Journal of Transport Economics and Policy, Volume 37, Part 1, January 2003, pp. 29–46

Behind the Subjective Value of Travel Time Savings

The Perception of Work, Leisure, and Travel from a Joint Mode Choice Activity Model

Sergio R. Jara-Díaz and Cristián A. Guevara

Address for correspondence: Professor Sergio R. Jara-Díaz, Universidad de Chile, Casilla 228-3, Santiago, Chile. Cristián A. Guevara is at the same institution.

This research was supported by Fondecyt, Chile, Grants 1010687 and 1000863, and by the Millennium programme P01-34. An intermediate version of this paper was written while Professor Jara-Díaz was a Visiting Scholar at the Institute of Transport Studies of the University of Sydney, whose hospitality is gratefully acknowledged, as well as the fruitful interaction with Professor David Hensher. The valuable comments of Ken Small helped the authors enormously with both presentation and discussion of the methodology. The collaboration of Reinaldo Guerra is appreciated. Remaining errors are the responsibility of the authors.

Abstract

Many travel choice models estimated throughout the world have been used to calculate the full value of travel time savings. Its components, however, have never been estimated quantitatively. This article takes into consideration the fact that travel (mode) choice and activity demand models come from a common microeconomic framework such that their specifications are linked. The authors show that estimating both types of models from the same population makes it possible to obtain all components of the subjective value of travel time savings empirically because the models share some common parameters. This novel approach is experimentally applied using information on travel choices and home-work activities for two income groups collected in Santiago, Chile.

Date of receipt of final manuscript: August 2002

Introduction

The subjective or behavioural value of travel time savings (*SVTTS*) calculated from discrete travel choice models as the trade-off between cost and time in modal utility, represents the willingness to pay to diminish travel time (either in-vehicle, waiting, or walking) by one unit. This *SVTTS* can be shown to reflect the sum of at least two effects; first, the willingness to substitute travel time for other more pleasurable or useful activities and, second, the direct perception of the reduction of travel time itself. Regarding the first effect, one such substitute activity could be paid work, in which case the *SVTTS* will also include the additional money earned (or its equivalent goods consumption) in addition to the subjective value of work time. Hundreds of travel choice models estimated throughout the world have been used to calculate the full value of travel time savings. Its **components**, however, have never been estimated quantitatively. After Jara-Díaz (1998), in this article we take into consideration the fact that travel (mode) choice and activity demand models come from a common microeconomic framework such that their specifications are linked. We show that estimating both types of models from the same population makes it possible to obtain all components of the *SVTTS* empirically (or to calculate them distinctly) because the models share some common parameters. This novel approach is experimentally applied using information on travel choices and home-work activities for two income groups collected in Santiago, Chile.

The paper is organised as follows. First, we develop a microeconomic model of time assignment to activities that follows DeSerpa (1971), from which a discrete travel choice model can be derived. An association is then established between the *SVTTS* and other relevant values of time: the value of leisure (or value of time as an individual resource, in DeSerpa's terminology), the wage rate, the marginal value of work, and the marginal value of travel time. Using a Cobb–Douglas form for utility, in section three we show that the mode choice model can be coupled with a labour supply model derived from the same framework in such a way that the components of the *SVTTS* can be actually calculated. To give an example of this approach, data on activities (time at work, at home and travelling) and on mode choice from a sample of users in Santiago (two income strata) are described in section four along with models and results. A synthesis and conclusions are offered in the final section.

The Components of the Subjective Value of Travel Time Savings

Let us consider the following model after DeSerpa (1971)

$$\text{Max } U(X, T) \tag{1}$$

$$I_f + wT_W - P^t X - c_t \geq 0 \rightarrow \lambda \tag{2}$$

$$\tau - \sum_{i=1}^{n} T_i = 0 \rightarrow \mu \tag{3}$$

$$T_i - h_i(X) \geq 0 \rightarrow K_i \qquad \forall i \neq R, Wf \tag{4}$$

$$T_j - T_j^{MIN} \geq 0 \rightarrow K_j, \qquad j = R, W_f \tag{5}$$

where U is the utility function, X, P and T are vectors of goods consumed, goods prices, and time assigned to activities, respectively, W_f corresponds to fixed work, W corresponds to variable work, w is the wage rate, I_f is fixed income, c_t is travel cost, n is the number of activities, $\hat{o}$ is the length of the period considered, R is travel, and T_j^{MIN} corresponds to a minimum time restriction on activities. Finally, λ, μ, and K_i are Lagrange multipliers.

