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Working Paper

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Publication date:
2005

Permanent link:
https://doi.org/https://doi.org/10.3929/ethz-a-006020307

Originally published in:
Arbeitsberichte Verkehrs- und Raumplanung 308

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September 2005

Abstract

In this paper we report the results of applying a new microeconomic framework to model time assignment to activities, goods consumption and mode choice jointly (Jara-Díaz and Guevara, 2003; Jara-Díaz and Guerra, 2003) that identifies the links between these decisions and permits the calculation of all the components of the subjective value of time defined in the literature: the value of time as a resource, value of assigning time to a specific activity and the value of saving time in a specific constrained activity. The samples used for the modelling come from the six-weeks travel diaries Mobidrive (Axhausen *et al.*, 2002) and Thurgau (Axhausen *et al.*, 2005; Löchl *et al.*, 2005) collected in Germany and Switzerland, respectively. In this paper we present the model system that includes time assigned to activities and mode choice, a description of the data sets, a summary of the generation work of necessary variables for the modeling, the results of the calibrated models, which include the values of leisure and work for both samples, besides the values of saving and assigning travel time for the German sample, and their analysis and interpretation.

The results are appropriate if we consider that the subjective values of time obtained are coherent with what was expected, positive values of leisure and negatives values of assigning travel time.

Keywords

Time assignment, mode choice, joint modelling, subjective values of time, six-weeks travel diary, Mobidrive, Thurgau

Preferred citation style

Greeven, P., S.R. Jara-Díaz, M. Munizaga and K.W. Axhausen (2005) Calibration of a joint time assignment and mode choice model system, *Arbeitsbericht Verkehrs- und Raumplanung*, **299**, IVT, ETH Zürich, Zürich.

1 Introduction

The modal utility *Vj* that is central to mode choice models is derived from the maximization of the direct utility within a framework of consumer behaviour that includes both time assigned to activities and goods consumption. Jara-Díaz (1998) recognises that a common behavioural framework leads to the simultaneous specification of models of time assignment to activities, goods consumption and mode choice, involving the same type of exogenous information. With this perspective Jara-Díaz and Guevara (2003) develop a joint model of time assignment to work (labour supply) and mode choice that is extended later by Jara-Díaz and Guerra (2003) by including all activities and goods consumption. This model permits the calculation of all components of the subjective value of time described by DeSerpa (1971): the value of time as a resource (value of leisure), value of assigning time to a specific activity and finally, the value of saving time in a specific constrained activity. The model has been previously estimated with the data of the TASTI survey of workers in Santiago, Chile (Munizaga *et al.*, 2004) collected expressly for this purpose (Greeven *et al.*, 2005).

In this paper this new simultaneous model of time assignment to activities and mode choice simultaneously is presented and applied to two data sets collected in the cities of Karlsruhe, Germany (Axhausen *et al.*, 2002), and Frauenfeld and villages on the Seerücken, Switzerland (Axhausen *et al.*, 2005; Löchl *et al.*, 2005).

The paper is organized as follows. In the section 2, we review the general model formulated by Jara-Díaz and Guerra (2003). A brief description of both data sets is presented in the section 3, whereas in the section 4, the calculation of necessary additional variables from the available information is summarized. Later in the section 5, the model and results obtained are presented, which include the values of time as a resource and of assigning time to work for both samples, besides the values of saving and assigning travel time for the German sample. Finally the conclusions and some possibilities of future investigation are presented.

2 The general model

The model developed by Jara-Díaz and Guerra (2003) takes into account four elements. First, individual utility, which arises from what individuals do as well as from the goods they consume during those activities. Second, a money budget constraint that includes all types of expenses and incomes. Third, a time budget constraint. Finally, technical constraints linking activity, its associated goods consumption and the time assigned to it.

Let I be the set of freely chosen activities, R the set of activities assigned a minimum required T_r^{Min}, T_w the time assigned to work, K the set of freely chosen goods, J the set of goods consumed with a specific required minimum X_j^{Min}, P_j is the price of good j, η_k and θ_i the exponents associated to good k and activity i, respectively, w the wage rate, c_f the total fixed expense that does not depend on the goods consumed, I_f the non work income, τ the total time available and Ω a positive constant. The consumers can be seen as if they were solving the following time assignment and goods consumption optimization problem:

$$
\begin{aligned}
&Max \;\; U = \Omega T_w^{\theta_w} \prod_{i \in I} T_i^{\theta_i} \prod_{r \in R} T_r^{\theta_r} \prod_{k \in K} X_k^{\eta_k} \prod_{j \in J} X_j^{\eta_j} \\
&s.a.
\end{aligned}
\tag{1}
$$

$$
I_f + wT_w - \sum_{k \in K} P_k X_k - \sum_{j \in J} P_j X_j - c_f \geq 0 \quad \leftarrow \quad \lambda \tag{2}
$$

$$
\tau - T_w - \sum_{r \in R} T_r - \sum_{i \in I} T_i = 0 \quad \leftarrow \quad \mu \tag{3}
$$

$$
T_r - T_r^{Min} \geq 0 \quad \forall r \in R \quad \leftarrow \quad \kappa_j \tag{4}
$$

$$
X_j - X_j^{Min} \geq 0 \quad \forall j \in J \quad \leftarrow \quad \varphi_j \tag{5}
$$

with the associated Lagrange multipliers. The authors note that unconstrained activities must have positive marginal utilities (positive θ_i), otherwise they would not be undertaken. Besides, every unpleasant activity (negative θ_i) will be assigned the exogenous minimum, because the sign of its marginal utility is the same irrespective of duration. This does not mean that an activity that is assigned the minimum time is necessarily unpleasant, because the optimal time assignment could be less than the exogenous minimum.

