STABILITY OR REGULARITY OF THE DAILY TRAVEL TIME IN LYON? – APPLICATION OF A DURATION MODEL

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Abstract: Escaping unidimensional analysis limits and linear regression irrelevancy, the duration model incorporates impacts of covariates on the duration variable and permits to test the dependence of daily travel times on elapsed time. In the perspective of a discussion of Zahavi's hypothesis, the duration model approach is applied to the daily travel times of Lyon (France). The relationships between daily travel times and socio-economic attributes and activity duration only support the "weak version of TTB stability hypothesis". Furthermore the non-monotonic estimated hazard questions the minimisation of daily travel times.

INTRODUCTION

Transport policy call for understanding and quantifying both the travel behaviour and the traveller's responses to changes of travel environment. It leads to the recognition of travel demand as a derived demand. The trips are made in order to engage in activities at different locations (Jones et al., 1983). On one hand, travel is one of many attributes of an activity. On the other hand, it can be considered as an activity interacting with other activities. Mokhtarian and Salomon, (2001) have shown that a part of the transport activity produces a positive utility. Hence, transport and other activities are competing each others for the scarce resource of time.

The interest of this paper is to analyse the time allocated to urban travel during one day. The individual travel time budget (TTB) is then computed as the sum of the duration of all the trips realised in one day. The TTB has been claimed by Zahavi (1979) as being a constant amount of time about 1 hour per day per capita. He also claimed that this amount is constant over different cities and different time periods. Hence, the Zahavi's conjecture can be formulated as the spatial and temporal stability of the TTB. Since, it has become a common conjecture in the transportation research field. The city's sprawl can easily be interpreted as a consequence of the increase in disposable speeds. Hence, speeds and any policies favouring speeds become responsible of the increase in mobility. Recently, Schafer and Victor (2000) have used the constant TTB concept to construct a mobility demand model and to predict the future mobility of the world population in 2050.

On one hand, some researches that confirm the relative stability can be found (Hupkes, 1982; Bieber, et al., 1994; Vilhelmson, 1999; Schafer and Victor, 2000). On the other hand, a lot of authors have adopted the opposite direction (Van der Hoorn, 1979; Godard, 1981; Landrock, 1981; Gordon, et al., 1991; Kitamura, et al., 1992; Purvis, 1994; Kumar and Levinson, 1995; Levinson and Kumar, 1995). The critics of Zahavi's conjecture have been concerned with the influence of some socio-economic, activity-related and area specific variables. For example, variables such as income, car-ownership, age, timing of the trips or urban density are shown to influence the TTB. This multiple critiques are warnings to the abusive application of the constant TTB concept in a non-world level.

A key question of the TTB is its level of observation and application. The stability hypothesis is formulated for the world level, but most of the critiques are at disaggregated level such as national, regional or urban level. At these levels, it is clear that the stability is not a valid hypothesis. Then, only regularities in relationship between TTB and variables could constitute a "weak hypothesis" on TTB (Goodwin, 1981). Having in view the search for regularities in TTB, and the understanding of the TTB in the context of the individual activity, we propose to examine the TTB at the urban level of the city of Lyon (France).

Furthermore, the TTB has been found to be related to several variables, such as characteristics of individuals, transportation system, or activities. Few models have been constructed to estimate the TTB. Furthermore, some have been developed to estimate the travel time associated to a specific activity or a specific trip. Chen and Mokhtarian (2002) distinguish four econometrics techniques applied to directly estimate the activity duration (including travel): the single linear equation approach; seemingly unrelated regression equations or structural equations modelling; linear and multinomial models; duration analysis.

The TTB analyses, before 1981, were unidimensional or limited to the linear analysis (Zahavi and Talvitie, 1980; Downes and Morrell, 1981; Goodwin, 1981; Gunn, 1981; Landrock, 1981; Prendergast and Williams, 1981; Roth and Zahavi, 1981; Tanner, 1981; Wigan and Morris, 1981). Levinson et al. (2003) conduct an analysis on US cities with regression models, using data from the United States (2000 Census). Subsequent models have been improved and applied to the time dedicated to specific activities. Hence, Kitamura et al. (1992), Hamed and Mannering (1993), Levinson (1999), Timmermans et al. (2002) have estimated linear equations on daily travel duration for the corresponding activity. Ma and Goulias (1998) used 2 Stages Least Squares method to integrate the expected endogeneity of activities. Structural equations model is applied to travel times in different modes by Golob (1990) while in different types of activity by Fujii et al. (1997, cited by Kitamura et al., 1997), Golob and McNally (1997) and Lu and Pas (1999). Finally, most of the applications of duration models are concerned with the activities duration, excluding travel (Hamed and Mannering, 1993; Ettema et al., 1995; Bhat, 1996a,b; Ma and Goulias, 1998; Popkowski Leszczyc and Timmermans, 2002; Timmermans et al., 2002).

Subsequently, the study of TTB can be improved by adopting a model that incorporates a set of variables and that overtakes the limits of the traditional linear model. Unlike the classic estimation methodologies, such as linear or logistic regressions, the duration models framework is suitable to study the duration allocated to the different activities. The duration model analyses the conditional probability of ending which integrates the notion of the temporal dynamics. It permits the likelihood of ending an activity to depend on the length of elapsed time since the activity has been started. This kind of model permits the examination of the duration processes in which the temporal dynamic needs to be included. Here, the conditional probability of ending a travel process, given that it has lasted to some specified time, permits to discuss Zahavi's hypothesis and the minimisation of travel time. The hypothesis of 1 hour TTB would lead this probability to increase before and after 1 hour of elapsed time. More generally, the minimisation of travel time in the allocation of time process would imply an increasing probability of the end-of-duration with elapsed time.

The purpose of the paper is to analyse the TTB of Lyon. It supports a discussion of the Zahavi's hypothesis. The duration model application to TTB permits to test the stability of the TTB through the functional form resulting from the duration model. Furthermore, this multidimensionnal modelling technique permits to examine how this TTB is dependant on some variables relative to individual and household socio-economic and mobility characteristics. Furthermore, the link between daily travel time and activities duration is analysed. It permits to examined part of the allocation of time process. Finally, the modelling of the duration dependence leads to question the travel time minimisation. The second part reviews Zahavi's analyses and TTB studies. In the third part, both the data and the duration model method are presented. Finally, in the fourth part, the results of the non-parametric, semi-parametric and parametric estimations lead critics of the TTB stability and the allocation of time mechanism.

ZAHAVI'S HYPOTHESIS AND TTB STUDIES

Stability of travel budgets

Following the first scholars who suggest the stability of the travel time and money expenditures (Tanner, 1961, Szalai, 1972) Yacov Zahavi studied it and claimed a specific hypothesis on the "Travel Time Budget" and the "Travel Monetary Budget". The TTB Zahavi's hypothesis has been defined at two different levels. First, it states that at an aggregate (world-wide) level, the mean TTBs for cities at different times are similar (Zahavi, 1979). Second, at the disaggregate (local) level, travel expenditures exhibit regularities that are assumed to be transferable in different cities and at different times (Zahavi and Ryan, 1980 ; Zahavi and Talvitie, 1980). At the world level, the constancy hypothesis can be named the "strong TTB hypothesis". And the "weak TTB hypothesis" is defined at the local level and suppose only regularities of relationships between TTB and others variables. This distinction leads to the corresponding definitions by Goodwin (1981) of travel "budgets" (constancy of TTB) and "expenditures" (regularities of TTB).