This model has the following characteristics. The level of utility is dependent on the consumption of all goods and on the time assigned to all activities (including work, unlike Becker, 1965; see also Evans, 1972). There are time and income constraints, and the latter includes a variable work time that generates income through a wage rate; there are exogenous minimum time restrictions for travel and fixed work, and endogenous ones for all the other activities, that depend on goods consumption.

The theoretical interpretation of the Lagrange multipliers within the framework of non-linear programming, establishes that they correspond to the variation of the objective function evaluated at the optimum due to a marginal relaxation of the corresponding restriction (see, among others, Luenberger, 1973). Thus, the multiplier μ associated to the time restriction is the marginal utility of time representing by how much utility would increase if individual time available was increased by one unit. By the same token, λ is the marginal utility of income and K_i is the marginal utility of saving time in the i^{th} activity.

From the interpretation of the multipliers, three concepts of time value were defined by DeSerpa: (a) the **value of time as a resource** for the individual (μ/λ), which should not be mistaken for the "resource value of time" as defined by Hensher (1977); (b) the **value of saving time** in the i^{th} activity (K_i/λ), and (c) the **value of assigning time** to the i^{th} activity ($(\delta U/\delta T_i)/\lambda$), which is the value of the marginal utility of that activity. It should be noted that the last two definitions are activity specific while the first is not. Also, the value of assigning time to an activity is the money value of the direct marginal utility. Beyond these definitions, one can add the objective marginal price of assigning time to an activity which, in the case of work, would correspond to minus the marginal wage (Gronau, 1986). Note that the value of saving time in the i^{th} activity will be nil if the individual voluntarily assigns to it more time than the required minimum (which is how DeSerpa defined a leisure activity). It will be positive otherwise. This means that the individual will be willing to pay to reduce the time assigned to a certain activity only if he or she is constrained to assign more time to it than desired.

In order to establish a relation between the different concepts of time value, the first-order conditions corresponding to problem (1)–(5) can be manipulated to obtain a result originally established by Oort (1969),

$$\frac{K_i}{\lambda} = \frac{\mu}{\lambda} - \frac{\partial U/\partial T_i}{\lambda} = w + \frac{\partial U/\partial T_w}{\lambda} - \frac{\partial U \partial T_i}{\lambda}. \tag{6}$$

This expression shows that the value of saving time in the i^{th} activity is equal to the value of doing something else minus the value of assigning time to that particular activity (because it is being reduced). It is worth noting that equation (6) improves over Becker (1965), for whom time was valued at the wage rate irrespective of its assignment, and over Johnson (1966), for whom the value of time was μ/λ for all activities. A nice interpretation is obtained if we note that, for those activities that are assigned more time than the minimum required ($K_i = 0$, a leisure activity), the value of assigning time $(\delta U/\delta T_i)/\lambda$ happens to be equal to μ/λ for all of them. This is the reason why DeSerpa called this ratio the value of leisure. On the other hand, equation (6) establishes that μ/λ is also equal to the total value of work, which has two components: the money reward (the wage rate), and the value of its marginal utility (or value of time assigned to work). Therefore, the value of saving time in a constrained activity is equal to the value of leisure (or work) minus its marginal utility value (presumably negative).

If we consider the particular case of travel, it can be shown that the value of saving travel time, K_i/λ or $SVTTS$, corresponds exactly to the ratio between the marginal utilities of time and cost that are estimated as part of the modal utility in a discrete travel choice model. This has been shown in different forms by various authors (Bates, 1987, after Truong and Hensher, 1985; Jara-Díaz, 2000; Jara-Díaz, 2002). The essence of this property rests on the fact that modal utility is a conditional indirect utility function of model (1)–(5), that is, an indirect utility that is conditional on travel cost and travel time. To be more specific, the activity-consumption model can be solved for T and X as functions T^* and X^* of utility parameters, the wage rate, travel cost, travel time, and all exogenous variables. These functions, which are conditional demands for goods and activities, can be replaced back in utility obtaining $U(T^*, X^*)$, which is the conditional indirect utility function usually called modal utility that commands mode choice. In the appendix we present a general though straightforward proof of the equality between K_i/λ and the ratio between marginal utilities in mode choice models, using a corollary of the sensitivity theorem from non-linear programming.

