Transport Policy 86 (2020) A7–A13

Contents lists available at ScienceDirect

Transport Policy

journal homepage: http://www.elsevier.com/locate/tranpol

Invited Research Paper

Transport and time use: The values of leisure, work and travel

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ABSTRACT

In this position paper we argue that transport decisions are intimately linked with the assignment of available time to activities, and that a full understanding of the so-called value of travel time savings (*VTTS*) requires modeling time use as a whole, in order to disentangle *VTTS* into the value of liberated time and the value assigned to the conditions of travel. A richer microeconomic framework has emerged from which the values of leisure and work can be empirically estimated, such that the components of *VTTS* can be calculated as well, which permits to identify correctly the priorities when deciding investments.

1. Introduction: time use and transport

Both life expectancy at birth and production have grown steadily in most regions in the world. Statistically, then, our generation expects on average a longer lifetime and has more access to goods and services than all our predecessors. In addition, and as never before, we are surrounded by multiple artifacts that facilitate communications, work and domestic (home) duties: cellphones, electronic mail, microwave ovens, remote controls, video machines, and so on. Although these artifacts reduce the amount of time to perform many daily activities, "lack of time" is one of the most popular complaints today, reflecting a subjective perception that seems to contradict the objective evolution of our living conditions. It is time to talk about time use and its valuation by individuals.

Understanding time assignment to activities has a history in the microeconomic literature, where the first formal analytical models emerged some fifty years ago within the ample framework provided by consumer theory where the individual is seen as a seeker of personal satisfaction (utility) within the limits imposed by constraints to acquire goods and services. Until the middle of the twentieth century, this utility was formulated as dependent only on the level of consumption; accordingly, the only constraint needed was purchasing power, the money budget constraint. In 1965 Gary Becker published an article introducing time within this framework without changing the essence of the model but accounting for the lack of an important element: consumption time.

Becker's idea was to look at market goods as instruments to acquire what he considered the ultimate sources of satisfaction: the final goods. To be effectively generated and consumed these final goods require not only market goods, but also time to consume. For example, a home-made hamburger requires ground meat, potatoes, frying pan, oil, and so on, and time to acquire those goods, prepare the hamburger and eat it. So, indirectly, utility was a function of both market goods and time assigned to preparation and consumption. As a consequence, in addition to the constraint imposed by purchasing power on goods consumed, a new time constraint was necessary as consumption plus working time have a limit imposed by biological cycles (e.g. a day, a week). In Becker's formulation, working time is endogenous (decided by the individual) and does not belong in utility, which is pivotal in his derivation of an overall value of time: the wage rate as the opportunity cost of consumption time.

Transport time entered the picture very soon after Becker's formulation, when Johnson (1966) expanded the role of time in utility beyond consumption, accounting for time at work as well; as a conclusion he asserted that diminishing transport time was equivalent to expanding available time such that its value was equal to the value of time as a resource which, in turn, would be different from the wage rate as the value of time assigned to work (the value of the marginal utility of labor) should be added. This was soon expanded by Oort (1969) in a footnote where a transport time reduction was shown to be different from a pure expansion of free or available time.

But it was DeSerpa (1971) who managed to reformulate the conceptual framework in a very precise way by the introduction of a set of technical constraints that, essentially, established that activities have to be assigned a minimum lapse of time that depended on the goods consumed to actually perform that activity. This allowed him to separate activities different from work in two families: those that are assigned more than the minimum required – which he defined as "leisure" – and those that stick to that minimum. This simple formulation induced many implications. A very important one deals with activities that are assigned more than the necessary minimum: at the margin, the time assigned to each should be valued equally because, as the individual is free to relocate time "in excess", any difference in value would not represent an

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https://doi.org/10.1016/j.tranpol.2019.12.001
Received 27 October 2019; Received in revised form 25 November 2019; Accepted 5 December 2019
Available online 13 December 2019
0967-070X/

individual optimum. As work time also entered utility directly, this single value of leisure was no longer equal to the wage rate w but to the total value of work that included the marginal value of time assigned to work in addition to w.