Zahavi has studied TTB and TMB, at a world level and has formulated the "strong hypothesis" of the double constancy of travel budgets: the constancy of travel money budget and that of travel time budget. In Zahavi's Unified Mechanism of Travel model (UMOT, 1979), both TTB and TMB appear as constraints:

- The average TTB for a city is calculated on the basis of the average *individual daily duration* of travel for the entire *mobile population*.
- The average TMB for a city is calculated on the basis of the average *available household income* that is spent on travel during one year by all the *mobile households* in the city.
- The two average travel budgets are constant over time for each city. The average travel budgets are similar for all cities in the world.

So, according to Zahavi, this double constancy is spatially and temporally transferable.

At disaggregate level, Zahavi (1974), Zahavi and Ryan (1980), Zahavi and Talvitie (1980) have shown that TTB and TMB are linked to the socio-economic characteristics of individuals, the characteristics of transport supply and urban structure. Furthermore, the stable forms of these relationships in different cities lead to their inclusion in a travel demand forecasting model. In the UMOT model, predictions of travel expenditures are based on the "weak hypothesis" of regularities in relationships between the time and money expenditures and variables such as speed and number of household members. These regularities mean that an individual's travel expenditure can be considered as a budget which amount is rationally determined. Zahavi was one of the first scholars to suggest the expenditure budgets concept and to incorporate time budgets in the optimisation program for individual travel choices.

The amounts resulting from the allocation of resources to transportation are supposed to be fixed (strong hypothesis of the UMOT) or at least predictable (weak hypothesis).

Systematic reinvestment of travel time savings – Latent demand for mobility

Zahavi describes the mechanism by which an individual acquiring higher speed gains access to new opportunities. A reduction in the temporal cost of transport allows the individual to extend space-time accessibility. The trade-off is therefore between time savings and accessibility improvements. The hypothesis of stable TTB means that the result of this choice

favours increases in accessibility. By deciding to reinvest all his/her travel time savings in additional travel, the individual chooses to extend the space-time prism of his activities. This extension results in either performing the same activities more frequently or at more distant locations, or even adding new activities to his/her timetable. In all these cases, the individual travels a bigger daily distance.

Because of the simplicity with which this hypothesis allows us to characterise the mechanisms involved in the economics of personal travel, it reveals an important characteristic of time: it cannot be stored. This is the origin of the reinvestment mechanism and the apparently paradoxical manner in which this scarce resource is managed. Once speeds are improved, the travel time savings can not be stored, they must be consumed in one way or another, and for this consumption to provide a genuine gain, it is more than likely that it will lead to new trips, for the simple reason that these involve new activities whose marginal utility is greater than those already performed (work, time at home, etc.).

TTB studies

Schafer and Victor (2000) and Joly (2004) confirm the stability observed by Zahavi at aggregate world level. The mean TTB of these three studies are close to one hour. Differences appear because of the divergent methods and because of different definitions. The mean TTB of Zahavi (1 hour) is defined on the mobile population and only for motorised modes of transport, while Schafer (1.1 hour) studies the entire population and all modes. Finally, in Joly (0.8 hour) the TTBs of 100 cities of the world, concern the urban population, but only motorised trips are observed. Nevertheless, the TTB distributions of the three works show similar attributes as, for example, mean, close interquartile ranges (60 min.), and similar dispersion around the mean.

But the stability seems to be valid only at the world level. The disaggregation of the level of observation reduces the robustness of the TTB stability hypothesis. For example, Levinson et al. (2003) conduct an analysis on US cities with regression models, using data from the United States (2000 Census), at a continental level. They show significant effects of congestion, income, population, population density and area. In the same way, using the UITP's "Millenium Cities Database", Joly (2004) shows the opposition of two urban organisations characterised by distinct TTB dynamics. First, an extensive model composed of North American and Oceanic agglomerations, which develops by the extension of their space and time consumption. Second, an intensive model characterising European cities and Asian metropolis find stability in consumption of space and time. Hence, an "European" city with near stable TTB is opposed to a "North American" city with a TTB that appears to be sensitive to variables such as urban density, mean GDP per capita, mean road speeds and daily travel distance.

Numerous studies using finer scale of observation questioned the apparent stability. Zahavi and Talvitie (1980), Zahavi and Ryan (1980), Chumak and Braaksma (1981), Hupkes (1982) are the first to valid the stability or the regularities. Since then, despite the difficulties of comparison, a large part of the studies of TTB do not support the "strong Zahavi's hypothesis". Mokhtarian and Chen (2004) present overview of the variables found to affect the TTB in numerous studies. Hence, TTB varies with socio-economic variables such as age, gender, employment status, car ownership, household size and income. Area-specific attributes are studied. For example, population and urban density are influencing variables (Landrock, 1981, Gordon et al., 1989). However, these studies can hardly be compared

because of the divergent definitions of urban, sub-urban or rural attributes. Activity-related characteristics are referred as influencing variables of the travel time to the corresponding activity. The studies of the relationship between the activity duration and the travel time have abandoned the definition of the TTB as a daily sum.

DATA AND METHODS

The data source used in the present study is a household mobility survey conducted between November 1994 and April 1995 by the CERTU ("Centre d'Etudes sur les Réseaux, les Transports, l'Urbanisme et les constructions publiques") in the French agglomeration of Lyon. The survey collects data on socio-demographic and mobility characteristics of the 6000 households and of each individual in the household. The survey also includes information on a week day mobility of all members of the household above 5 years of age. Each trip is described by (a) the starting and stopping times, (b) the types of activities at origin and at destination, (c) the travel mode. Thus, the one-day out-of-home activities diary can be deduced, from the first trip to the last trip of the day.

Table 1 presents the summary statistics. The mean TTB is near the TTB obtained by both Zahavi and Schafer. Here, travellers going out of the urban area (less than 5% of the sample) can not be assimilated to the representative daily urban travel and then are excluded from the analysis. And TTB greater than 6 hours (less than 1% of the sample) are considered as censored duration.

Table 1

Summary statistics of TTBs (in min)

N	11232	Mean	76.5	Median	65
Mode	60	Interquartile Range	60	Range	353
Standard error	51.74	Quantile 25% (Q1)	40	Quantile 75% (Q3)	100

The TTB can be regressed, using a stepwise selection. The table 2 shows the weak results of the linear regression of the TTB on the household and individual characteristics. Despite the low R square, classical variables are found to be significant. Our results can be compared with the ones obtained by other studies and mentioned in Mokhtarian and Chen (2004). The OLS estimation reveals the followings:

- As observed by Goodwin (1981), Prendergast and Williams (1981), Kumar and Levinson (1995), the day of the trips has significant effect on the daily time allocated to travel. Here, the TTBs are greater at the end of the week. It reveals a part of the regularities of the mobility day-to-day and/or week-to-week cycles (Roth and Zahavi, 1981; Prendergast and Williams, 1981; Downes and Morrell, 1981; Gunn, 1981). Goodwin (1981) proposed three causes of day-to-day variations. First, a pure random variation. Second, a systematic variation, due to the fact that not all types of trips are made every day. Third, a lag effect. The travel behaviour observed in the current period may be due to constraints from an unobserved previous period. Here each individual is observed only on one day. Then to interpret the result as a weekly cycle, we need to assume homogeneity between individuals.