Although empirical values for K_i/λ can be estimated using the discrete travel choice framework, so far no methodology has been developed to estimate the different elements in equation (6) from a model system. Perhaps the only antecedent is Truong and Hensher's (1985) attempt at obtaining μ/λ as part of the coefficient of travel time in mode choice models (which they claim was $\mu/\lambda - K_i/\lambda$), which prompted Bates' (1987) identification of that coefficient as K_i/λ only.[1] For a full discussion on the *SVTTS*, see Jara-Díaz (2000).

As shown above, the behavioural framework represented by equations (1) to (5) not only originates a mode choice model, but a set of activity (and consumption) models as well. Therefore, as suggested by Jara-Díaz (1998), information on time assigned to activities could be used to estimate conditional time assignment models that involve the same set of parameters as the mode choice model. Now we present a methodology from which the values of leisure, work, and travel can be calculated by combining travel and activity models using appropriate data.

A Model System for Activity Time Assignment and Travel

Let us consider a somewhat simpler version of the model presented in the previous section, with a Cobb–Douglas utility function and a single technical relation:

$$\text{Max } U = \Omega T_w^{\theta_w} T_t^{\theta_t} \prod_{i \in I} T_i^{\theta_i} \prod_{k \in K} X_k^{\eta_k} \tag{7}$$

[1] Although related with business travel time, Hensher (1977) reported a survey based approach to calculate what he called "the disutility of travel compared with the equivalent time spent at the office" (p. 88).

subject to

$$wT_w - \sum_{k \in K} P_k X_k - c_t \geq 0 \leftarrow \lambda | \tag{8}$$

$$\tau - T_w - T_t - \sum_{i \in I} T_i = 0 \leftarrow \mu \tag{9}$$

$$T_t - T_t^{Min.} \geq 0 \leftarrow \kappa, \tag{10}$$

where θ_i and η_k are parameters corresponding to activities and goods respectively, Ω is a utility constant, w is the wage rate, and c_t is trip cost. I is the set of all activities but work and travel, and K is the set of all goods. Note that sub-index t stands for work trip. We are assuming that the individual either chooses freely how much to work, or finds himself in a long-run equilibrium (salary and work hours). First-order conditions can be obtained for goods, travel, work and other activities. These are

$$\frac{\partial U}{\partial T_i} = \mu = \frac{\theta_i}{T_i} U \qquad \forall i \neq W, t \tag{11}$$

$$\frac{\partial U}{\partial T_W} + \lambda w - \mu = \frac{\theta_W}{T_W} U + \lambda w - \mu = 0 \tag{12}$$

$$\frac{\partial U}{\partial T_t} - \mu + K_t = \frac{\theta_t}{T_t} U - \mu + K_t = 0 \tag{13}$$

$$\frac{\partial U}{\partial X_K} - \lambda P_K = \frac{\eta_k}{X_k} U - \lambda P_K = 0 \qquad \forall k \tag{14}$$

$$(T_t - T_t^{MIN}) K_t = 0. \tag{15}$$

Before manipulating these equations, recall from the previous section that model (7)–(10) can be solved *conditional* on the mode chosen for the work trip, from which a conditional solution for goods, $X^*(w,c_t,T_t)$, and activities, $T^*(w,c_t,T_t)$, can be obtained. If these solutions are replaced back in U, a conditional indirect utility function is obtained. This represents the so-called modal utility, and provides the framework to estimate a mode choice model for the work trip (see Jara-Díaz, 1998). If this modal utility V is linearly approximated within each income group (more precisely, for a given w), then

$$V_t{}^j \approx \gamma^j - \gamma^t t_j - \gamma^c c_j, \tag{16}$$

where c_j is modal cost (price), t_j is modal travel time (aggregated for consistency) and the γs are parameters. As shown in the appendix, the coefficient of time is the multiplier K_t and the coefficient of cost is minus the marginal utility of income, such that the value of saving time in the work trip can be calculated in the usual manner as (see also Jara-Díaz, 1998, and Bates, 1987)

$$\frac{\gamma^t}{\gamma^c} \equiv \frac{K_t}{\lambda} = SVTTS. \tag{17}$$

Expression (17) creates an explicit analytical link between the multipliers of the activity-consumption model (7)–(10) and the parameters of the travel model represented by (16). Note that the very existence of a value for $SVTTS$ implies that K_t is different from zero and, therefore, that $T_t = T_t^{MIN}$ by virtue of equation (15).

