70	-0.65	-2.27	10.72
4 or more	0.00	-0.35	0.11	-5.33	-10.53

No of adults in the household	No of children in the household				
	0	1	2	3	4 or more
1	0.00	0.00	0.00	0.00	0.00
2	-1.04	0.17	1.61	-1.99	0.46
3	-1.93	-1.62	1.56	-4.37	11.13
4 or more	-0.53	1.13	3.73	-6.02	-8.70

(b) Individual Total Daily Out-of-home Time Expenditure (min)

No of adults in the household	No of children in the household				
	0	1	2	3	4 or more
1	304.99	332.33	319.08	300.12	296.24
2	317.53	356.20	342.61	334.40	317.43
3	369.56	385.54	366.44	339.46	324.38
4 or more	390.70	392.34	346.59	307.27	309.43

Incremental out-of-home time expenditure changes:

No of adults in the household	No of children in the household				
	0	1	2	3	4 or more
1	0.00	27.35	14.09	-4.87	-8.74
2	0.00	38.67	25.08	16.87	-0.10
3	0.00	15.98	-3.12	-30.10	-45.18
4 or more	0.00	1.64	-44.11	-83.43	-81.27

No of adults in the household	No of children in the household				
	0	1	2	3	4 or more
1	0.00	0.00	0.00	0.00	0.00
2	12.54	23.87	23.52	34.28	21.19
3	64.57	53.20	47.36	39.34	28.13
4 or more	85.71	60.00	27.51	7.15	13.19

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Table 3. Households' daily travel time and out-of-home time expenditures

(a) Household Daily Travel Time Expenditure (min)

No of adults in the household	No of children in the household				
	0	1	2	3	4 or more
1	71.34	124.32	169.54	211.56	235.02
2	121.15	174.23	228.41	273.51	315.67
3	163.12	214.71	258.91	303.13	487.53
4 or more	238.33	275.74	312.81	348.13	226.25

(b) Household Total Daily Out-of-home Time Expenditure (min)

No of adults in the household	No of children in the household				
	0	1	2	3	4 or more
1	304.99	598.01	829.05	910.03	1098.09
2	560.08	926.81	1165.96	1330.92	1416.43
3	886.45	1257.64	1407.57	1586.10	1923.57
4 or more	1376.35	1564.23	1530.74	1679	1201.06

Incremental travel time changes:

No of adults in the household	No of children in the household				
	0	1	2	3	4 or more
1	0.00	52.98	98.21	140.22	163.68
2	0.00	53.08	107.26	152.36	194.52
3	0.00	51.59	95.79	140.01	324.42
4 or more	0.00	37.41	74.48	109.80	-12.08

Incremental out-of-home time expenditure changes:

No of adults in the household	No of children in the household				
	0	1	2	3	4 or more
1	0.00	293.02	524.06	605.05	793.11
2	0.00	366.73	605.88	770.85	856.35
3	0.00	371.19	521.12	699.65	1037.12
4 or more	0.00	187.88	154.39	302.65	-175.29

No of adults in the household	No of children in the household				
	0	1	2	3	4 or more
1	0.00	0.00	0.00	0.00	0.00
2	49.82	49.91	58.87	61.95	80.65
3	91.78	90.39	89.37	91.58	252.51
4 or more	166.99	151.42	143.27	136.57	-8.77

No of adults in the household	No of children in the household				
	0	1	2	3	4 or more
1	0.00	0.00	0.00	0.00	0.00
2	255.09	328.80	336.91	420.89	318.34
3	581.46	659.63	578.52	676.07	825.47
4 or more	1071.36	966.22	701.69	768.97	102.97

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Figure 4. The distribution of individual travel time and different type of household structures