From the first order conditions, Jara-Díaz and Guerra (2003) obtain a system of equations for time assigned to work (6), time assigned to unconstrained activities (7) and goods consumption (8).

$$
T_w^* = \left[(\tau - T_f)\beta + \frac{G_f}{w}\alpha \right] + \sqrt{\left[\left(\tau - T_f\right)\beta + \frac{G_f}{w}\alpha \right]^2 - \frac{G_f}{w}\left(2\alpha + 2\beta - 1\right)\left(\tau - T_f\right)} \tag{6}
$$

$$
T_i^* = \frac{\tilde{\theta}_i}{(1 - 2\beta)} \left(\tau - T_w^* - T_f \right) \quad \forall i \in I \tag{7}
$$

$$X_k^{\ *} = \frac{\tilde{\eta}_k}{P_k\left(1-2\alpha\right)}\left(wT_w^{\ *} - G_f\right) \quad \forall k \in K \tag{8}$$

where A is summation of the exponents over all unrestricted activities and B is the summation of the exponents over all unrestricted goods. Besides

$$G_f = \left(\sum_{j\in J} P_j X_j^{\ Min} + c_f - I_f\right) \quad , \quad T_f = \sum_{r\in R} T_r^{\ Min} \quad , \quad \tilde{\theta}_i = \frac{\theta_i}{\left(A+B+\theta_w\right)} \quad \forall i \in I \wedge i \in R$$

$$\tilde{\eta}_k = \frac{\eta_k}{\left(A+B+\theta_w\right)} \quad \forall k \in K \wedge k \in J \quad , \quad \beta = \frac{B+\theta_w}{2\left(A+B+\theta_w\right)} \quad , \quad \alpha = \frac{A+\theta_w}{2\left(A+B+\theta_w\right)}$$

(9)

Because of the restrictions on consumption (2) and time (3), only up to *n-1* time assignment or good consumption models can be estimated (with *n* the size of the corresponding set of unrestricted activities or goods). On the other hand, the authors note that one can formulate and estimate as many discrete choice models as restricted variables exist, unless one choice determines two or more variables simultaneously. In many cases one does not know exactly which activities (or goods) are restricted, which is something that can be explored empirically.

Solving the system explicitly for time assignment to activities and goods consumption conditional on mode choice, the authors obtain an expression for the conditional modal indirect utility function. This is obtained by replacing the optimal values from equations (6), (7) and (8) in (1), which yields

$$V = \tilde{\Omega}\left(wT_w^{\ *} - G_f\right)^{1-2\alpha}\left(\tau - T_w^{\ *} - T_f\right)^{1-2\beta} T_w^{\ *2\alpha+2\beta-1} \prod_{r\in R}\left(T_r^{\ Min}\right)^{\tilde{\theta}_r} \prod_{j\in J}\left(X_j^{\ Min}\right)^{\tilde{\eta}_j} \tag{10}$$

Using this model system allows not only efficient estimation, but also allows us to obtain an estimate of the different values of time. These are the value of time as a resource (value of leisure), the value to assigning time to a specific activity, and the value of saving time for a specific constrained activity. Following Jara-Díaz and Guerra (2003), the value of leisure is

$$\frac{\mu}{\lambda} = \frac{(1-2\beta)}{(1-2\alpha)} \frac{\left(wT_w^{\ *} - G_f\right)}{\left(\tau - T_w^{\ *} - T_f\right)} \tag{11}$$

the value of assigning time to work is

$$\frac{\partial U/\partial T_w}{\lambda} = \frac{(2\alpha + 2\beta - 1)}{(1-2\alpha)} \frac{\left(wT_w^{\ *} - G_f\right)}{T_w^{\ *}} \tag{12}$$

and the value of saving time in a constrained activity *t* is

$$\frac{\kappa_t}{\lambda} = \frac{\mu}{\lambda} - \frac{\partial U/\partial T_t}{\lambda} = \frac{(1-2\beta)}{(1-2\alpha)} \frac{\left(wT_w^* - G_f\right)}{\left(\tau - T_w^* - T_f\right)} - \frac{\tilde{\theta}_t}{(1-2\alpha)} \frac{\left(wT_w^* - G_f\right)}{T_t^{Min.}} \tag{13}$$

As shown by Bates (1987), Jara-Díaz (2002) and Jara-Díaz and Guevara (2003) in different ways, this last value, in the case of travel, can be obtained directly from a discrete choice model as the ratio between the marginal utilities of time and cost.