Now we will elaborate on conditions (11) to (14) in order to obtain an operational model for time assigned to work from which valuable information on other relevant parameters can be estimated and eventually used for the calculation of $SVTTS$ components.

First, solving equation (14) for $P_k X_k$ summing over k and applying (8) yields

$$\frac{\lambda}{U} = \frac{B}{(wT_w - c_t)}, \tag{18}$$

where B is the summation over all goods exponents, $\Sigma\eta_\kappa$. On the other hand, solving equation (11) for T_i, summing over i and applying (9) yields

$$\frac{\mu}{U} = \frac{A}{(\tau - T_w - T_t)}, \tag{19}$$

where A is the summation over all activity parameters but work and travel, $\Sigma\theta_i$.[2] Finally, from equation (12)

$$\frac{\mu}{U} = \frac{\theta_w}{T_w} + \frac{\lambda}{U} w. \tag{20}$$

Using equations (18), (19) and (20) we obtain

$$\frac{A}{(\tau - T_w - T_t)} = \frac{\theta_w}{T_w} + \frac{B}{(T_w - c_t/w)}, \tag{21}$$

[2] B and A can be interpreted as the coefficients of synthetic variables representing goods and all activities but work and travel, respectively. Thus, expression (7) can be seen as an expanded goods/leisure utility, including work and travel.

from which we obtain the quadratic equation

$$(A+B+\theta_w)T_w^2 - \left[(\tau - T_t)(B+\theta_w) + \frac{c_t}{w}(A+\theta_w)\right]T_w + \frac{c_t}{w}\theta_w(\tau - T_t) = 0, \tag{22}$$

which is an implicit labour supply model where T_w is a function of c_t/w, T_t and the utility parameters. Solving for T_w yields

$$T_w = \frac{\left[\tau - T_t)(B+\theta_w) + \frac{c_t}{w}(A+\theta_w)\right] \pm \sqrt{\left[(\tau - T_t)(B+\theta_w) + \frac{c_t}{w}(A+\theta_w)\right]^2 - 4\frac{c_t}{w}\theta_w(A+B+\theta_w)(\tau - T_t)}}{2(A+B+\theta_w)}. \tag{23}$$

In order to investigate whether equation (23) has two roots or only one is valid, we can solve equation (21) for $\theta_w = 0$, which yields

$$T_w = \frac{B}{A+B}(\tau - T_t) + \frac{A}{A+B}\frac{c_t}{w}. \tag{24}$$

This represents the optimal work time for an individual that extracts neither utility nor disutility from work. Now we can explore the general expression (23) as θ_w approaches zero. With the minus sign T_w approaches zero, while with the plus sign expression (24) is recovered. This shows that only the plus sign should be considered in equation (23).

Defining

$$\alpha = \frac{A+\theta_w}{2t(A+B+\theta_w)}$$

$$\beta = \frac{B+\theta_w}{2(A+B+\theta_w)} \tag{25}$$

equation (23) can be written as

$$T_w = \beta(\tau - T_t) + \alpha\frac{c_t}{w} + \sqrt{\left[\beta(\tau - T_t) + \alpha\left(\frac{c_t}{w}\right)\right]^2 - [2(\alpha+\beta) - 1]\frac{c_t}{w}(\tau - T_t)}. \tag{26}$$

Equation (26) is a model for the labour supply of individuals who are characterised by direct preferences implicitly represented by α and β, which are the parameters to be estimated. In this model, travel time, travel cost, and the wage rate are the exogenous variables, and T_w is the dependent variable.

Models (16) and (26) can be estimated using information on trips and activities undertaken by the same individuals. Now we will see that this procedure permits the calculation of all the components of the value of saving travel time in equation (6) using the estimated values of the parameters in the model system. The key is the calculation of the value of leisure μ/λ.

From equations (18) and (19), the value of μ/λ depends on the ratio A/B, which can be calculated from equations (25) as $(1-2\beta)/(1-2\alpha)$.Then

$$\frac{\mu}{\lambda} = \left(\frac{1-2\beta}{1-2\alpha}\right)\left(\frac{wT_w - c_t}{\tau - T_w - T_t}\right). \tag{27}$$

From this, the value of time assigned to work can be calculated by subtracting w, as can be deduced from equation (6). Similarly, the value of time assigned to travel can be obtained by subtracting μ/λ from $SVTTS$ obtained from (17).