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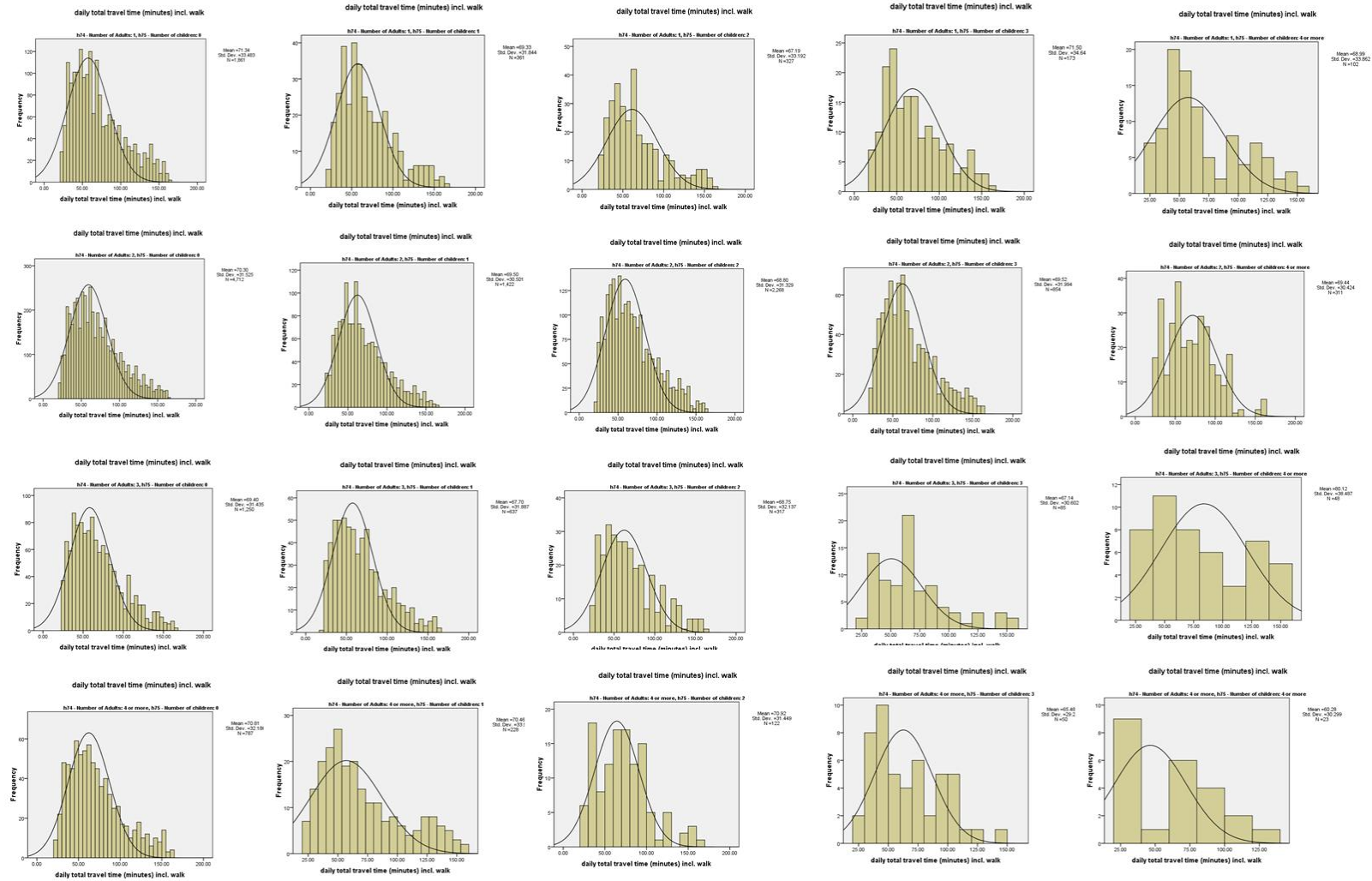
Figure 5. The distribution of individual out-of-home time expenditure and different type of household structures