Regarding those other activities that stick to the minimum necessary – i.e. constrained because of technical reasons - DeSerpa showed that the willingness to pay for a reduction in the constraint was not only due to the possibility of re-assigning time to leisure or work (equally valued at equilibrium), but also due to the reduction of a potentially unwanted activity *per se*; and transport was among those. This willingness to reduce travel time became a whole issue in the literature, less because of the amount of time assigned to travel (relatively small compared to activities like work or sleep) but because – unlike other potentially unwanted activities as domestic work – it is a tertiary activity, i.e. it cannot be delegated to a third party (Burda et al., 2007; Jara-Diaz and Rosales-Salas, 2017).

2. From discrete travel choices to time use

In order to perform activities in a place that is not where the individual is originally located, that person has to move and this movement requires the mandatory assignment of time; from this viewpoint, time and space – the two dimensions that define the Economics of Transport – are not symmetrical concepts, as one can move in time without moving in space but one cannot move in space without moving in time. As time is organized in cycles, an evident trade-off emerges between travel time and other activities. As travel has a cost, behind this trade-off lays an implicit valuation of travel time.

When faster trips are more costly, the most basic relationship between transport and money is revealed by individual travel choices: the so-called value of travel time savings, *VTTS*, which basically represents the willingness to pay to diminish travel time by one unit. At an individual level, the *VTTS* is usually calculated from travel choice models – specifically mode or route choice – using the discrete choices paradigm, where individual preferences are represented by a conditional indirect utility function as explained below.

In 1978 Kenneth Train and Daniel McFadden published a paper that is considered to have provided the microeconomic foundations for the discrete travel choice models, within the context of urban commute to work. Their ideas can be presented in a relatively simple way today. An individual has to choose the right amount of goods and leisure by adjusting time at work and choosing transport mode. Money made at work has to be spent in consumption and transport, while available time has to be assigned to work, transport and leisure (defined as "the rest"). Because of the constraints, the more time is assigned to work the more consumption can be gained but the less leisure is achieved; this is exactly the reason why the model was presented as one where there was a "goods-leisure trade-off". But the choice of number of hours at work was a continuous one while the choice of travel mode to work was discrete: one out of many modes available had to be chosen. This dual choice – time at work and mode – could be approached as if it was made in two steps, solving first the problem of finding the optimal time at work assuming mode was already chosen, which generates a conditional indirect utility function (CIUF) representing the maximum utility provided that mode had been elected. Then – and this is the second part – the actually chosen mode has to be interpreted as the one that maximizes the CIUF.

One of the important properties of the conditional indirect utility function commanding mode choice – the "modal" utility – in Train and McFadden's model, is that the resulting *VTTS* is exactly equal to the wage rate w, which should not be a surprise as their model is just the discrete counterpart of Becker's formulation where the wage rate is the overall value of time: at work (the source of income to acquire goods) and at consumption (the opportunity cost of not working). But this pioneering model has also a hidden property that was not made evident because the authors used the expenditure function to arrive at their result; if the result of the first step was obtained directly solving for time at work Tw conditional on mode choice (i.e. conditional on travel cost c_t and travel time t_t), an equation for Tw and an equation for the (optimal conditional) amount of leisure would be found. In other words, behind the mode choice model underlies a time use model. If utility was given the Cobb-Douglas form as in Train and McFadden's paper, the equation for Tw would be equation (1) where τ is time available and γ the exponent of leisure[1] (see Appendix).

$$T_w^* = (1-\gamma)(\tau - t_t) + \gamma w^{-1} c_t \tag{1}$$

It is worth adding that the discrete approach behind the derivation of a CIUF can be used to explore other conditions as, for instance, dropping the assumption on endogenous income through the free choice of working hours – a fixed-income, fixed-working hours model - leaving mode choice as the only decision made by the individual traveler. This originated an alternative goods/leisure trade-off formulation which Jara-Diaz and Farah (1987) baptized as the expenditure rate model (as opposed to the wage rate model) where disposable income (money to be spent) and disposable time (period to consume) acted as the main determinants of the *VTTS* because the trade-off between leisure and consumption was only left to the choice between fast-expensive against slow-cheap modes. With that simple framework one is able to explain empirically estimated (low) values of time for retired individuals or large values for those traveling longer distances (Jara-Diaz, 1990, 2007).