3 Description of the data sets

The model described in the previous section requires detailed information about time assigned to activities and income structure of the individuals, besides information concerning variables of level of service for the mode choice model. In this section we describe two data sets used which were collected in Karlsruhe and Halle, Germany, and Frauenfeld and villages on the Seerücken, Switzerland (part of the Canton Thurgau). Both surveys were based on a six-weeks travel diary and personal interviews. For the German sample, only the information from Karlsruhe was used (159 individuals, of which 90 are workers) (Mobidrive: Axhausen *et al.*, 2002). The Swiss sample consists of 230 individuals, of which 126 are workers (Thurgau: Axhausen *et al.*, 2005; Löchl *et al.*, 2005). Table 1 summarises the general characteristics of each sample of workers, including all types of works: full/part time, self-employed workers and apprentices.

Table 1 Aggregate description of the workers in the samples

Characteristic	Karlsruhe	Thurgau
Gender [% women]	46.7	37.3
Marital status [% married]	63.3	74.6
Most frequent age range	36-45 (28.9 %)	46-55 (33.3 %)
Average household size	2.5	2.5
Average household income [EURO/month][1]	2,425.4	6,122.5
Share of full time workers	63.3	77.8
Households with only one worker [%]	48.1	62.4

[1] One EURO = 1.956 DEM = 1.521 CHF (average 2003)

Besides the difference in income between both samples, the Swiss sample has a smaller proportion of female workers and a larger proportion of households with a single source of labour income.

From the available information, the time assigned to the activities carried out between the trips was calculated. These activities were grouped into four categories plus travel. This new aggregation of activities comes from the original trip purposes. Table 2 shows the link between the grouping of activities and the original information.

Table 2 Aggregation of activities

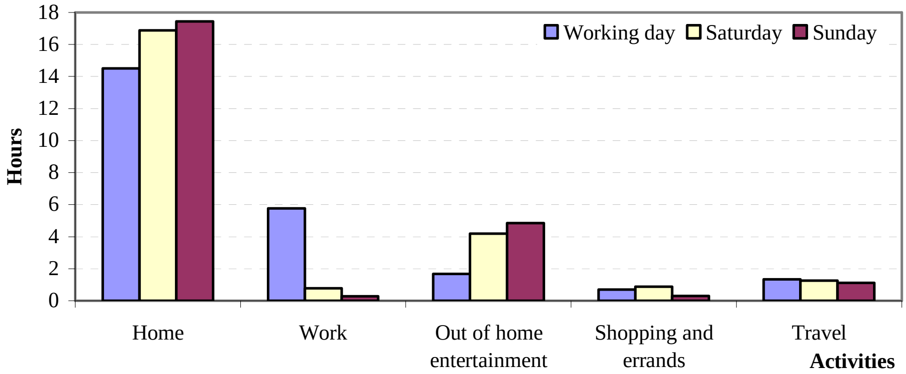
Activities	Original trip purposes
Home	Home
Work	Work related business School Work
Out of home entertainment	School Leisure
Shopping and errands	Pick up / Drop off Private business Shopping: Daily Shopping: Long term Other
Travel	-

For apprentices, the original purpose school was considered as work, because they earn money during schooling. For the rest of the workers, school was added to out of home entertainment.

Figure 1 reports the average time assigned to each of the five aggregate activity types on each type of day. It can be seen that in the Swiss sample, individuals work almost seven hours on a working day, compared with their German counterparts that work an average of almost six hours. On Saturday both samples work around one hour, while on Sunday this time drops to around 30 minutes. Time assigned to shopping and errands is similar for both samples, with a peak on Saturday. Time assigned to travel is relatively stable during the three days, although the Swiss respondents allocate an average of 25 minutes more per day than in the German ones, reflecting the rural and small town nature of their home residences. The larger differences are present in the time assigned to home and out of home entertainment. Although for both samples, the two activities increase on the weekend, Swiss people allocate an average of 6 hours and 40 minutes to out of home entertainment during a weekend day, around two hours more than their German counterparts.