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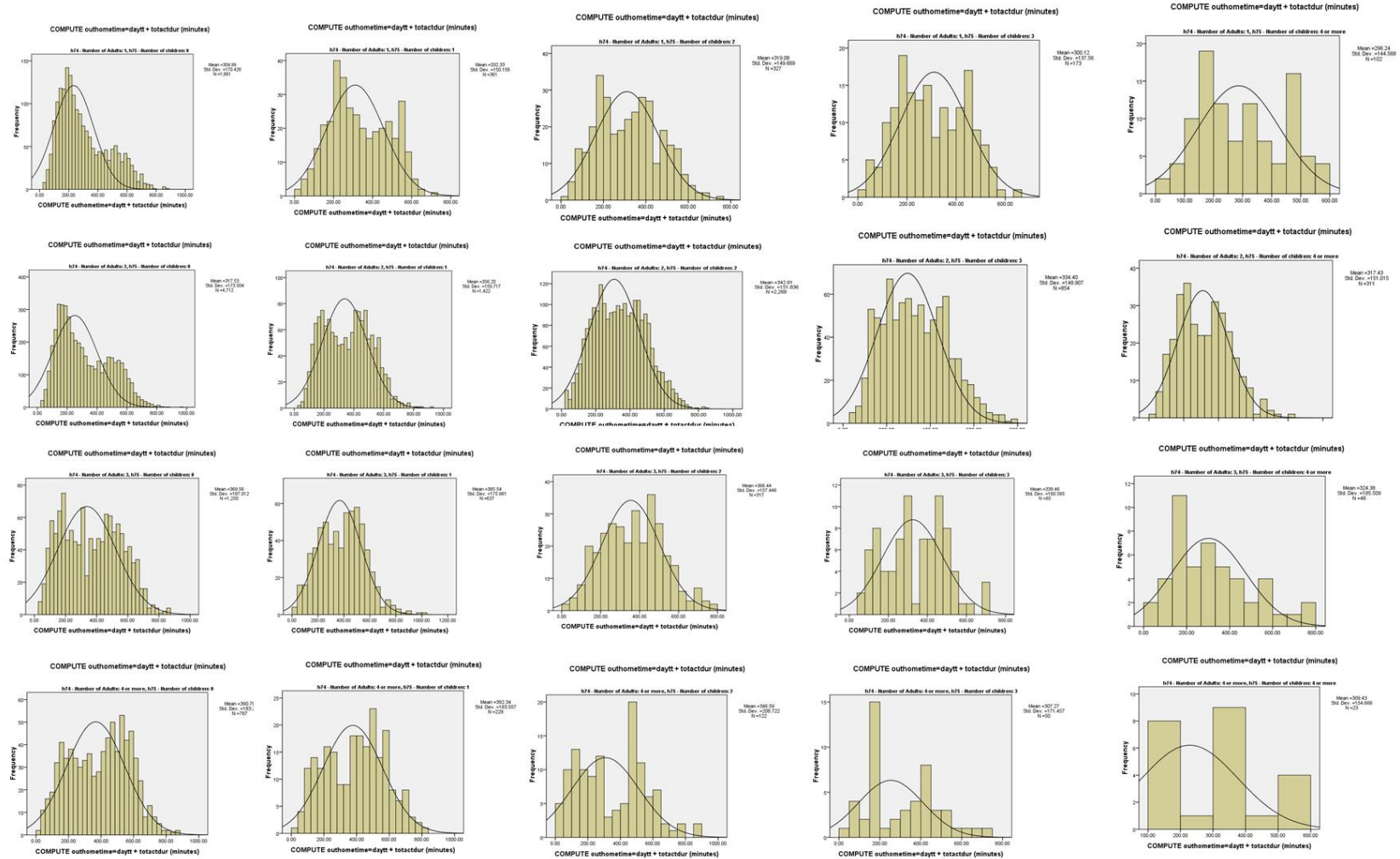
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(a)   Travel time distribution of FT workers