For synthesis, we have been able to obtain the value of time as a personal resource (value of leisure), and the values of assigning time to work and travel. This has been done using the parameters of the model represented by equations (16) and (26), which can be jointly estimated using travel information (observed choice, cost and time of all alternatives), time assigned to work and the wage rate.

Application

Data description

The database on time assignment was constructed from information reported by 366 workers within the context of the 1991 O-D survey in Santiago (DICTUC-CADE, 1991). They were randomly chosen from those who presented a very simple activity scheme: home-travel-work-travel-home. The data contains information regarding time assigned to four aggregated activities during a normal working day, namely working, being at home, travel to work, and travel back home. Individuals belong to two income strata: those with a net family income between Ch\$ 110,000 and Ch\$ 40,500 (approximately US\$250 and US\$85) in 1991, and those with a higher income. The corresponding average wage rates are 22.8 and 50.4 Ch\$/min respectively. Table 1 shows the average time assignment.

Table 1
Average Time Assignment (hours, standard deviation in parenthesis)

Income	*Work*	*Home*	*Travel to work*	*Return travel*	*#*
Med	7.25	15.45	0.45	0.86	294
	(3.22)	(3.23)	(0.28)	(0.61)	
High	7.18	15.72	0.32	0.79	72
	(2.68)	(2.61)	(0.18)	(0.47)	

Although time assignment looks similar for both groups on average, the high income group assigns more time to being at home and less time to work and travel, which suggests that (if preferences are homogeneous) the former activity is more attractive and a higher income allows for a re-assignment. Average time allocation for the return trip is much greater than for the work trip. This reported fact is probably hiding discretionary time included in the return travel. This would mean that at least two activities are being combined in the aggregate data on return travel, that is, the return trip itself and discretionary stops (presumably with marginal utilities having opposite signs).

Travel to work information (mode choice and availability) is shown in Table 2. The criteria for mode availability correspond to those presently used in the strategic model ESTRAUS, reported in CIS (1994). For example, car driver requires a car at home and a driver's license, bus and taxi were considered as always available, metro and shared taxi required a

Table 2
Mode Choice and Availability by Income Group

		Mode choice			*Availability*		
Code	*Mode*	*Medium Income*	*High Income*	*Total*	*Medium Income*	*High Income*	*Total*
CD	Car driver	102	47	149	149	64	213
CP	Car Passenger	4	5	9	5	5	10
BUS	Bus	138	12	150	294	72	366
STX	Shared taxi	8	1	9	286	72	358
MET	Metro	11	2	13	72	15	87
WA	Walk	17	0	17	67	14	81
TXI	Taxi	7	4	11	294	72	366
B-M	Bus–Metro	3	1	4	145	45	190
ST-M	Shared taxi–Metro	4	0	4	145	44	189
	Total	294	72	366	294	72	366

Source: CIS (1994)

home connected with the corresponding network, walking implied less than four kilometres, and so on. Besides mode choice, the database includes level of service (walking, waiting, and in-vehicle travel times) and cost for all modes, for each individual. The average travel cost is Ch$170 and Ch$226 for workers in the medium and high income strata respectively. Socio-economic information comprises sex, gender, driver's licence, net income, number of individuals, number of cars at home, and others.

Model estimation

It is quite important to emphasise that individuals in the sample are assumed to be in a long-run equilibrium regarding their jobs. It means that they have achieved a satisfactory arrangement in terms of salary and work hours, through job search, negotiation, and adaptation. This assumption makes the model appropriate to their situation. As we have no information to validate this hypothesis, the numerical results should be taken with care; nevertheless, both the procedure and the analysis that follow are illustrative of the proposed methodological approach.

Note that, as both models (mode choice and work time) are derived from the same framework, the error terms could be interrelated. However, we assumed that the error term in the conditional indirect utility function (modal utility) comes from an additive error term in the direct utility (7), and that the error term in the labour supply model (26) was purely a measurement error. Although under these assumptions error terms are independent, this is an area for future research. The usual IID Gumbel distribution was assumed for the error term in the mode choice model and a normal distribution was used for the additive error term assumed in the labour supply equation.

The time assignment model represented by equation (26) was estimated using the non-linear least squares routine implemented in TSP. Originally, we tried parameters α and β differentiated by income strata, concluding that only β was strata-specific. Results for the mode choice model (with aggregated travel time) were obtained using maximum likelihood techniques within the same package. Different specifications and segmentations within each income stratum were tried for the linear approximation (16) of the indirect utility function. Although data was a limitation for the number of segments to be considered, we started with six segments differentiated by their wage rate. As some yielded statistically similar coefficients, we ended up with three linear models, two for the medium income group (which have been called "medium low" and "medium high") and one for the high income group.