Figure 1 Average duration of activity types

Mobidrive, Karlsruhe workers



Thurgau, workers

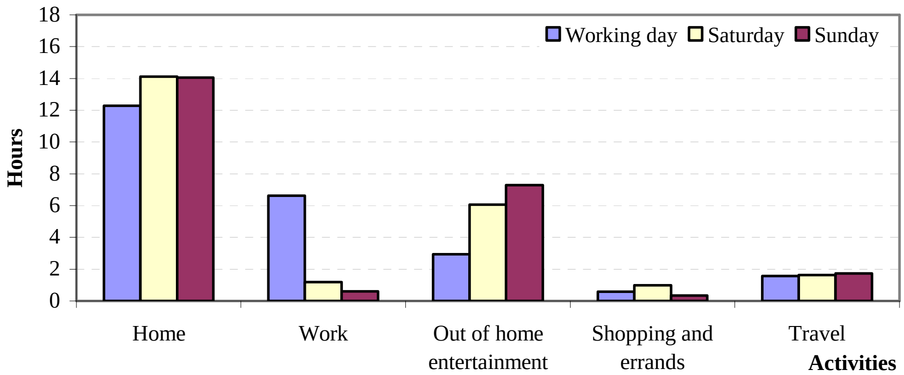
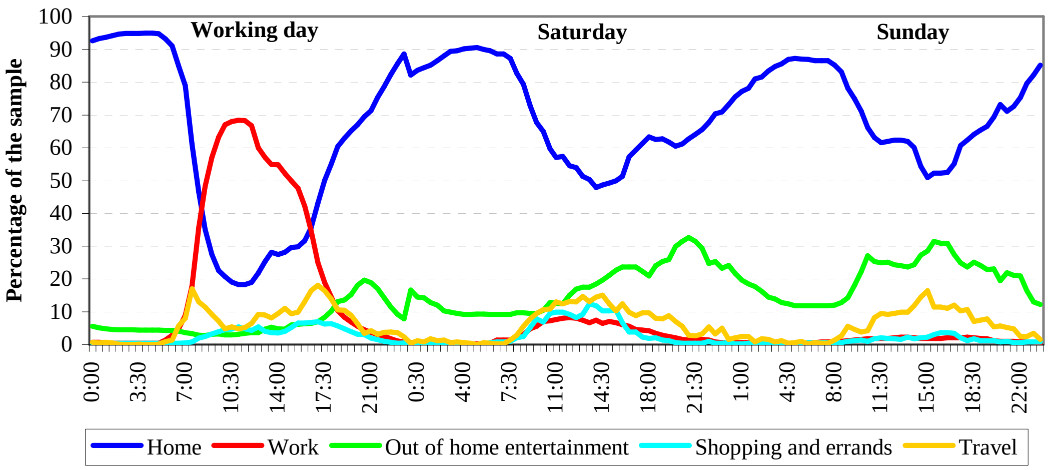


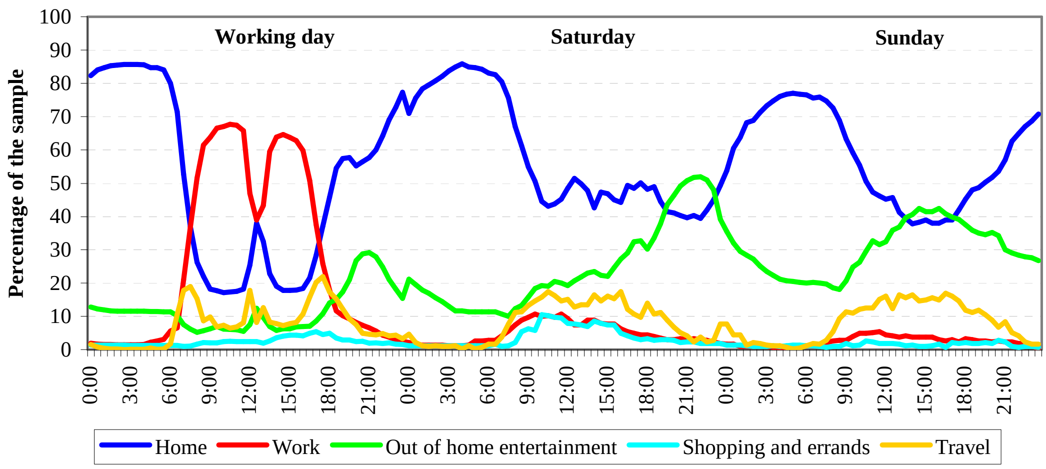
Figure 2 shows the proportion of individuals who were engaged in a particular activity at any moment during the day. The most outstanding working day difference takes place at the lunch time, since in the German case the workers stay at the work place during this time, whereas their Swiss counterparts go home. For all three types of day, the pattern of out of home entertainment is more intense in the Swiss sample. Shopping and errands are concentrated strongly during Saturday morning for both samples. For the German case the predominant activity during the weekend is staying at home, while for the Swiss sample out of home entertainment predominates over home on Saturday night and Sunday afternoon.

Figure 2 Time allocation by time of day and type of day

Mobidrive, Karlsruhe workers



Thurgau, workers



For the German sample, besides the information of the travel diary, the necessary variables of level of service for the calibration of mode choice models were generated by König and Axhausen, 2001. For this work 1159 home to work trips were used. These trips do not include trips with origin or destination equal to "Elsewhere", definition used by the researchers, because these ones did not have the information on variables of level of service for the available modes. Besides, we did not consider some combined modes because their choice percentage was low and it was not possible to generate the variables of level of service for these modes in other trips where they might have been available. The cost of car driving includes fuel, variable (repair and maintenance) and parking costs. The cost of the public transport is equal to zero if the person has a public transport season ticket and 2.50 DEM

(1.28 EURO) if the person does not. Walking was available only if the distance of the trip was less than a maximum defined by age. These maximums were defined to be equal to the maximum distance observed in trips where the chosen mode was walk, and were calculated by purpose and age. Table 3 shows the mode choice and availability and the average costs and travel time for trips with that mode.