(b) Travel time distribution of Non-FT workers

(c) Out-of-home time expenditure of FT workers

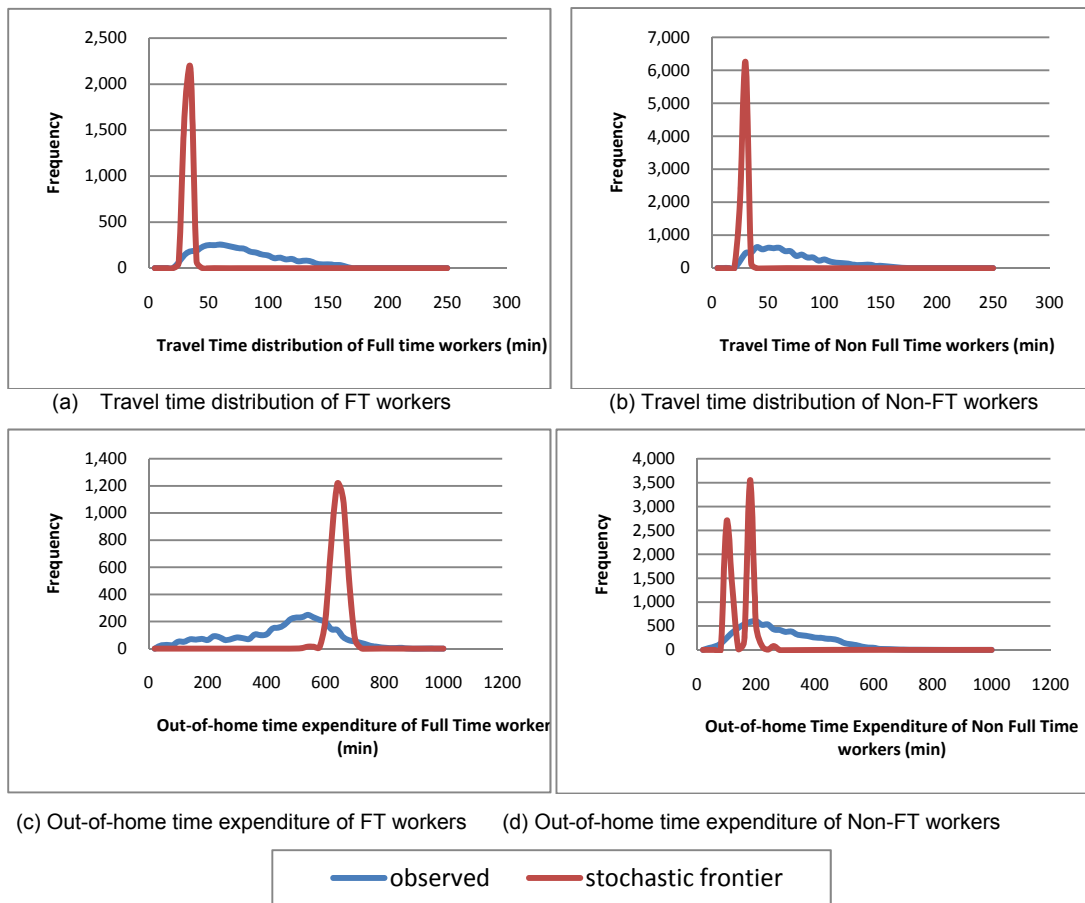(d) Out-of-home time expenditure of Non-FT workers

Figure 6. The Stochastic Frontier of individual's out-of-home and travel time expenditures

The result at Table 4 shows that the high income households have later travel time prisms vertex location than others, which shows that high income households have a higher minimum travel time need than lower income household (4.28 minutes/person/day more than lower income household, on average). Male full time workers have earlier travel time prisms vertex location than female, which shows that male have less minimum travel time than female (about 1.36 minutes less), though the gender impacts only significant at α=10%. The household structure (number of adults and children) was not found to have a significance influence on the individuals' travel time prisms vertex location.