Results are shown in Tables 3 and 4. The statistical results show that the set of parameters is significant in both models, that the choice model is

Table 3
Results for the Time Assignment Model (Equation 26)

Parameter-Income	*Estimate*	t-*statistic*
β medium	0.096063	13.3742
β high	0.120825	13.6678
α	−2.27272	−6.40726

Mean of dep. var. = 434.112
R-squared = 0.265713
Std. Dev. Of dep. var. = 187.245
Adjusted R-squared = 0.0261667
Sum of squared residuals = 0.94E+07
LM het. test = 6.59060 [.010]
Variance of residuals = 25953.9
Durbin–Watson = 2.02238 [<0.629]
Std. Error of regression = 161.102
Log-Likelihood = −2377.85

Table 4
Results for the Mode Choice Model (Equation 16)

Parameter	*Estimate*	t-*statistic*
CD	0.45	1.68
CP	2.23	2.07
STX	−2.46	−7.62
MET	−0.42	−1.24
WA	0.53	1.47
TXI	−0.77	−1.58
B−M	−2.28	−4.23
STM	−2.44	−4.69
γ^t medium low	−0.0708	−4.20
γ^t medium high	−0.0576	−3.60
γ^t high	−0.0910	−4.19
γ^c medium low	−0.0058	−3.18
γ^c medium high	−0.0032	−3.60
γ^c high	−0.0019	−2.00
L(θ)	−267.026	
L(C)	−341.81	
χ2 95%	21.01	
ρ2	0.218	

indeed superior to the modal constants only model (ll = −267 against ll = −341), and that the time assignment model has a relatively small R^2. With these estimated coefficients, modal shares were exactly reproduced (because of the modal constants). The time assigned to work at the mean of each group was reproduced with very small errors (0.04 per cent and 0.26 per cent for the medium and high income groups respectively, 0.02 per cent for the sample mean).

Analysis of results

From the results reported in Table 4, *SVTTS* can be calculated using equation (17) as the simple division of the time and cost parameters of the mode choice model. On the other hand, using equation (27) and the results reported in Table 3, the value of leisure time for each individual can be calculated (with τ equals 24 hours, as in the regression). This has been done using the ANALYZ routine implemented in TSP to calculate the expression $(1 - 2\beta)/(1 - 2\alpha)$ for each income stratum, which was then multiplied by $(wT_w - c_t)/(\tau - T_w - T_t)$ for each individual. The averages for each income group are shown in Table 5.[3]

Knowing *SVTTS* and the resource value of time, all components can be calculated by subtraction from equation (6). These results (averages for each income group) are shown in Table 6.

The results are quite interesting. First of all, the *SVTTS* is 95 per cent explained by the value of assigning time to travel (last column), because

Table 5
SVTTS and the Value of Leisure
(Ch$ 1991/min)

	Estimate	t-*statistic*
SVTTS med low	12.18	3.57
SVTTS med high	18.09	3.71
SVTTS high	46.74	2.12
μ/λ med	0.85	8.68
μ/λ high	2.29	8.21

[3] A sensitivity analysis for the estimates of α and β and the calculation of μ/λ was performed reducing available time τ by different amounts in order to consider sleeping time. Although the (average) value of leisure remained very small for each income group, the estimates decreased with sleeping time. This was to be expected, as the same time assignment structure was being looked at as if less total time was available.

Table 6
Average Values of Time for the Two Income Groups (Ch$ 1991/min)

Income Level	Subjective Value of Travel Time Savings	Value of Time as a Resource	Wage Rate	Value of Time Assigned to Work	Value of Time assigned to Travel
	$SVTTS$	μ/λ	w	$\frac{\partial U/\partial T_W}{\lambda}$	$\frac{\partial U/\partial U \partial T_t}{\lambda}$
Medium	16.14	0.85	22.77	−21.92	−15.29
High	46.74	2.29	50.41	−48.12	−44.45

the value of time as a personal resource (or value of leisure) is relatively small. As expected, the *SVTTS* is larger for the higher income group. Leisure value is also larger for the high income group, whose disutility of work is valued more than that of the individuals in the middle income group. Note also that in both groups people dislike work more than travel, which adds a negative value to the wage rate in the formation of the *SVTTS*. The picture, however, is slightly different if the analysis is made in terms of the marginal utilities of the undertaken activities instead of their corresponding money values. To see this, note that the marginal utility of income (the absolute value of the cost coefficients of the discrete travel choice model in Table 4) is, on average, larger for the relatively poor group, in fact more than twice that of the richer group. This means that the marginal utilities of time assigned to work, travel, and leisure are in fact closer than their money values. In particular, the marginal disutilities of work are practically equal for both groups.