Table 3 Mode choice and availability of Karlsruhe workers in the Mobidrive survey for home to work trips

Mode	Average value for the chosen mode		Percentage of	
	Time [min]	Cost [EURO]	Choice	Availability
Walk	22.2	0	2.1	16.8
Bike	13.5	0	26.1	92.8
Car driver	12.4	4.36	46.9	94.7
Car passenger	6.8	0	1.9	84.0
Public transport	24.1	0.12	23.0	86.0

4 Calculation and imputation of the required variables

4.1 Wage rate

In both samples the income information recorded was at household level and expressed in ranges which requires the imputation of the wage rate for each worker inside the same household necessary. Each income range was assigned a mean value.

To carry out this estimate a wage rate model was estimated using the available information in the *Einkommens- und Verbrauchserhebung 2000* survey (Bundesamt für Statistik, 2000). This survey has information about incomes and expenses for the representative Swiss household. Since the idea is to find a model for the individual wage rate, only one person households were used, because in that case the household income is the personal income. The wage rate was calculated from the weekly working hours that individuals reported and their labour income.

For the specification of the model the following explanatory variables were included as dummies:

- Age: expressed in five groups (<=25, 26-35, 36-45, 46-55, >55).
- Gender
- Education: expressed in three levels (low, medium and high). Table A. 1 describes the grouping of the educational levels present in each survey to these new categories.
- Work schedule: full and part time.

The self-employed were not considered, because their income is frequently missing or underreported and their working hours are difficult to assign. Finally, a linear regression model was estimated with the following specification:

$$\begin{aligned} log(wage\ rate) = &\beta_0 + \beta_1 (age_{26\text{-}35}) + \beta_2 (age_{36\text{-}45}) + \beta_3 (age_{46\text{-}55}) + \beta_4 (age_{>55}) + \\ &\beta_5 (man) + \beta_6 (education_{medium}) + \beta_7 (education_{high}) + \\ &\beta_8 (man)(age_{>55})(education_{high}) + \beta_9 (age_{>55})(education_{high}) + \\ &\beta_{10} (full\ time) + \beta_{11} (full\ time)(education_{medium}) \end{aligned} \tag{14}$$

Table A. 2 shows the calibrated parameters for this model. Using these results, a wage rate was imputed for all individual in a household and the percentage differences between them were computed as well. The persons in a household were ranked on their imputed wage rates. The way to update the imputed wage rates to match the reported household income was

$$I_N = \sum_{i \in N} w_i WH_i = \sum_{i \in N} w_b (1 + p_i) WH_i \quad \Rightarrow \quad w_b = \frac{I_N}{\sum_{i \in N} (1 + p_i) WH_i} \tag{15}$$

where I_N corresponds to the income of the household N, WH_i represents the working hours of the person i inside the household N, w_i is the wage rate of the person i inside the household N (these are the unknown variables that we want to update). w_b corresponds to the lowest imputed wage rate from the wage rate model. The wage rates of the other household members can be expressed relative to the base rate using the percentages of difference (p_i) that were obtained earlier.

This way to calculate the wage rate supposes that the household income comes totally from the work, which is the reason why households with retired people were not included since their income does not come completely from work. Also, households with apprentices were not included either, because although apprentices earn money the wage rate model is not suitable for them, because their education is not complete, as they are still in training. Finally, as the wage rate model does not include the self employed, the households with self employed people were not included either, because the rankings can not be obtained for those households.

4.2 Further expenses

The fixed expenses included, which do not depend on other goods consumed, are travel expenses, cost of season tickets for public transport, insurance and tax for cars and rents or mortgages.

It was necessary to calculate the cost of every trip that the individuals undertook. For this calculation, different assumptions were used depending on the chosen mode. The different assumptions are listed in Appendix B for each mode and each survey.

A monthly season ticket cost 60 DEM (10.68 EURO) in Karlsruhe in the survey year. A wider variety of season tickets were used by the Swiss respondents (See Table B. 2 for the details).

With regard to insurance and tax the assumptions used differ from one sample to the other. For Mobidrive, there was detailed information available about the automobiles owned by the households and therefore this information was used together with the available information from the Mobiplan project (Kreitz *et al.*, 2002) to obtain insurance and tax expenditure for the different cars of a household. For Thurgau, there was no information on the types of cars owned by the households. This required an approximation. As stated before, the *Einkommens- und Verbrauchserhebung 2000* survey has information on all expenses of Swiss households, including car expenditures. Average of the insurance premiums and taxes paid were calculated for each income level, as defined in the Thurgau survey and these averages were used as an approximation. Table B. 3 presents these values by income group.

Both samples had information on rents or mortgages and extra costs (electricity, heating, etc.).

All household expenditures (housing, cars) were allocated to its members proportional to their incomes.