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- The estimate of the age effect produces classical results. Few studies found an insignificant age effect (Roth and Zahavi, 1981). As mentioned by Prendergast and Williams (1981), and Kitamura et al. (1992), we observe that people of middle ages spent more time on travel than younger (below 20) or older people (above 50).
- Here, the introduction of the principal mode shows a decrease of the TTB with the use of private motorised mode (car and motorcycle) and the use of private non-motorised mode (walking and cycling). Consequently, it can be shown that the use of the public transport mode is associated to higher TTB. If only the car ownership is introduced as an indicator of the mode use, the same decreasing relation with TTB is obtained. As surveyed by Mokhtarian and Chen (2004), the link between TTB and car ownership is often significant but the direction of this effect is not consistent. These contradictory results may arise because of the mix use of different modes.
- The employment status appears to have significant effect. Here, in opposition to housewife and young at school, the worker and unemployed have higher TTB. Moreover, the worker have a significantly higher TTB than unemployed. This result is similar to the effect found by Van der Hoorn (1979), Zahavi and Talvitie (1980), Roth and Zahavi (1981), Prendergast and Williams (1981), Wigan and Morris (1981), Supernak (1982), Kraan (1995), Ma and Goulias (1998), Lu and Pas (1999). Since, the distinction between employed people and unemployed people is the base of recent activity-based models (see for example, CEMDAP of Bhat et al., 2004).
- Most of the studies found a significant effect of gender on TTB. Men spent more time travelling than women (Gunn, 1981; Prendergast and Williams, 1981; Wigan and Morris, 1981; Kitamura et al., 1992; Levinson and Kumar 1995; Robinson, 1997). Furthermore, Prendergast and Williams (1981) and Robinson (1997) analysed the interactive effect between gender and employment status on travel time. We obtain similar results, the maximum TTB correspond to male worker and the minimum TTB is associated to housewife and unemployed women.
- The effect of household size on travel time is positive. But, some studies showed different results. Zahavi and Ryan (1980), Zahavi and Talvitie (1980) and Purvis (1994) observed a negative effect of household size on travel time per person. And Roth and Zahavi (1981) found insignificant effect. The number of household members can be viewed as a way to reduce the member's part of the household responsibilities. Then, it permits to increase his/her participation in out-of-home activities and his/her mobility and TTB.
- In the same way, the effect of the number of children can be viewed as an indicator of the responsibilities charges upon the household members. Household members with children under 5 years have to reduce their out-of-home participation and as a consequence their mobility and their TTB.
- The residential location is an influent variable on the TTB of Lyon. As mentioned in Mokhtarian and Chen (2004), many studies have identified the area characteristics as influent variables on travel times. To understand the specific effect of the three areas of Lyon identified as influent on TTB, we miss information on their attributes (as for example population density, size, design of neighbourhoods), and on their transport systems and land use. The central location, in denser area, leads to higher TTB. The suburban locations have lower TTB, except for the 2nd ring West zone.
- The results of previous studies on the income effect are not in the same direction. As for car ownership multiples opposite effects are possible and observed (Zahavi and Talvitie,

1980; Prendergast and Williams, 1981; Roth and Zahavi, 1981; Tanner, 1981; Lu and Pas, 1999). Here, the members of high household income have higher TTB. It may be due to a mobility that is less restricted by the money constraints.

- As mentioned earlier, most of the studies that found a major impact of activities duration on travel time concentrate on the link between travel time to a particular activity and the activity duration. The negative sign for the work daily duration seems to indicate, as found by Kitamura et al. (1992) that the more a person spends on work, the less time he/she spends on non-work travel. Lu and Pas (1999) and Principio and Pas (1997) have found that travel time increase with the time spent on out-of-home activities and decrease with the time spend at home. Here we have no information on the use of the time spent in-home. So we can only observe some small positive effects on the TTB of daily duration of the non-work out-of-home activities (leisure and shopping). The "kiss and drive" indicator appears clearly significant and increases the TTB.

The influence of variables seems to be confirmed by the OLS regression. But the weak performance of the model indicates that the relationships between these variables and the TTB may not be linear.

To perform a more flexible multidimensionnal analysis of the TTBs the duration model methodology is applied. First, this technique is suitable to deal with duration data that are non-negative and that can be censored and time-varying[1]. The simple linear classical method is irrelevant to model positive variables or partially observed or measured variables. This kind of variable needs the application of a Tobit model, which rely on the hypothesis of normal residuals. Second, the duration distribution is rarely normal. This distribution is usually an asymmetric distribution with specific form, as for example some bimodal distributions that can be found in medicine and or in demographic analysis. But, the robustness properties of the linear estimators are lost without the normality distribution (Lawless, 2003). Third, the duration model introduces the duration dependence concept. It models the conditional probability of the end-of-duration of a process, given that it has lasted to a specified time, and permits the likelihood of ending to be depending on the length of elapsed time. Hence, this probability can vary during the process. Finally, this conditional probability can question the TTB stability hypothesis and the minimisation of the temporal component of travel costs. Indeed, the estimation of this conditional probability, named hazard rate, will inform us on the temporal dynamics of TTB. Then, increase of this probability in elapsed time will imply accelerated decrease of estimated TTB. Given TTB stability around 1 hour, the hazard should increase faster after 1 hour of elapsed time in transport. Hence, given the minimisation of travel time expenditure, we should observe, at least, a monotonically increasing hazard, with elapsed time.

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[1] Time-varying variables can be variable or indicator of the variations in the individual situation during the day. For example, indicators relative to the achievement of a non-discretionary activity, the traffic conditions, the accompanying person, the situation of the other household members, etc.

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Table 2

OLS regression of TTB

Influent Variables	Estimates	
Intercept	72.8	***
Male	7.38	***
Age between 20 and 50 years	1.39	
Worker	17.66	***
Unemployed	3.80	***
Number of children under 5 years	-3.79	***
Number of household members	1.22	***
High household income	4.18	***
Central location	3.60	**
1st ring East	-2.62	***
2nd ring West	3.41	***
3rd ring East	-3.42	***
Monday	-7.25	***
Tuesday	-4.26	***
Wednesday	-4.90	***
Working duration	-0.002	
Leisure duration	0.099	***
Shopping duration	0.117	***
Kiss and drive (0/1)	16.36	***
Walking	-44.88	***
Bicycle	-22.83	***
Motorcycle	-41.30	***
Private transport modes (car)	-25.47	***
R-Square	0.18	

* 0.1, ** 0.05, ***0.01 level of significance

Used in biometrics and industrial engineering fields, the duration models have been applied in transportation fields in multiple ways: accident analysis (Jovanis and Chang, 1989; Mannering, 1993; Nam and Mannering, 2000), car ownership (Mannering and Winston, 1991; Gilbert, 1992; Hensher, 1998), traffic queuing (Paselk and Mannering, 1993), duration before acceptance of a new toll (Hensher and Raimond, 1992), and traveler's activity behaviour. The analysis of the activity behaviour focus on: the time spent at home between trip generating activities (Hamed and Mannering, 1993; Mannering et al., 1994; Misra and Bhat, 2000), the duration of out-of-home activities (Bhat, 1996a,b; Niemeier and Morita, 1996; Kitamura et al., 1997; Timmermans et al., 2002); the duration between two occurrences of an activity (Schonfelder and Axhausen, 2000; Bhat et al., 2002); the duration between planning and execution of an activity (Mohammadian and Doherty, 2004).