In its original version, the goods-leisure trade-off framework was indeed elegant but troublesome when one examines the resulting *VTTS* equal to the wage rate, the opportunity cost of both consumption and travel time. Why are we willing to pay to diminish travel time? Essentially there are two reasons: one is to increase the amount of time that an individual can assign freely to other activities (more pleasurable and/or rewarding, leisure or work), and the other is to diminish a presumably unpleasant activity, whose perception depends on the conditions of travel. So the *VTTS* involves exactly the two components identified by DeSerpa (1971) in a model that differs from Becker's substantially. This observation was motivating enough to go back to the connection with time use in three successive pieces we published in 2003, based upon a general approach devised in Jara-Díaz (1998).

The original idea was to replace Train and McFadden's formulation of the discrete choice inspired on Becker, by one that rested upon DeSerpa, a richer model indeed. This meant the introduction of all activities (including work and travel) and consumption as direct sources of utility. Such a discrete formulation was formulated by Jara-Diaz and Guevara (2003) to set up a model where time could be assigned to work, travel and all other activities, and where money from work could be spent in market goods and travel. Utility was a function of time assigned to all activities, time at work, travel time and all goods consumed. Under this formulation – and keeping Train and McFadden's Cobb-Douglas utility -, the CIUF required a new solution for time at work that was explicitly obtained as a function of the same variables in equation (1): travel cost c_t, travel time t_t and the wage rate w (see Appendix); parameters α and β are transformations of the original utility parameters.

$$T_w^* = \beta(\tau - t_t) + \alpha\frac{c_t}{w} + \sqrt{\left(\beta(\tau - t_t) + \alpha\frac{c_t}{w}\right)^2 - (2\alpha + 2\beta - 1)(\tau - t_t)\frac{c_t}{w}} \tag{2}$$

As shown in the Appendix, if Tw was not in utility (its exponent equals 0), then $\alpha + \beta = 0.5$ and solution (2) collapses into the form of equation (1) as a particular case. A most important and novel property of this model, though, was that we were able to estimate the values of α and β econometrically using information on T_w in our sample. Moreover, we could calculate the value of time as a resource – that DeSerpa had proved equal to the value of leisure (VoL) – that we showed to be given by

[1] In equation (1), we are not considering a non-labor income.

$$\frac{\mu}{\lambda}=\frac{1-2\beta}{1-2\alpha}\frac{(wT_w^*-c_t)}{(\tau-T_w^*-t_t)} \tag{3}$$

We also proved that the *VTTS* could be expressed (as in DeSerpa, 1971) as

$$VTTS=\frac{\kappa_t}{\lambda}=\frac{\mu}{\lambda}-\frac{\partial U/\partial t_t}{\lambda}=\text{VoL}-\text{VTAT} \tag{4}$$

This meant that the *VTTS* obtained from the travel choice model – that had been always considered as a single artifact - could be decomposed into the value of doing something else (the VoL) and the value of time assigned to travel (VTAT). By estimating a separate mode choice model for one trip we performed this decomposition for the first time, which was the aim and main contribution of Jara-Diaz and Guevara's model. But this new framework left an important question open which was pointed out to us by Kenneth Small, namely how it can be that time at work in equation (2) is decided by travel time? (This question applies to Train and McFadden's model as well, as shown by equation (1)). This motivated a generalization of the approach that generated our first complete Time Use Model (TUM) which I present in the next section.

3. The basic time use model

The challenge exposed in the previous section was to depart from a framework that had a magnifying lens on transport to a more general one. Working along this line I realized that there was a missing piece in DeSerpa's model, namely the unilateral role of the technical constraints as in his model they referred only to the minimum time needed to perform an activity, determined by the amount of goods consumed. But, what about goods needed to perform an activity? This question prompted the model in Jara-Díaz (2003) presented in equations (5)–(9) where I rescued an element somewhat hidden in the formulation by Evans (1972), namely that goods consumption also had a minimum necessary determined by the activities undertaken.