5 Modelling, results and subjective values of time

5.1 Activity model

The activity model was calibrated for both samples. The estimation of the continuous model in this work includes the equations (6) and (7), considering the week as the modelling period. For the modelling, the activities were grouped in the five categories defined in the Table 2: Work, out of home entertainment, home, shopping and errands, and travel. The last two activities were considered to be restricted to their minimum time. Time assigned to work is modelled through equation (6), whereas time assigned to out of home entertainment is modelled by equation (7). The second unconstrained activity corresponds to home, which is not modelled as it can be obtained from the time budget constraint. The variable G_f includes weekly travel expenses, cost of public transport season tickets, insurance and tax for cars, and rent/mortgage. As it was explained before, it was supposed that the income came entirely from work, so non work income was not included in the model.

For the calibration of the model, a Normal additive error term was assumed for each equation, with different standard deviations for each one. It is expected that the presence of common parameters and exogenous variables to all the equations causes correlation between these. This should be considered when the system is estimated. To calibrate the model, a full information maximum likelihood procedure was used, allowing for correlation and heteroscedasticity. Both samples were constructed excluding individual weeks that reported zero values for the time assigned to the modelled activities (work and out of home entertainment) and those that presented missing (wage rate, rent/mortgage) or incorrect values. To be able to compare this model with the joint model, for the German sample, we only used the observations that had both types of information, activity and mode choice. As explained before we did not consider all home to work trips, which is the reason why some observations of the activity model did not have a corresponding observation in the mode choice model and therefore, they were not included in the calibration sample. In the case of the Swiss sample, there were individuals that had the required information for the activity model, but we were not able to use all their weeks because in some of them they did not report a day or they reported a day as holiday so we did not know how they allocated their time in those days and we could not use the weeks where that happened. Besides, some observations in this sample had problems with the report of the trips, since the starting and ending time of some trips were not coherent. Finally, because of the fact that we used assumptions for the wage rate and the expenses of the persons, some observations had negative income constraint that can not be used. All these reasons explain the sample shrinkage from the initial sample size.

5.2 Mode choice model

Using the available information in the German sample about variables of level of service for the trips from home to work, the mode choice of the individuals was modelled. The main use of the calibration of the mode choice model is to obtain a starting point for the joint model that is described later. The joint model estimates of the activity model and a model of discrete choice. This is the reason why only one representative trip was chosen for each week modelled in the activity model. This representative trip was chosen, when it was possible, among the trips done on Tuesday, Wednesday or Thursday. If the person reported more than one chosen mode in that week, a trip with the most common choice for that person was used. Because of the low choice percentages of the modes walk and car passenger, the alternatives considered for the modelling include only: Bike (B), Car driver (CD) and Public transport (PT). The calibrated model corresponds to a multinomial logit with a modal utility linear in cost and total trip time.

5.3 Joint model

To estimate the behaviours described before jointly, which in principle are of different nature, discrete and continuous, the method proposed by Lee (1983) was used. It allows to include correlations between different decisions. For other applications see Munizaga *et al.* (2003) and Bhat (1998).

Table 4 shows the calibrated parameters for the different models. The likelihood ratio tests that compare models with and without correlation and their critical values are included as well.

The Swiss activity model allowing for correlation is a clear improvement over the version without correlation. In the German sample, the best activity model is that one does not include the correlation between the activities. In the case of the joint model, the LR test shows that the reported model is better than a version without correlations, and also that it should be preferred to one that incorporates all the possible discrete – continuous correlations (six in total: three modes times two continuous equations). The discrete – continuous correlations have to be interpreted with the opposite sign, because of the transformation proposed by Lee (1983). Therefore, a negative value of ρ indicates the presence of positive correlation between the error of a certain discrete alternative, if it is chosen, and the continuous variable. For example, the sign of the first correlation indicates that unobserved factors which increase the propensity to choose bike, also increase time assigned to work.

The time and cost parameters obtained from the choice mode model, both alone and incorporated to the joint model, are reasonable. The parameters of the activity model are not directly interpretable, but only through the values that it are possible to obtain from them.

Table 4 Parameter estimates: activity, mode choice and joint models

Parameter	Thurgau Activity model Coeff.	t	Karlsruhe Activity model Coeff.	t	Mode choice model Coeff.	t	Joint model Coeff.	t
Bike constant	-	-	-	-	-0.836	-2.8	-0.692	-2.4
Car driver constant	-	-	-	-	-1.210	-2.6	-1.156	-2.6
Time	-	-	-	-	-0.172	-4.6	-0.165	-4.6
Cost	-	-	-	-	-0.150	-3.8	-0.138	-3.6
α	0.396	19.9	0.432	23.8	-	-	0.429	23.4
β	0.086	12.1	0.090	10.6	-	-	0.076	7.5
θ Out of home entertainment	0.183	22.0	0.116	10.5	-	-	0.152	11.0
σ Work	740.40	25.5	605.38	15.7	-	-	613.68	15.2
σ Out of home entertainment	1170.71	25.5	1030.46	15.7	-	-	1045.42	15.2
ρ Work – Out of home entert.	-0.227	-4.3	-	-	-	-	-	-
ρ Work – Bike	-	-	-	-	-	-	-0.478	-2.8
ρ Out of home entertainment - B	-	-	-	-	-	-	0.413	2.7
ρ Work – PT	-	-	-	-	-	-	-0.381	-2.4
ρ Out of home entertainment – PT	-	-	-	-	-	-	0.578	5.1
-2ΔLL (model – model without correlations)	17.1 $\chi^2(5\%,1)=3.8$		-				16.7 $\chi^2(5\%,4)=9.5$	
-2ΔLL (model – model with all possible correlations)	-		2.2 $\chi^2(5\%,1)=3.8$				4.5 $\chi^2(5\%,3)=7.8$	
L(0)[1]	-5580.25		-2095.31		-124.47		-2219.74	
L(θ)	-5357.30		-2006.57		-101.43		-2099.57	
ρ^2	0.040		0.042		0.185		0.054	
Sample size	75 individuals 325 weeks		26 individuals 124 weeks		26 individuals 124 weeks		26 individuals 124 weeks	