Hensher and Mannering (1994) and Bhat (2000) present detailed overviews of the existing applications of duration models in transportation field.

OVERVIEW OF DURATION MODELS

In the duration model framework the hazard function, $h(t)$, is the conditional probability of the non negative variable, T, which represents the duration of the process. Then $h(t)$ is the instantaneous probability that the process ends in an infinitesimal interval Δ after time t, given that this process has lasted to the time t. The hazard function is given by:

$$h(t) = \lim_{\Delta \to 0^+} \frac{P\big(t \le T < t + \Delta \,/\, T > t\big)}{\Delta}$$

This conditional probability can be expressed in terms of the density, $f(t)$, and cumulative density, $F(t)$, functions of T.

$$f(t) = \lim_{\Delta \to 0^+} \frac{P\big(t \le T < t + \Delta\big)}{\Delta}$$

$$F(t) = P(T < t) = \int_0^t f(u)\,du$$

Then, the probability of ending in an infinitesimal interval of range Δ, after t is given by: $f(t)*\Delta$. The probability that the process lasts to time t is $1-F(t)$. Hence, the hazard function can be written as:

$$h(t) = \frac{f(t)}{1 - F(t)}$$

The complementary probability of $F(t)$ is $S(t)$, the survival (probability to survive until t) or the endurance probability, (Bhat, 2000):

$$S(t) = \Pr[T \ge t] = 1 - F(t)$$

Then the hazard can be expressed as:

$$h(t) = \frac{f(t)}{S(t)} = \frac{dF(t)/dt}{S(t)} = \frac{-dS(t)/dt}{S(t)} = \frac{-d\ln S(t)}{dt}$$

The hazard and the survival functions describe the duration process. The hazard function expresses the opposite of the rate of variation of the survival, evaluated at each time t. So the shape of the hazard function has important implications for the duration dynamics. To study this shape, one may use three approaches: parametric, non-parametric and semi-parametric estimations.

Non-parametric approach

The non-parametric approach is similar to an exploratory data analysis. The survival function is estimated using the Kaplan-Meier product limit estimator (Kaplan and Meier, 1958). The KM estimator of survival at time t_j is computed as the product of the conditional survival proportions:

$$S_{KM}(t_j) = \prod_{k=1}^{j} \frac{r(t_k) - d(t_k)}{r(t_k)},$$

where $r(t_k)$ is the total population at risk for ending at time t_k. $d(t_k)$ is the number of individuals stopping at t_k. The corresponding survival curve is a step function with a drop at each discrete end-of-duration time. The definition of these steps is of special importance in presence of discrete times, i.e. many unique event times. This discretisation may arise when the reported duration times are rounded off. In presence of discrete times, event times are grouped into intervals. Then, the steps are defined by arbitrary determined intervals. Assuming a constant hazard within each discrete period, one can then estimate the shape of hazard by a continuous-time step-function. This method is known as the life-table method. Here, for the TTB of Lyon, we can show the rounding to the nearest 5 minutes in reporting the travel time duration. In our case of rounded times, a width of 5 minutes is believed to be the suitable interval. The estimation of the hazard and the survivor functions characterising the distribution of the duration variable, T, will be given at the midpoint of the interval.

This approach produces an empirical approximation of survival and hazard, but it hardly models effect of covariates. Then, only tests of classification effects of covariates on survival functions are conducted. In our case, tests confirm the relationship between the daily travel duration and most of the covariates used in the following part.

Parametric approach

The incorporation of the covariates effects can be done through two parametric forms: the proportional hazards form and the accelerated lifetime form. The first form assumes a multiplicative effect of covariates on a baseline hazard function. In the second form, a direct effect on duration is assumed.

Proportional hazard model

The proportional hazard model (PH model) assumes that the hazard function is decomposed as:

$$h(t/X) = h_0(t) \cdot g_0(X) = h_0(t) \cdot exp(-\beta X),$$

where $h_0(t)$ is the baseline hazard. $h_0(t)$ is a function of survival time and represents the duration dependence, i.e. the variation of the probability of ending in time. $g_0(.)$ is a function of the covariates and gives the change of the hazard function caused by the covariates. The separation of the time effect and the covariates effects leads the PH model to assume the proportionality between the hazard rates of two individuals, i and j, with different attributes. Given that the covariates effects are not time dependent, the hazard ratio is given by:

$$\frac{h_i(t)}{h_j(t)} = \exp\{\beta_1(x_{j1} - x_{i1}) + ... + \beta_k(x_{jk} - x_{ik})\},$$

The distributional assumptions for the baseline hazard $h_0(t)$, impose specific forms to the shape of the hazard function: constant, monotone or U-form.

The estimation will conduct to the distributional parameters and covariates estimators. Coefficient estimators can be either interpreted in terms of its effect on the hazard ratio or defined as derivative of the log-hazard with respect to the associated covariates:

$$\beta_k = \frac{\partial \ln h(t)}{\partial X_k}$$

Subsequently, positive coefficient implies that an increase in the corresponding covariate decreases the hazard rate and increases the expected duration. Hence, if the covariate j increases by 1 unit, the hazard changes by $100(e^{-\beta} - 1)\%$. In case of binary covariate, the hazard ratio interpretation is straightforward.

The accelerated lifetime model

The second parametric form permits the covariates to affect the duration dependence. Then, it assumes that the covariates act directly on time. The survival function in the ALT model is:

$$S(t/X) = S_0[t \exp(-\beta X)],$$

where $S_0(t)$ is baseline survivor function. Furthermore, corresponding hazard function is:

$$h(t/X) = \frac{-\partial S(t/X)/\partial t}{S(t/X)} = h_0[t \exp(-\beta'^* X)] \cdot \exp(-\beta'^* X)$$

The ALT model can be expressed as a log-linear model, such that $\ln t = \beta' X + \varepsilon$, with density function of the error term $f(\varepsilon)$, that differs according to the type of estimated model. Then, the coefficients can be interpreted after exponential transformation with respect to the following derivative:

$$\beta_k = \frac{\partial \ln T}{\partial X_k}$$

In case of binary covariate, e^β gives the expected survival time ratio. For quantitative covariates, $100(e^\beta -1)$ gives variation in percent of the expected survivor time for each 1 unit increase of the covariate.

In the two parametric approaches, there exist a need to specify the used distribution function. The classically used distributions for duration distributions are the exponential, Weibull, log-logistic, Gompertz, log-normal, gamma, and generalised gamma distributions. Validity of the exponential and Weibull distributions can be graphically tested in the non-parametric approach. If the hazard is constant ($h(t) = \lambda$) then :

$$-\log S(t) = \int_0^t h(u)du = \lambda t .$$

This implies that a plot of $-\ln \hat{S}(t)$ against t should be a straight-line through the origin.