Unlike travel time models, the individuals' out-of-home time prisms vertex location shows much stronger relationship with the individuals' socio-demographic and household structure conditions. Males, younger people and high income households have later prisms vertex location than females, older people and lower income households. On the other hand, having children reduced the individuals' out-of-home prisms vertex location significantly. Having one, two and three children at the household has reduced the individuals' out-of-home prisms vertex location about 27, 34 and 24 minutes, respectively. Even after the out-of-home individual trips taken into account, having one and two children at the household has still significantly reduce the individuals' out-of-home prisms vertex location for about 15 and 23 minutes less, respectively. This shows that individual out-of-home time expenditure is not only constrained by out-of-home activities and trips that are associated with children travel needs but also by in-home child-bearing activities.

As the full time workers cases, the non-full time workers who come from high income households have later travel time prisms vertex location than others (see Table 5). Part-time workers also have a later travel time prisms vertex location than others – presumably, this due to his/her out-of-home commitments which require them to spend more minimum travel time than others. As the full time workers cases, the household structure (number of adults

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and children) found did not significantly influence the individuals' travel time prisms vertex location.

Table 4. Estimation results of Stochastic Frontier of Full Time workers' daily travel time and out-of-home time expenditures

	FT worker TT (cost frontier)				FT worker OHT (prod. frontier)			
	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats
Constant	25.92	6.96	13.63	3.30	502.76	18.60	279.58	11.41
Male	-1.36	-1.89	0.04	0.05	25.94	5.31	10.77	2.44
Less than 25 years old	2.16	0.58	-0.09	-0.02	145.38	5.46	160.73	6.84
25-44 years old	4.51	1.29	1.98	0.52	119.76	4.75	132.00	5.94
45-64 years old	3.33	0.95	0.32	0.08	99.15	3.93	106.78	4.81
Medium income household	-1.44	-1.21	-0.99	-0.79	17.80	2.12	16.85	2.26
High income household	4.28	3.57	3.96	3.18	25.26	3.03	25.13	3.39
Car availability	1.35	1.27	-3.22	-2.80	1.83	0.25	-3.24	-0.48
Another adult in the household	-1.32	-1.43	-1.13	-1.18	-9.50	-1.51	-8.56	-1.52
One child in the household	-0.32	-0.33	-1.21	-1.14	-26.87	-4.03	-14.50	-2.36
Two children in the household	-0.20	-0.21	-0.85	-0.77	-33.84	-5.02	-22.93	-3.65
Three children in the household	0.21	0.13	-2.14	-1.19	-24.15	-2.12	-14.00	-1.36
Four or more children in the household	-2.65	-0.77	-0.78	-0.22	-4.26	-0.19	-3.54	-0.18
Personal trips			6.77	14.02			115.30	35.35
Escorting trips			5.13	9.07			-4.16	-1.32
Mixed purpose trips			8.07	18.58			-2.60	-1.10
λ	8.12	12.95	5.93	18.06	3.05	28.27	1.92	28.84
σ	54.60	4860	50.43	4836	252.28	4781	191.03	4831
N	3955		3955		3955		3955	
Log-likelihood	-19042		-18852		-25632.39		-24949.3	

In case of out-of-home time expenditure for non-full time workers, the younger individuals and high income households have a later out-of-home time prisms vertex location than older respondents. Students and part-time workers have 4 and 19 minutes out-of-home time prisms vertex location later than unemployed respondents, respectively. Interestingly living with other adults reduced the individuals' out-of-home time prisms vertex location about 13 minutes (though it is only significant at α=10%). Like travel time case, the amount of children within household found did not have a significant influence to the non-full time workers' out-of-home time prisms vertex location.

5. CONCLUSION AND DISCUSSION

Using Stochastic Frontier Model and a dataset from the 2004 UK NTS, this study aims to explore the nature of the unseen travel budget's boundaries of each individuals and how it varies for different type of household structure. The descriptive analysis shows that, despite the different combination of household structure, the average amounts of individual daily travel time were look similar, between 67-71 minutes. There were not any clear trends how the trends change between different household types. Interestingly, the link between time expenditure and household structure become clearer when we analyse the household as one unit. The analysis shows that one additional child to the household, increase the household's daily travel time expenditure about 52 minutes, whilst the additional of the second and the third children to the household increase the average household's travel time expenditure about 50 and 44 minutes, respectively. One the other hand, one and two adults increase in a household with up to one child increase the average household's travel time expenditure about 50 and 41 minutes, respectively.