[1] For the activity and joint model includes only the calibration of the standard deviations (σ).

From the calibrated parameters, all the components of the subjective value of travel time defined in the literature can be calculated. The value of time as a resource and of assigning time to work can be obtained from the equations (11) and (12), while the value of saving travel time is calculated as the ratio between the parameters of time and cost of the mode choice model. Finally, it is possible to obtain the value of assigning travel time as the difference between the values of time as a resource and of saving travel time. Table 5 shows the average values of time in EURO/hour and as a percentage of the corresponding wage rate for the different models.

Table 5 Average Values of Time [EURO/hour]

	Thurgau			Karlsruhe								
	Activity model			Activity model			Mode choice model			Joint model		
Value of	Val.	t	% wage	Val.	t	% wage	Val.	t	% wage	Val.	t	% wage
Leisure μ/λ	23.6	5.6	87.7	12.1	4.0	119.8	-	-	-	10.5	4.1	104.0
Work $(\partial U/\partial T_w)/\lambda$	-3.3	-0.8	12.3	2.0	0.7	19.8	-	-	-	0.4	0.2	4.0
Saving travel time κ/λ	-	-	-	-	-	-	35.2	4.2	348.5	36.7	4.2	363.4
Assigning travel time $(\partial U/\partial T)/\lambda$	-	-	-	-	-	-	-	-	-	-26.2	-4.6	259.4
Wage rate	26.9	-	100.0	10.1	-	100.0	10.1	-	100.0	10.1	-	100.0

One EURO = 1.956 DEM = 1.521 CHF (average 2003)

Before analysing these results, the basic equalities between the subjective values of time for this type of model are recalled. First, the relation between the values of leisure and work can be expressed as (Jara-Díaz *et al.*, 2004)

$$\frac{\mu}{\lambda} = w + \frac{(\partial U/\partial T_w)}{\lambda} \tag{16}$$

and the relation between the value of leisure and the values of saving and assigning time to a constrained activity *t* is the following one

$$\frac{\kappa_t}{\lambda} = \frac{\mu}{\lambda} - \frac{(\partial U/\partial T_t)}{\lambda} \tag{17}$$

The first observation is that the values of leisure for both samples are positive as expected, and that the values of assigning time to work are not statistically significant. The value of assigning time to work is negative for the Swiss sample, reaching 12% of the wage rate, which indicates that people dislike assigning time to work and that they probably would not assign time to that activity (or would assign less) if it was not paid. For the German sample, this value is positive, but it does not represent a great percentage of the wage rate, reaching 4% in the joint model. The interpretation of the differences in these values is not straightforward, since many variables are involved: marginal utilities for work, wage rates and marginal utilities if income. Besides, the fact is that, in the samples, the time assigned to activities is different for each case, so the equilibrium in (16) takes place at a different points in the time space. But other cultural and social factors can influence as well. The value of saving travel time is positive, which indicates the willingness to pay of people to diminish the time assigned to this activity. Although this value can seem high, it is in the range of values obtained by other work using MOBIDRIVE and more sophisticated discrete choice modelling tools (Cirillo and Axhausen, 2005). Finally, from the results of the joint model it is possible to see that the trip to work generates disutility for the individuals of the German sample.

6 Conclusions

The model proposed by Jara-Díaz and Guerra (2003) takes into account all elements in the theory of consumer behaviour, while still obtaining a manageable formulation for the estimation of the models. It permits the calculation of all components of the subjective value of time and demonstrates with clarity the link between the time assignment and mode choice models. The joint estimation of these models allows a better understanding of the consumers and to calculate the different values of time described in the literature.

From the econometric point of view the calibration process was successful, as all the relevant parameters turned out to be significant and the inclusion of correlations proved to be an improvement in statistical terms in some of the models. The microeconomic interpretation of the results is also appropriate if we consider that the subjective values of time obtained are coherent with what was expected, positive values of leisure and negative values of assigning travel time. Finally, the values of assigning time to work are different for both samples but none of them is significantly different from zero. Anyhow, the German sample values its working time positively, whereas Swiss sample negatively, which means they probably would not assign time to that activity (or would assign less) if it was not paid.