And the plot of $\ln[-\ln \hat{S}(t)]$ against $\ln(t)$ tests the Weibull distribution. In this case, the hazard is $\ln h(t) = \alpha + \beta \ln t$. Hence, a plot of $\ln[-\ln \hat{S}(t)]$ against $\ln(t)$ should be a straight-line with β slope.

The parametric approaches permit simultaneous estimation of covariates effects and of duration dependence. However, the distributional assumption for the baseline hazard is risky. Meyer (1990) has shown that the parametric approach inconsistently estimates the baseline hazard when the assumed parametric form is incorrect.

Semi-parametric approach

Finally the semi-parametric approach focuses solely on the covariates coefficient estimates. This estimation technique estimates the PH model using the partial likelihood framework suggested by Cox (1972), which do not need the specification of the baseline hazard function, $h_0(t)$. One avoids then the risk of a mis-specified baseline function. The quality of the estimation of the covariates coefficients is considered to be more robust than the fully-parametric approach (Oakes, 1977). But the Cox model excludes the baseline hazard and does not allow for consideration of the duration dependence.

ESTIMATION AND RESULTS

Non-parametric estimation

The lifetable method constitutes first exploration of the covariates effects and of the distribution to be used in the parametric approach. The graphical and statistical tests permit to identify influential classification variables and distribution forms.

The resulting survival and hazard functions are presented in figure 1. The survival curve presents two inflexion points. The first, near 20 minutes, seems to indicate the existence of minimum TTB level of 20 minutes, that is declared by almost all travellers. The second point, near 110 minutes corresponds to a diminishing probability of the ending after 2 hours of travel. The survival is decreasing and convex.

The hazard curve is characterised by peaks for 1, 2 and 3 hours that result from the rounding of declared travel times. The hazard curve presents clearly a point where the slope is reversed. The hazard is increasing until near 90 minutes, and then decreasing.
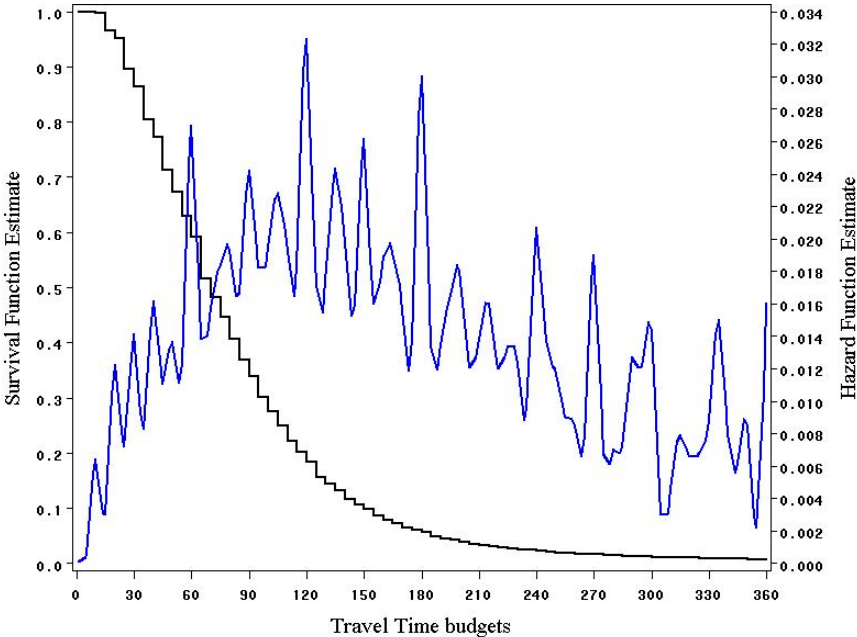

Figure 1

Survival and hazard curves for TTB in min

The non-monotonic form of the hazard curve suggests that non-monotonic distributions (log-logistic and log-normal) will be appropriate distributions in a fully-parametric model. Furthermore, the graphical test of linearity of the transformations ($-\ln(\hat{S})$ and $\ln[-\ln(\hat{S})]$), rejects the hypothesis of exponential and Weibull distributions.

The median survival times are presented in figure 2. For each time t, it approaches the expected survival time given that the process has lasted to t. For a null TTB, the median survival time is 65 minutes, near the Zahavi's TTB level. The decreasing part of the curve suggests that travellers reduce the travel times during the first hour. But from 90 to 120 minutes, the median survival time is stable. Then, individuals that have already a 1.5 hour TTB, are expected to pass 30 minutes more in travel. And finally the median survival time is increasing after 130 minutes. The population concerned with the non-decreasing median residual lifetime is about 30% of the sample.
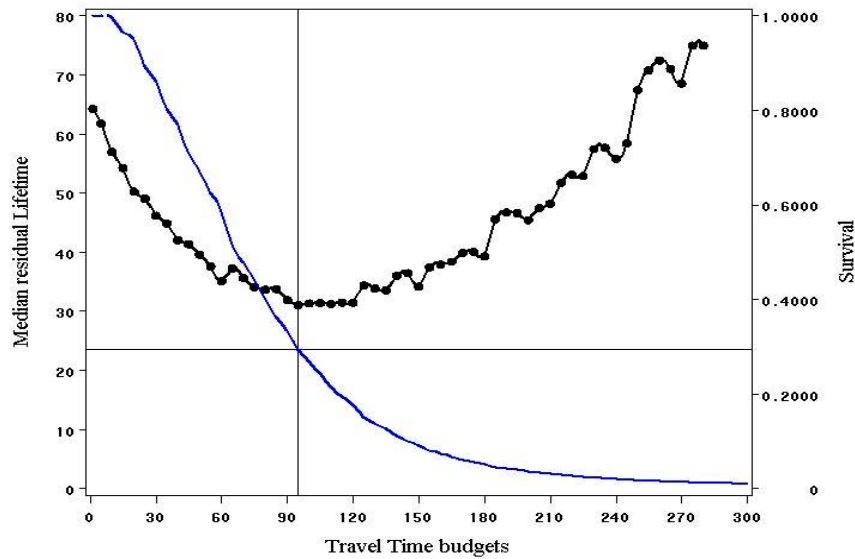
Figure 2

Median survival lifetime

The hazard rate and the median survival time suggest a transition in the allocation of time to transportation, near the 90 minutes level. Everything happens as if, after this level, the travellers failed to diminish their travel times. Therefore, one can segment the population. First, a group of individuals who minimise travel times and that is characterised by a near 1 hour TTB. Second, a group of travellers that abandon, or can not achieved the minimisation of travel times.

Finally the non-parametric estimation produces graphical and statistical tests of classification variables effect on survival. The variables used in the following parametric and semi-parametric models are tested to be associated with distinct survival. Figures 3(a) to 3(f) illustrate examples of the corresponding survival curves for the different classes of the variables. The form of the estimated survival curves for these classes are near the general survival curve. Upper survival curve means higher TTB.