$$Max\ U(X,T,T_w) \tag{5}$$

subject to

$$I+wT_w-\sum_i P_iX_i\geq 0 \qquad (\lambda) \tag{6}$$

$$\tau-T_w-\sum_j T_j=0 \qquad (\mu) \tag{7}$$

$$X_i-g_i(T)\geq 0\quad \forall i \qquad (\eta_i) \tag{8}$$

$$T_j-f_j(X)\geq 0\quad \forall j \qquad (\kappa_j) \tag{9}$$

This model accounts for all activities and for a complete set of technical relations. Equations (8) were a generalization of Evans' (1972) transformation matrix defined to convert activities into goods consumed, and equations (9) generalized DeSerpa's technical constraints on activities. The next step was to simplify equations (8) and (9), replacing the endogenous minima of activities and consumption (functions g_i and f_j), by exogenous quantities as follows

$$X_i-X_i^{min}\geq 0\quad \forall i \qquad (\eta_i) \tag{10}$$

$$T_j-T_J^{min}\geq 0\quad \forall j \qquad (\kappa_j) \tag{11}$$

This simplification allowed us to obtain an analytical solution of the problem formed by equations (5)–(7) and (10))-(11) with utility given the usual Cobb-Douglas form. First order conditions conduced to a system of equations that contained explicit expressions for time at work, for leisure activities (i.e. those that are assigned more time than the exogenous minimum, contained in set A^f), and for freely chosen goods (i.e. those that are assigned a quantity larger than the minimum necessary, contained in set G^f). As shown in the appendix, the system is (Jara-Diaz and Guerra, 2003)

$$T_w^*=\beta(\tau-T_c)+\alpha\frac{E_c}{w}+\sqrt{\left(\beta(\tau-T_c)+\alpha\frac{E_c}{w}\right)^2-(2\alpha+2\beta-1)(\tau-T_c)\frac{E_c}{w}} \tag{12}$$

$$T_j^*=\frac{\gamma_j}{1-2\beta}(\tau-T_w^*-T_c)\quad \forall j\in A^f \tag{13}$$

$$X_i^*=\frac{\delta_i}{P_i(1-2\alpha)}(wT_w^*-E_c)\quad \forall i\in G^f \tag{14}$$

In equations (12)–(14) γ_j, δ_i, and β are (normalized) utility parameters related with freely chosen activities and goods (see Appendix). It should be noted that equation (12) for time at work is a generalization of Jara-Diaz and Guevara (2003) presented in equation (2), with travel time and cost replaced by two variables that represent committed time T_c and committed expenses E_c. So equation (12) is an explicit proper labor supply model, where time at work depends not only on the wage rate but also on E_c and T_c. Also, note that in equation (14) the price of good *i* could be moved to the left-hand-side forming the expense on that good. This facilitates matters empirically because of two reasons: first, the use of expenses rather than physical quantities; and second, if wanted or needed, the aggregation of (some) consumption in common units (money) was made possible.

The complete system of equations 12–14 is a general model for time use and goods consumption, where the role of committed time and committed expenses seems passive but is actually quite important. This becomes evident in the final expression obtained for the value of leisure (see Appendix):

$$\text{VoL}=\frac{\mu}{\lambda}=\frac{1-2\beta}{1-2\alpha}\frac{(wT_w^*-E_c)}{(\tau-T_w^*-T_c)} \tag{15}$$

In this equation the VoL can be interpreted as the product of an expenditure rate – given by the ratio between available money for consumption and available time to consume – and an expression that represents the preference for leisure.

Adding error terms to equations (12)–(14) and assuming a multivariate normal distribution for them form the basis for the empirical estimation of the parameters and the corresponding values of leisure and work, recalling that for every individual the value of leisure is equal to the total value of work that included the marginal value of time assigned to work in addition to *w*. This basic model prompted a series of empirical applications that are very useful for comparisons (Jara-Diaz et al., 2008; Konduri et al., 2011; Jara-Diaz, Munizaga and Olguín, 2013; Jara-Diaz and Astroza, 2013). Although the most important contribution of this series of articles is the formulation and solution of a time use model that lies behind travel choices, the connection with travel decisions got buried within the definition of committed time and committed expenses which include total (mandatory) travel time and travel cost in the period, respectively. Before going into this, note that the estimated values of the activities and goods parameters exhibit some interesting properties. One is that, at the observed optimum, the ratio between the time-related preference parameters for freely chosen activities (leisure) equals the ratio between the corresponding time assignments (see equations C.6 and C.15 in Appendix). In other words, total free time is assigned in such a way that more attractive activities are assigned more time, and this is done until they are all valued equally.