Finally, something can be said regarding the utility parameters θ_i and η_j. From Table 6, both θ_t and θ_w are negative. What about A (the sum of the other activities' coefficients) and B (the sum of all goods' coefficients)? The estimated parameters α and β tell us something about them. From equations (25), the sum $\alpha + \beta$ can be used to obtain an expression for the ratio $\theta_w/(A+B)$. Taking an average value of 0.1 for β (see Table 3), this ratio is around −0.85, which shows that $A+B$ is positive. On the other hand, manipulating α/β one can show that both A and B are positive, which is a very interesting result because B could be interpreted as a synthetic goods related coefficient and A as a leisure related one, as if equations (7)–(10) represented an aggregated goods-leisure-work-travel model.

As stated earlier, all these numerical results should be taken with great care because of the assumptions made regarding the labour market.

Individuals have been assumed to be in long-run equilibrium and their wages have been assumed to be exogenous. If this was not the case, the employers' demand for labour should be taken into account.

Synthesis, Conclusions and Further Research

In this paper we have developed an approach to include time assigned to activities in the estimation of the components of the subjective value of travel time, experimentally applied to a small but reliable sample of travellers in Santiago, Chile, whose time assignment pattern is known in a fairly aggregate fashion. The values of leisure and work can be obtained from this approach.

We have shown that coupling microeconomically founded activity models and travel choice models can be quite rewarding from the viewpoint of the understanding of individual behaviour, particularly through the analysis of the value of time. This is the most important conclusion from our work. The specific data studied exemplify this by letting us know the perceptions of work time, leisure, and travel time that hide behind the formation of a willingness to pay to reduce travel. This opens a whole world of possibilities in the joint analysis of activities and displacements from a microeconomic viewpoint.

The next steps are fairly evident. One is to work with more detailed information on activities and travel, specifically obtained for this purpose, including information regarding the work contract. Also, information on consumption patterns will make the corresponding consumption models useful as well. Note that the framework presented here can be easily expanded to obtain explicit models for the optimal assignment of time to activities other than work, which generates a larger system to be estimated. A second important line of research is to develop full analytical forms for the conditional indirect utility function commanding mode choice, in order to overcome the linear approximation used here for given levels of the wage rate. Also on the analytical side, a third line to follow is to consider more complete microeconomic frameworks, such as the one suggested by Jara-Díaz and Calderón (2000) regarding the technical constraints, to generate new models that include novel dimensions regarding goods-activities production functions. Finally, there is an econometric challenge in the joint estimation of activity-travel models with a microeconomic basis; the stochastic structure of the activity model should be discussed further as part of this task.

Appendix

Proof of the Equivalence between the $SVTTS$ and K_i/λ
To prove the equivalence between the subjective value of time obtained from a discrete travel choice model and the ratio K_i/λ of the time assignment problem, the sensitivity theorem from non-linear programming can be used. Let $f, g, h \in C^2$ and consider the family of problems

$$\begin{aligned} &\operatorname{Min} f(X) \\ &\text{s.a. } \mathrm{h}(X) = c \\ &g(X) \leq d. \end{aligned} \tag{a}$$

Assume that for $c=0$, $d=0$, there is a local solution X^*, and multipliers λ, μ, ≤ 0, that satisfy second order conditions for a strict local minimum. Assume also that no active inequality restriction is present. Then for all pairs (c,d) in a region that contains (0,0), there is a solution $X(c,d)$, that depends continuously on (c,d), such that $X(0,0)=X^*$, and $X(c,d)$ is a relative minimum of problem (a). Also,

$$\begin{aligned} \nabla_c f(x(c,d))]_{0,0} &= -\lambda^t \\ \nabla_d f(x(c,d))]_{0,0} &= -\mu^t. \end{aligned} \tag{b}$$

In other words, the multipliers are associated with the corresponding solution and they represent incremental or marginal prices, that is, prices associated with small variations in the constraints levels (Luenberger, 1973).