The difference in survival curves between male and female appears after 60 minutes (figure 3(a)). It can be explained by the fact that, as shown by Niemeier and Morita (1996), women spend more time in activities linked to the household responsibilities. Then, they appear to have to return home sooner and to have shorter travel times. Segmentation with respect to the classes of age shows that young people (under 20) have the lowest TTB. Individuals between 20-50 years of age present the highest TTB (figure 3(b)). In figure 3(c), workers are characterised by upper survival curve, then a worker will have higher TTB. And young at school and housewife have the lowest TTB. A licensed driver will have higher TTB (figure 3(d)). Members of high household income have higher TTB, but the difference seems to be small (figure 3(e)). Finally, the different survival curves for the days of trips are illustrated in figure 3(f). The TTB increases from Monday to Friday.
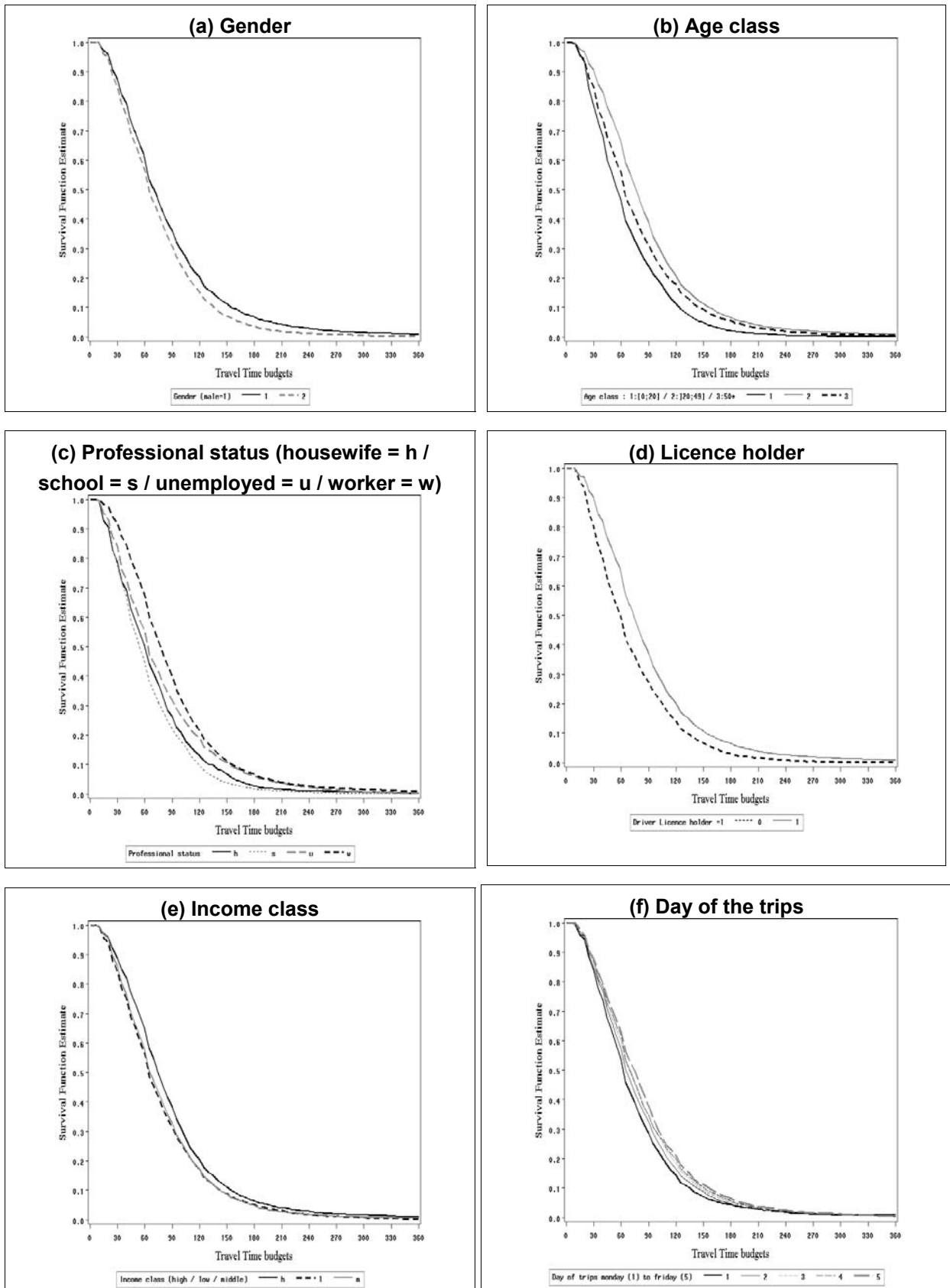
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(a) Gender

(b) Age class

(c) Professional status (housewife = h / school = s / unemployed = u / worker = w)

(d) Licence holder

(e) Income class

(f) Day of the trips

Figure 3
Survival curves

The performed non-parametric tests of survival equivalence inform us about the relationship between TTB and the considered variables. But these tests are only unidimensional. The intuition given by these tests needs to be examined by considering the whole set of variables. Then, we estimate the semi-parametric Cox model, which is multidimensional and does not need to specify an *a priori* distribution.

Semi-parametric estimation - Cox estimation

The Cox method assumes a proportional hazard model. Table 3 presents estimators of the Cox model. Three estimations are performed with nested covariates sets in order to verify the stability of the estimators. A stepwise selection process is applied to select the covariates on the S3 covariates set. The first set of variables (S1) is composed of household and individual characteristics. The second set (S2) is equal to S1 with addition of the "kiss and drive" indicator and the daily activity times: work activity (full time and part time work and time at university for students); leisure activity (sport, cultural and social out-of-home activity); shopping activity. Finally the set S3 adds the principal mode used in the day[2].

In the PH model, estimates can be interpreted with their corresponding hazard ratios. It is defined as the ratio of hazards evaluated at different values of the considered covariate. For example, the hazard ratio of the binary variable high household income is 0.915. Then, the hazard rate of high household income individuals is 91.5% of the hazard of individuals that are not in this high income class. The covariates with hazard ratio less than 1 ($\beta<0$) will reduce hazard rate and as a consequence increase survival and TTB. For the quantitative variables, estimates can be interpreted with respect to the derivative of the logarithm of the hazard rate. Then, a one minute increase of the leisure duration leads to a variation of the TTB equal to $100 (e^{0.002} - 1) = 0.2\%$. Hence, a 1 hour increase of the leisure times leads to a 12% increase in TTB.

Almost all variables are found to have the same effect on the TTB as in the OLS estimation. Male have lower hazard and higher TTB. The TTB increases with age until 50 years. Worker have higher TTB. Unemployed have higher TTB than young at school and housewife, but smaller than worker.

The presence of children decrease the TTB, with stronger effect if the children are under 5 years of age. The number of household members is positively linked to the TTB. And high household income members have higher TTB. The residential location affect TTB. The central location still show higher TTB. And the day of trips is influent. These estimates are stable on the three covariates sets.

The introduction of the activities duration (S2) show a positive link between TTB and leisure and shopping duration. The work duration appears to have a small negative effect on TTB. Finally, if people have to "kiss and drive" somebody then their TTB increase significantly.

Modes of transport have the highest hazard ratios. They can be ordered by increasing TTB: walk, motorcycle, car, cycle, and transit. Walk and motorcycle hardly decrease the expected TTB with a hazard ratio greater than 2.

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[2] The principal mode of transport used is defined as the one with the highest corresponding number of trips.