4. Time use and travel as joint decisions

Using the theoretical framework developed between 2003 and 2008 – turned into an operational econometric model –, the empirical results concentrated on the values of leisure and work as interesting by themselves,[2] particularly because this was the first microeconomic model from which these values could be obtained objectively, i.e. by looking at what individuals do and choose within their constraints: amount of goods and services bought and amount of time devoted to the different activities. Previous approaches to find or estimate such value can be found in the areas of household production and labor economics, e.g. Alvarez-Farizo et al. (2001), who used contingent rating to calculate *VTTS* for leisure trips; or Lee and Kim (2005), who used a switching regression model to estimate the reservation wage.

But the original intention of our model remained: to calculate the value of leisure in order to be able to disentangle the *VTTS* into the value of liberated time and the value of travel conditions. The link with transport - which was the main motivation in Jara-Diaz and Guevara (2003) - was never lost. The central idea was always to combine a time use model with a travel choice model in order to obtain both components of *VTTS* for all segments in the model. In the original paper the theoretical connection between the multiplier of the technical constraint on transport time and the *VTTS* was rigorously established, but the estimation of the work time model and the mode choice model for the same individuals was made independently. We improved this by recognizing the correlation between the functions representing both models, i.e. work and travel (Munizaga et al., 2006). In 2008 we used a locally collected data base on time use and trip-to-work mode choice specifically aimed at estimating the first simultaneous time-use travel-choice model (Munizaga et al., 2008). In that paper the system of equations included not only work but all freely chosen activities, plus mode choice to work, showing that the resulting VTAT was indeed different from what would be obtained with independent estimation of the time-use and mode-choice models (both resulted negative). A question, though, remained unanswered: is it reasonable to consider a whole work-leisure cycle on one hand and a single (daily) decision as mode choice for one trip on the other? This prompted a research initiative that is worth summarizing here.

In 2014 an ambitious research project housed at BOKU,[3] Vienna, was put forward by a team including researchers from Austria, Germany and Switzerland. The main objective was to estimate the basic time-use model presented in Jara-Diaz et al. (2008) together with travel choice models covering the same period using data specifically collected from a representative sample of Austrian workers. Information was gathered directly from individuals regarding all activities, expenses and trips made during a whole week, along with income and detailed socio-economic information.

For the first time data included not only time assigned but also expenses made in the same period, such that the complete system of equations 10–12 could be estimated increasing the efficiency of the parameters. This was done concentrating exclusively on the time-use-goods-consumption equations (Hössinger et al., 2019). In parallel, a clever method was devised to estimate mode choice models for the whole week, obtaining not only the *VTTS* for different segments but also what is called in the literature the “mode” and “users” effects behind travel time valuation (Schmid et al., 2019). Although the time use and the mode choice models were estimated independently, both models involved the same individuals, such that the VTAT for each individual in the sample could be calculated using equation (4), obtaining quite interesting results; for instance, the largest (positive) value for the VTAT in all segments was for public transport which, in our opinion, reflected well the very comfortable conditions for using transit in Austria.

As part of the same research project, an ambitious sophisticated procedure was designed to estimate what we considered the most complete simultaneous time-use, consumption and travel model ever attempted (Jokubauskaite et al., 2019). The calculated values of time obtained with the simultaneous procedure are close to those obtained by Hössinger et al. (2019) and Schmid et al. (2019) in their independently estimated models: an average VoL lower than the average wage rate (which means a negative value of work); a *VTTS* that varies strongly across modes (with car more than double that of public transport); and a VTAT that is positive only for public transport. Of course, the joint estimation should be preferred because it is indeed statistically superior to the independent estimation (and permits the calculation of standard deviations for the VTAT).

5. Synthesis and ongoing issues

Standing on the shoulders of Becker (1965), DeSerpa (1971), Evans (1972), and Train and McFadden (1978), time use and mode choice models have been provided with a solid microeconomic support that we have presented here as an integrated framework based upon two key observations:

- The derivation of a conditional indirect utility function that commands mode choice requires an underlying time use model.
- The values of time that are revealed by mode choice have an explicit connection with the values of leisure and work revealed by activities and consumption choices.

When individuals are looked at from this viewpoint, a number of elements appear that indeed enrich the analysis and illuminate the empirical work, pushing the estimation methods towards new frontiers. There are, however, a number of issues within the realm of the microeconomics of consumer behavior that remain to be discussed and incorporated. Some of these issues pertain to the domain of the time use models and others are related with travel choice.