Corollary. The ratio K_i/λ is equal to the ratio between the marginal utilities of travel time and travel cost calculated from the (conditional) indirect utility function obtained from a mode choice model.

Proof. Rewriting problem (1)–(5) adequately to correspond with the form in (a), we have

$$\begin{gathered} \operatorname{Min} - U(X,T) \\ s.to \\ -I_f - wT_W + P^t X \leq -c_v \rightarrow \lambda \\ -\tau + \sum_{i=1}^{n} T_i = 0 \quad \rightarrow \mu \\ -T_i + h_i(X) \leq 0 \quad \rightarrow K_i \quad \forall i \neq V, W_f \\ -T_V \leq -T_V^{MIN} \rightarrow K_V \\ -T_{W_f} \leq -T_{W_f}^{MIN} \rightarrow K_{W_f}. \end{gathered}$$

Applying the theorem, and recalling that utility in discrete travel choice theory is a conditional indirect utility function that gives that maximum U for a given alternative, we have

$$\frac{\partial - U^{OPT}}{\partial - T_V^{MIN}} = \frac{\partial U^{OPT}}{\partial T_v^{MIN}} = \frac{\partial V_i}{\partial T_v^{MIN}} = -K_V$$

$$\frac{\partial - U^{OPT}}{\partial - c_v} = \frac{\partial U^{OPT}}{\partial c_v} = \frac{\partial V_i}{\partial c_v} = -\lambda,$$

which demonstrates the equivalence.

References

Bates, J. (1987): "Measuring Travel Time Values with a Discrete Choice Model: a Note," *The Economic Journal*, 97, 493–8.

Becker, G. (1965): "A Theory of the Allocation of Time," *The Economic Journal*, 75, 493–517.

CIS (1994): *Análisis y seguimiento de planes estratégivcos de ESTRAUS. Informe final a SECTRA* (Analysis and follow-up of ESTRAUS strategic plans. Final report to SECTRA), Santiago.

DeSerpa, A. (1971): "A Theory of the Economics of Time," *The Economic Journal*, 81, 828–46.

DICTUC-CADE (1991): *Encuesta Origen Destino de Viajes en el Gran Santiago. Informe Final a SECTRA* (Origin Destination Survey for Trips in Great Santiago, Final Report to SECTRA), Santiago.

Evans, A. (1972): "On the Theory of the Valuation and Allocation of Time," *Scottish Journal of Political Economy*, 19, 1–17.

Gronau, R. (1986): "Home Production—a Survey." In Ashenfelter and Layard (eds.) *Handbook of Labour Economics*, Vol. 1, North Holland, Amsterdam.

Hensher, D. (1977): *Value of Business Travel Time*. Pergamon Press, Oxford.

Jara-Díaz, S. (1988): "Time and Income in Travel Choice: towards a Microeconomic Activity Framework." In *Theoretical Foundations of Travel Choice Modelling*, T. Garling, T. Latia and K. Westin, eds. Pergamon Press, Oxford, 51–73.

Jara-Díaz, S. (2000): "Allocation and Valuation of Travel Time Savings." In *Handbook of Transport Modelling*, D. Hensher and K. Button, eds. Pergamon Press, Oxford, 303–19.

Jara-Díaz, S. (2002): "The Goods/Activities Framework for Discrete Travel Choices: Indirect Utility and Value of Time." Chapter 20 in Mahmassani, H. (ed.) *In Perpetural Motion: Travel Behavior Research Opportunities and Application Challenges*, Pergamon, 415–30. Originally presented at the 8th IABTR Conference, Austin Texas, 1997.

Jara-Díaz, S. and C. Calderón (2000): "The Goods-Activities Transformation Function in the Time Allocation Theory," *9th IABTR Conference*, Gold Coast, Australia.

Jonson, M. (1966): "Travel Time and the Price of Leisure," *Western Economic Journal*, 4, 135–45.

Luenberger, D. (1973): *Introduction to Linear and Nonlinear Programming*. Addison-Wesley, Reading, MA.

Oort, O. (1969): "The Evaluation of Travelling Time," *Journal of Transport Economics and Policy*, 3, 279–86.

Truong, T and D. Hensher (1985): "Measurement of Travel Time Values and Opportunity Cost from a Discrete-Choice Model," *Economic Journal*, 95, 438–51.