Table 3

Results of Cox model estimations – Stepwise selection

Semi-parametric Cox Estimation	S1: HH and individual variables		S2: S1 + activities duration		S3: S2 + principal mode used	
Dependent variables	Estimates	Hazard Ratios	Estimates	Hazard Ratios	Estimates	Hazard Ratios
Male	-0.132 ***	0.877	-0.173 ***	0.841	-0.182 ***	0.834
Age over 50 years	0.275 ***	1.317	0.215 ***	1.240	0.181 ***	1.198
Age	-0.005 ***	0.995	-0.004 ***	0.996	-0.006 ***	0.994
Worker	-0.342 ***	0.710	-0.477 ***	0.621	-0.424 ***	0.654
Unemployed	-0.235 ***	0.790	-0.115 ***	0.891	-0.076 **	0.927
Number of children above 6 years	0.074 ***	1.077	0.079 ***	1.082	0.052 ***	1.053
Number of children under 5 years	0.104 ***	1.110	0.143 ***	1.153	0.075 ***	1.078
Nb of HH members	-0.049 ***	0.952	-0.066 ***	0.936	-0.050 ***	0.951
High HH income	-0.089 ***	0.915	-0.069 ***	0.934	-0.072 ***	0.931
Central location	-0.080 **	0.923	-0.080 **	0.923	-0.123 ***	0.885
1st ring East	0.078 ***	1.082	0.066 **	1.069	0.071 ***	1.074
3rd ring East	0.064 **	1.066	0.087 ***	1.090	0.096 ***	1.101
Monday	0.110 ***	1.116	0.065 ***	1.067	0.054 **	1.055
Thursday	-0.042 *	0.958	-0.058 **	0.944	-0.073 ***	0.930
Friday	-0.084 ***	0.920	-0.065 **	0.937	-0.068 **	0.934
Work duration			0.0003 ***	1.000	0.0003 ***	1.000
Leisure duration			-0.002 ***	0.998	-0.002 ***	0.998
Shopping duration			-0.002 ***	0.998	-0.002 ***	0.998
Kiss and Drive (0/1)			-0.240 ***	0.787	-0.268 ***	0.765
Walking					0.921 ***	2.512
Bicycle					0.293 ***	1.341
Motorcycle					0.866 ***	2.378
Public transport					-0.111 ***	0.895
Car					0.371 ***	1.450
Log Likelihood	-101470.5		-101189.42		-100705.99	

* 0.1, ** 0.05, ***0.01 level of significance

This semi-parametric approach confirms the non-parametric intuitions on covariates effects and selects the most influential covariates to be included in the model. But the hazard function is not estimated with this method, then it gives no information on the duration dependence.
In the final part of the estimation, the full parametric model allows to estimate both covariates coefficients and the duration dependence simultaneously.

Parametric estimation

Classically, applied duration models to duration activity have used Weibull distribution function (Mannering et al., 1994; Kitamura et al., 1997). This distribution corresponds to a monotonic hazard, which in our case is not observed. The non-parametric approach concludes to a non-monotonic hazard function and rejects exponential and Weibull distribution functions. Then, the accelerated lifetime models with the log-normal and log-logistic distributions are estimated. In general, likelihood-ratio statistics can be used to compare models, those are nested within another. The exponential, Weibull and log-normal models are special cases of the generalised gamma model, and can then be compared. But the log-logistic is not nested within the generalised gamma distribution. Then, we can only compare the goodness-of-fit of the log-normal and log-logistic model with likelihood level and residuals of Cox-Snell.
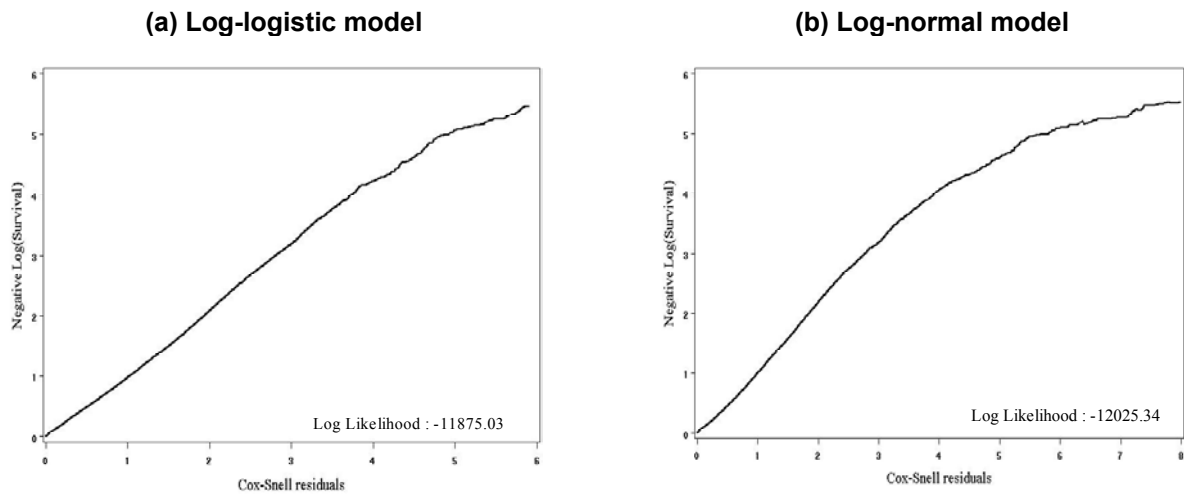
(a) Log-logistic model	(b) Log-normal model

Figure 4

Cox-Snell residuals plot

Figures 4(a) and 4(b) show the Cox-Snell residual and log-likelihood. The best goodness of fit is obtained with the log-logistic distribution. Then, only the estimates of covariates for the log-logistic model is presented in Table 4.

Most of the covariates are significant at 5% with same signs as in the Cox estimation (except the young at school covariate). The model is constructed with the three different sets of covariates (S1, S2 and S3). In an accelerated lifetime model, exponential of the estimates can be interpreted in terms of expected time ratio. For example, with S1, the expected TTB of men is 9% greater than the expected TTB of women. Older people are characterised by a 12% lower TTB. The professional status affects the travel duration. Hence, worker (full time, part time workers and students) have higher TTB. And young at school have lower TTB. The household responsibilities, represented by the number of children leads to lower TTB. And the number of household members increases the TTB. The individuals characterised by high household income have higher TTB. The residential location affects the TTB. The central location increases TTB, and the 1st and the 3rd ring of the East of Lyon decrease it. Finally, the mobility depends on the day of the trips. The TTB on Monday are lower and on Friday are higher. These results are classical findings of the other studies on travel times. At the disaggregated level, the travel times budget can not be constant.

Second, with covariates set S2, the introduction of activities related variables improved the likelihood of the model. The "kiss and drive" indicator has a strong positive effect on the TTB. Leisure and shopping affect positively the TTB. For example, for an increase of 60 minutes of leisure activities, the TTB increase by 12%. And the effect of work duration is small. This result is confirmed by the applications of the other estimation techniques: semi-parametric and non-parametric estimations. Then it may indicate than the daily sum of the travel times is not clearly dependent on the daily work time. The examination of the competition between activities and travel for the time resources, using the time budgets definition enlightens some relationships between TTB and leisure and shopping activities.