Among the issues that should receive special attention within the time use area I would like to mention the role of some activities, and the unit of observation or the subject of research. As shown here, solving for work time T_w is a key step towards obtaining the system of equations for activities and consumption. In fact, equations (1), (2) and (12) are labor supply models of increasing complexity from which the parameters that are necessary to calculate the value of leisure can be directly estimated. It is not difficult to show analytically that the effect of the wage rate on T_w in equation (12) depends on the levels of committed time T_c and committed expenses E_c, i.e. the sign of the derivative varies with those levels and can explain the different segments in the traditional backward-bending labor supply curve – the so-called substitution and income effects - and even more sophisticated shapes discussed in the literature of labor economics. The cases of extreme poverty in either time or money and their connection with travel choices is an area definitely worth exploring.

Estimating in the best possible way the value of leisure at the individual level makes the time use elements in the consumption-activities model particularly relevant to consider. Unveiling what lies behind *VTTS* using equation (4) once the VoL is obtained, illuminates the emphasis that decision makers should put when deciding on investments in the transport sector whenever speed and comfort collide; if VoL is larger than –VTAT it would be better to aim at faster travel; more comfortable trips should be preferred otherwise. In order to estimate more reliable VoL, there are two activity types that should be explored

[2] It is impossible to avoid the direct linkage between the values of both leisure and work with the notion of happiness. The VoL is literally the value assigned to freely chosen activities, reflecting the overall value assigned to free time, and the (marginal) value of work can be negative (meaning that the individual is marginally working for the money) or positive (marginally working for pleasure and money).

[3] Universität für Bodenkultur (University of Natural Resources and Life Sciences).

and studied with great care: what can be called maintenance activities (sleep, eat), and domestic work. Sleep seems particularly important as it consumes one third of daily time and there are required amounts recommended in order to recover strength (for work and sports, for example), and to be alert in all activities in general. Its relation with the VoL is intuitively strong; formulating its role correctly is a challenging task that requires interaction with other fields of knowledge as health sciences and sociology.

Domestic work is a type of activity that presents some peculiarities. First, in many surveys this coincides with the concept of "unpaid labor" when performed by a member of the household (usually female), and it refers to tasks that can be performed by an outside provider for a payment: cooking, cleaning, laundry, childcare, etc. So it means money saved that is traded for time assigned; the connection with the VoL is quite evident.

Regarding the unit of observation, it makes a difference if one looks at the individual worker against the household as a whole, not only in those cases where more than one paid worker is present, but also because of domestic labor. From this viewpoint, the literature on cooperative and non-cooperative household models contains elements that should be integrated into the time use models that try to capture correctly the VoL. This is relevant at least for two reasons: a budget constraint at a household level might involve a lower marginal utility of income, and consumption externalities might emerge both on the goods consumption side and on the time assigned to activities by the family members; as a result, values of leisure should increase regarding those obtained with workers looked in isolation.

Regarding the domain of travel choices, the specification of the CIUF is indeed dependent on the analytical solution of the time use model, which could be obtained *a la* Train and McFadden if a single trip was considered, keeping in mind that their model was conceived within the context of urban commute. When all trips in the period are looked at from the perspective of the discrete choice paradigm, the CIUF for a single trip makes no sense and an overall CIUF is unmanageable, although the concept remains. Nevertheless, some properties can be translated from the (aggregate) time-consumption world to the (disaggregate) mode choice space, as for example the presence of income effect which, as shown in Jara-Diaz and Videla (1989), can be captured by a squared-in-cost term in the CIUF, something that extends to time components as well. This way, the proportion of expenses or time assigned to (mandatory) travel within a work-leisure cycle has a counterpart in the specification of the CIUF for each trip; if those proportions are large, the CIUF should be specified containing higher order cost and time terms.

Finally, there is a very clear connection between the time use-consumption model and the set of travel choices in the same period: total travel cost and total travel time enters E_c and T_c in the time use models described previously. This means that the summation of travel time and travel expenses across all observed choices in the period considered has to add up to quantities that enter exogenously into the time use model. Mode choices make these quantities endogenous, something that could be treated analytically as constraints that would constitute an explicit link between both models; considering this in the simultaneous estimation of the travel and time-use models is yet another avenue to be explored.