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Table 5. Estimation results of Stochastic Frontier of Non Full Time workers' daily travel time and out-of-home time expenditures

	Non-FT worker TT (cost frontier)				Non-FT worker OHT (cost frontier)			
	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats	Coeff.	t-stats
Constant	25.37	54.19	14.59	18.79	90.95	27.78	14.59	18.79
Male	0.15	0.42	0.73	1.68	-4.55	-1.78	0.73	1.68
Less than 25 years old	-1.03	-1.16	0.52	0.48	86.27	13.83	0.52	0.48
25-44 years old	0.73	0.84	2.02	1.93	18.71	3.16	2.02	1.93
45-64 years old	0.43	0.81	0.64	1.03	11.94	3.22	0.64	1.03
Students	0.02	0.01	2.73	1.63	38.01	3.86	2.73	1.63
Part-time workers	2.26	3.97	2.72	3.97	73.01	18.65	2.72	3.97
Medium income household	-0.12	-0.21	-0.47	-0.72	3.84	1.02	-0.47	-0.72
High income household	2.14	2.54	2.39	2.48	12.42	2.21	2.39	2.48
Car availability	0.61	1.31	-2.01	-3.57	4.16	1.32	-2.01	-3.57
Another adult in the household	-0.40	-1.01	-0.82	-1.75	-5.40	-1.92	-0.82	-1.75
One child in the household	1.31	1.57	0.34	0.34	-2.07	-0.37	0.34	0.34
Two children in the household	0.57	0.70	-1.45	-1.44	1.25	0.23	-1.45	-1.44
Three children in the household	1.39	1.50	-0.99	-0.88	-1.64	-0.26	-0.99	-0.88
Four or more children in the household	0.29	0.27	-0.42	-0.31	-10.79	-1.43	-0.42	-0.31
Personal trips			3.99	12.40			3.99	12.40
Escorting trips			3.93	14.67			3.93	14.67
Mixed purpose trips			5.85	20.95			5.85	20.95
λ	14.39	13.18	8.71	20.53	2.64	34.29	8.71	20.53
σ	51.88	10345	48.76	10329	178.34	10335	48.76	10330
N	8388		8388		8388		8388	
Log-likelihood	-39629.54		-39378.6		-51705		-39378.6	

Further analysis with Stochastic Frontier model shows that most of individuals may have not reach their limit yet to travel and may still be able to spend further time in travel activity. The model and distribution tests show that only full-time workers' out-of-home time expenditure which is actually have reached it limit and the existence of dependent children will reduce the unseen constraints of their out-of-home time thus reduce their ability to engage further at out-of-home activities. Even after the out-of-home trips taken into account in the analysis, the model shows that the dependent children's in-home responsibility will still reduce the unseen boundary of individual ability to travel and engage at out-of-home activities. The analysis also reveals that some groups of population (e.g. high income households, younger people etc.) have a larger needs of spending minimum travel time and also more bigger time constraints in doing their out-of-home travel and activities, whilst others (e.g. male full-time workers) need less travel time to satisfy their minimum travel needs.

Whilst there may be a travel budget, the study shows that most individual have not reach the limit – only full time workers has reached their out-of-home time expenditure limit. Therefore, for some cases, this study only succeeds to reveal the minimum amount of travel that individual need to spend. For the individuals who have not reach their out-of-home time expenditure limit, they have not had to negotiate their activities yet and their household structure found did not significantly influence the minimum amount of travel time they need. This study also suggests that the individual out-of-home time expenditure may be a better budget indicator in drawing the constraints in individual space-time prisms than individual TTB.

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This study have not take into account the arrangement at household level, the day-to-day variability of the inter- and intra-household interactions to the individual travel time and out-of-home time expenditure and also separation analysis between fully unemployed and part-time workers. These would remain as the future direction of the study.

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