Finally, the S3 set introduces the principal modes of transport used for the daily trips. These covariates are highly significant and influent. They are clearly indicators of the accessible

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speeds. Then, one may suspect strong endogeneity between the mode of transport chosen and the travel times.

Over the three covariates sets, the estimates are stable. And the estimated scale parameters of the log-logistic distribution are less than unity, corresponding to a non-monotonic hazard with inverted U-shape. The hazard rate in the S3 model is then increasing until 76.8 minutes and decreasing afterwards. Figure 5 shows the hazard rate for the S3 set.

Table 4

Log-logistic parametric models

Parametric log-logistic distribution	S1: HH and individual variables	S2: S1 + activities duration	S3: S2 + principal mode used
Dependent variables	Estimates	Estimates	Estimates
Intercept	4 ***	3.567 ***	3.872 ***
Male	0.091 ***	0.096 ***	0.078 ***
Age over 50 years	-0.118 ***	-0.086 ***	-0.054 **
Age	0.0006	0.002 **	0.002 ***
Worker	0.148 ***	0.268 ***	0.232 ***
School	-0.215 ***	0.068 **	0.109 ***
Number of Children	-0.045 ***	-0.068 ***	-0.035 ***
Nb of HH members	0.037 ***	0.056 ***	0.042 ***
High income HH	0.086 ***	0.051 ***	0.041 ***
Central location	0.059 **	0.045 **	0.044 **
1st ring East	-0.049 ***	-0.038 **	-0.030 *
3rd ring East	-0.055 ***	-0.067 ***	-0.070 ***
Monday	-0.084 ***	-0.043 ***	-0.037 **
Thursday	0.040 **	0.039 **	0.041 ***
Friday	0.070 ***	0.050 ***	0.053 ***
Work duration		0.0001 ***	0.0001 ***
Leisure duration		0.002 ***	0.002 ***
Shopping duration		0.002 ***	0.002 ***
Kiss and drive (0/1)		0.265 ***	0.275 ***
Walking			-0.727 ***
Bicycle			-0.277 ***
Motorcycle			-0.694 ***
Public transport			0.066 ***
Car			-0.362 ***
Scale	0.401	0.385	0.360
Log Likelihood	-13134.411	-12644.226	-11875.030

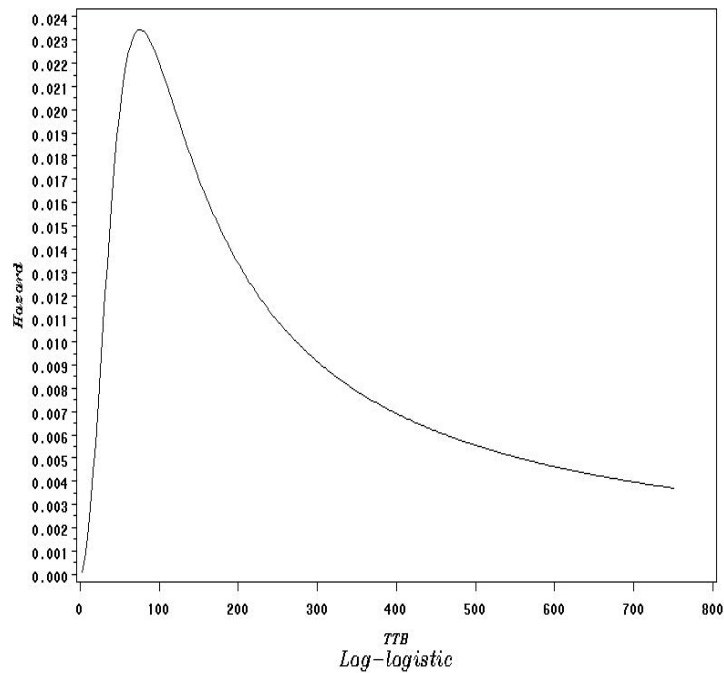* 0.1, ** 0.05, ***0.01 level of significance

Figure 5

Estimated hazard for log-logistic model

CONCLUSION

The Travel Time Budgets stability observed by Zahavi at the world level has been recently validated by Schafer and Victor (2000). At this level of observation, it can be used as an indicator of the world mobility. It can then explain a part of the systematic reinvestment in additional trips of travel-time savings due to increased speeds, which are observed almost all over the world. However, the application of the stability hypothesis to a finer scale of observation, is irrelevant. Zahavi's studies and numerous followers, who analyse TTB in different cities, have shown many relationships existing between TTB and numerous socio-economic, urban and transport variables at a disaggregate level. Major part of these analyses of TTB is unidimensional or limited to the linear model. To overcome these limits, we propose to apply a survival analysis, which is suitable to investigate duration data.

The survival analysis presented in this paper is applied to the travel time budgets (TTB) of Lyon (France). The sum of daily travel times is analysed with respect to the non-parametric lifetable approach, the semi-parametric Cox approach and the full-parametric approach. The first method gives incentives to use a non-monotonic *a priori* distribution in the full-parametric model. The stepwise selection in the Cox model permits a selection of covariates to be included in the parametric approach. Finally, the parametric model is constructed using the resulting set of covariates of the Cox model and non-monotonic distributions.

Usual covariates relative to individual and household, such as gender, age, employment status, presence of children, household income, household location, day of trips and the mode used, are found to be significant. Furthermore, attributes of the activity pattern affect the TTB. If the individual has to "kiss and drive" somebody, his/ her TTB will be significantly longer.

The TTB appears to be positively linked to the leisure and shopping activities duration. The work time is found to have a near zero effect or, as suggested by Kitamura et al. (1992), to have a negative effect on TTB.

These influent variables show the irrelevancy of the "strong TTB stability hypothesis" in the city of Lyon. The stability will mask the multiple mechanisms acting in the time allocation process. But some of the covariates we identified are recurrent in the TTB analyses of different cities and periods. For example, age, gender, employment status have similar effect in many studies. Furthermore, the activity pattern act on the mobility behaviour. TTB are found to be sensitive to the activity duration (leisure and shopping). Then, the "weak TTB hypothesis" can be justified at the disaggregate urban level. Surveys of different cities through time are needed to validate precise regularities that act on TTB.

The non-parametric estimation and the scale of the log-logistic distribution used in the parametric model implie a non-monotonic inverted U-shaped hazard. The corresponding estimated hazard rate is characterised by an inflexion point near 76 min. The non-monotonic hazard implies that the probability of ending daily transport, given it has lasted to a specified time, is not stable. Under TTB stability hypothesis, or more generally under travel time minimisation this conditional probability is expected to be monotonically increasing. The monotonic hazard will characterise a duration that is generated by a minimisation process. The estimated log-logistic hazard seems to show that everything happens as if two groups of travellers exist. The behaviour of a first group of individuals can be represented by the minimisation mechanism. And a second group is composed of individuals that can not or do not want to minimise their TTB.

To gain robustness, the eventuality of heterogeneity between individuals needs to be included in this study. Furthermore, the application of duration model to the TTB failed to consider transport as a derived demand. The interaction between travel times and activity need to be included. The competition between activities for the time resource can be modelled through the competing risk model framework. Duration models may offer an appropriate framework to reach the integration of derived demand concept into the allocation of time modelling.

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