The theory developed so far regarding transport and time use has been conceived having in mind a work-leisure cycle, which can be a week, a month, a semester or a year. The general view summarized here can be adapted to face the specific challenges that arise depending on the context, e.g. the usual role of weekends in a week (mostly leisure) can be assigned to vacation periods when modeling a whole year. Whatever the time frame is, theoretically supported transport and time use models are indeed necessary in order to improve our understanding of an activity that is undergoing important technological changes that can modify the way we look at vehicles beyond a simple moving device. We should encourage researchers to keep on contributing creative and solid work in this area of knowledge.

Acknowledgements

This research was partially funded by Fondecyt, Chile, Grant 1160410, and CONICYT PIA/BASAL Grant AFB180003. The collaboration of Diego Candia is gratefully appreciated.

Appendix. the analytical models

Train and McFadden (1978).

$$Max\ U(G,L) \tag{A.1}$$

subject to

$$G + c_t = wT_w + E \tag{A.2}$$

$$L + T_w + t_t = \tau \tag{A.3}$$

$$t \in M$$

where T_w is working time, w is wage rate, E is income from other sources, τ is total available time and M is the set of available modes. Using T_w as a "pivot", replacing G and L as functions of T_w from (A.2) and (A.3) into (A.1), the optimal value for T_w can be found conditional on mode choice (i.e. on c_t and t_t), i.e a conditional demand for working time, $T_w^*(E - c_t, w, \tau - t_t)$. Following this procedure,

$$Max\ \ U(G,L) = Max\ \ U\ \ (E - c_i - wT_w, \tau - t_i - T_w) \tag{A.4}$$

The optimal condition is

$$\frac{\partial U}{\partial T_w} = \frac{\partial U}{\partial G}\frac{\partial G}{\partial T_w} + \frac{\partial U}{\partial L}\frac{\partial L}{\partial T_w} = -\frac{\partial U}{\partial G}w - \frac{\partial U}{\partial L} = 0 \tag{A.5}$$

Considering a Cobb-Douglas utility function, i.e., $U = KG^{1-\gamma}L^{\gamma}$ and using (A.5), we get:

$$\frac{\partial U}{\partial T_w} = (1-\gamma)KG^{-\gamma}L^{\gamma}w - \gamma KG^{1-\gamma}L^{\gamma-1} = 0 \tag{A.6}$$

From (A.6) the optimal T_w can be found:

$$T_w^* = (1-\gamma)(\tau - t_t) + \gamma w^{-1}(c_t - E) \tag{A.7}$$

Jara-Díaz and Guevara (2003).

$$Max \;\; U(X, T, T_w, t) \tag{B.1}$$

subject to

$$wT_w - \sum_i P_i X_i - c_t \geq 0 \qquad (\lambda) \tag{B.2}$$

$$\tau - T_w - \sum_j T_j - t_t = 0 \qquad (\mu) \tag{B.3}$$

$$t_t - t_t^{min} \geq 0 \qquad (\kappa_j) \tag{B.4}$$

where X is the vector of goods consumed (with market price P_i), T is the vector of all activities except for work and transport, and t_t^{min} is a exogenous technical minimum for transport time.

Considering a Cobb-Douglas utility function, i.e., $U = \Omega T_w^{\theta_w} \; t_t^{\theta_t} \prod_{j \in J} T_j^{\theta_j} \prod_{i \in I} X_i^{\delta_i}$, we can solve the optimization problem to obtain the optimal working time. From the first order conditions of the problem, the following equation is obtained:

$$\frac{A}{(\tau - T_w - t_t)} = \frac{\theta_w}{T_w} + \frac{B}{\left(T_w - \frac{c_t}{w}\right)} \tag{B.5}$$

where A is the summation over all activity parameters but work and travel, $\sum \theta_j$, and B is the summation over all goods exponents, $\sum \eta_i$. Defining $\alpha = (A + \theta_w)/2(A + B + \theta_w)$ and $\beta = (B + \theta_w)/2(A + B + \theta_w)$ and using B.5 allows obtaining the optimal working time:

$$T_w^* = \beta(\tau - t_t) + \alpha\frac{c_t}{w} + \sqrt{\left(\beta(\tau - t_t) + \alpha\frac{c_t}{w}\right)^2 - (2\alpha + 2\beta - 1)(\tau - t_t)\frac{c_t}{w}} \tag{B.6}$$

The solution with the negative root is discarded by analyzing the expression as θ_w approaches to zero. If $\theta_w = 0$ (equivalent to consider that the utility is not affected by the working time), from the definitions of α and β it is easy to see that $\alpha + \beta = 0.5$, and equation (B.6) collapses into the optimal working time from the model by Train and McFadden, when considering synthetic variables G representing all goods consumption and L representing all activities but work and travel, when non-working income is zero.

Jara-Díaz and Guerra (2003); Jara Diaz et al. (2008).

$$Max \;\; U(X, T, T_w) \tag{C.1}$$

subject to

$$I + wT_w - \sum_i P_i X_i \geq 0 \qquad (\lambda) \tag{C.2}$$

$$\tau - T_w - \sum_j T_j = 0 \qquad (\mu) \tag{C.3}$$

$$X_i - X_i^{min} \geq 0 \quad \forall i \qquad (\eta_i) \tag{C.4}$$

$$T_j - T_J^{min} \geq 0 \quad \forall j \qquad (\kappa_j) \tag{C.5}$$

where X_i^{min} and T_J^{min} are exogenous technical minima for good consumption and time allocated to activities respectively. It is important to note that in this model, transport time is included in vector T.

Considering a Cobb-Douglas utility function, i.e., $U = \Omega T_w^{\theta_w} \prod_{j \in J} T_j^{\theta_j} \prod_{i \in I} X_i^{\varphi_i}$, we can solve the optimization problem to obtain the optimal working time. From the first order conditions of the problem, the following equations are obtained:

$$\frac{\theta_j U}{T_j} - \mu = 0 \quad \forall j \in A^f \tag{C.6}$$

$$\frac{\varphi_i U}{X_i} - \lambda P = 0 \qquad \forall i \in G^f \tag{C.7}$$

$$\frac{\theta_w U}{T_w} + \lambda w - \mu = 0 \tag{C.8}$$

Equation (C.6) implies that the time assigned to a freely chosen activity is proportional to its parameter (see C.15 below). Equations C.6 and C.7 for all unrestricted activities and goods plus constraints C.2 – C.5 yield:

$$\frac{\mu}{U} = \frac{\Theta}{(\tau - T_w - T_c)} \tag{C.9}$$

$$\frac{\lambda}{U} = \frac{\Phi}{(wT_w - E_c)} \tag{C.10}$$

where Θ is the summation of the exponents θ_j over all unrestricted activities (those activities that are assigned more time than the minimum), Φ is the summation of the exponents η_i over all unrestricted goods, T_c is the summation of time allocated to restricted activities and E_c is the summation of expenses on restricted gods minus non-working income. Defining $\alpha = (\Theta + \theta_w)/2(\Theta + \Phi + \theta_w)$, $\beta = (\Phi + \theta_w)/2(\Theta + \Phi + \theta_w)$, $\gamma_j = \theta_j/ 2(\Theta + \Phi + \theta_w)$ and $\delta_i = \varphi_i/2(\Theta + \Phi + \theta_w)$, and using (C.8)-(C.10) allows to obtain the optimal working time:

$$T_w^* = \beta(\tau - T_c) + \alpha\frac{E_c}{w} + \sqrt{\left(\beta(\tau - T_c) + \alpha\frac{E_c}{w}\right)^2 - (2\alpha + 2\beta - 1)(\tau - T_c)\frac{E_c}{w}} \tag{C.11}$$

From equation (C.6), (C.7), (C.9) and (C.10) we obtain:

$$T_j^* = \frac{\gamma_j}{1 - 2\beta}\left(\tau - T_w^* - T_c\right) \quad \forall j \in A^f \tag{C.12}$$

$$X_i^* = \frac{\delta_i}{P_i(1 - 2\alpha)}\left(wT_w^* - E_c\right) \quad \forall i \in G^f \tag{C.13}$$

Using equations (C.9) and (C.10) and expression for the value of leisure is obtained

$$\frac{\mu}{\lambda} = \frac{1 - 2\beta}{1 - 2\alpha}\frac{\left(wT_w^* - E_c\right)}{\left(\tau - T_w^* - T_c\right)} \tag{C.14}$$

From equation (C.12) and the definition of γ_j , an expression for the ratio between times assigned to freely chosen activities is obtained

$$\frac{T_j^*}{T_k^*} = \frac{\gamma_j}{\gamma_k} = \frac{\theta_j}{\theta_k} \quad \forall j, k \in A^f \tag{C.15}$$

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