The possibilities inherent in these samples and this set of models are many. It is possible to mention, for example, to improve the assumptions about costs for the Swiss sample, especially the regarding ones to cars once one is provided with more detailed information of these, and to obtain the necessary variables of level of service for the calibration of the discrete choice model that allows later the estimation of the joint model, to prove new aggregations of the activities and definitions of unconstrained and constrained activities, to calibrate different parameters or models for different types of persons, and to replace the linear approximation used in the modal utility by the function presented in the section 2.

7 Acknowledgements

This research was partially funded by Fondecyt, Chile, through grants 1010687, 1050643 and 1030694, and the Millenium Nucleus "Complex Engineering Systems".

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9 Appendixes

Appendix A. Wage rate model

Table A. 1 Classification of education levels in low, medium and high for the three samples

Education level	*Einkommens- und Verbrauchserhebung 2000*	MOBIDRIVE	THURGAU
Low	1. Obligatorische Schule 2. Keine Ausbildung abgeschlossen 3. Anlehre (in Betrieb und Schule) 4. Haushaltlehrjahr, 1 – 2 jährige Handelsschule	0. Noch keine 1. Grundschule 2. Hauptschule	1. Primarschule
Medium	5. Diplommittelschule, allgemeinbildende Schule (Verkehrsschule) 6. Berufslehre (Eidg. Fähigkeitsausweis) 7. Vollzeitberufsschule (Handelsmittelschule / Lehrwerkstätte) 8. Berufsmaturität 9. Maturitätsschule, Lehrerseminar 10. Höhere Berufsausbildung mit Meisterdiplom, Eidg. Fachausweis	3. Mittlere Reife 4. Fachabitur 5. Abitur 6. Polytechnische Oberschule 7. Lehre 8. Meister	2. Ober-, Real-, Sekundarschule 3. Mittelschule (Gymnasium, Kantonsschule) 4. Berufsfachschule / Berufsschule mit Abschluss / Diplom
High	11. Techniker- oder Fachschule (2 Jahre Vollzeit, 3 Jahre Teilzeit) 12. Höhere Fachschule, HTL, HWV (3 Jahre Vollzeit oder 4 Jahre Teilzeit) 13. Universität, Hochschule (Lizentiat, Dissertation, Nachdiplom)	9. Fachhochschule / Pädagog. Hochschule 10. Universität, natur- /ingenieurwiss. Studium 11. Universität, geistes- /sozialwiss. Studium.	5. Fachhochschule 6. Universität

Table A. 2 Parameter estimates for the wage rate model

Variable	Coefficient	t-stat.
Constant	2.939	30.3
Age 26-35	0.154	2.3
Age 36-45	0.287	4.1
Age 46-55	0.345	4.8
Age > 55	0.208	2.6
Man	0.067	1.8
Education medium	0.184	2.0
Education high	0.711	10.0
(Man)(Age > 55)(Education high)	1.660	6.1
(Age > 55)(Education high)	-0.685	-3.6
Full time	-0.153	-2.0
(Full time)(Education medium)	0.240	2.6
R^2	0.286	
N	524	

Appendix B. Assumptions for trip costs by mode, insurance and tax costs for cars and cost of public transport season tickets.

In Mobidrive there is information on trip costs, which includes single tickets for the public transport, parking cost, taxi, etc. In spite of this, it was preferred to calculate the cost again when this was possible and to use the reported cost in another case. For THURGAU, there is no information about trip costs, therefore for all the modes it had to be imputed.

Walk: A cost of zero was assumed for both samples.

Bike: A cost of zero was assumed for both samples.

Car passenger: A cost of zero was assumed for both samples.

Others: The reported cost was used for the German sample, whereas a cost of zero was assumed for the Swiss sample.

Motorcycle

$$CT=\frac{Price\_gasoline*distance[km]}{28.6[km/l]} \tag{18}$$

where the price of the gasoline corresponds to 1.9 DEM/lt. (0.97 EURO/lt.) for the German sample (this value was used by König and Axhausen, 2001) and 1.4 CHF/lt. (0.92 EURO/lt.) for the Swiss sample. The value of 28.6 [km/lt.] corresponds to the consumption of a motorcycle of 125 cc. Parking cost was not included.

Car driver

For the German sample, the researchers of the project generated fuel consumptions and variable costs per kilometre from the available vehicle information. In THURGAU, there is no detailed information on the vehicles. We use the average values from the German sample instead. A value of 7.4 lt./100 km. was used for the consumption and 0.69 DEM/km = 0.54 CHF/km (1 DEM=0.51 EUR=0.78 CHF average 2003) for the variable cost. For the value of the variable cost, which includes repair and maintenance, we tried to use a similar approach to the used one for the insurance and tax expenses, but the costs of repair and maintenance in the Einkommens- und Verbrauchserhebung 2000 survey did not have a clear link between income and cost, and the variation inside of a group was very large. Besides, this information was not available for all households that reported insurance and tax costs. The cost per kilometre together with the travelled distance of the trip allowed to calculate the fuel and variable costs of the trip. Finally, in German case, a parking cost was added if the destination of the trip was the centre of the city, this value corresponds to 2 DEM/hour. For the Swiss sample this cost was not considered. The gasoline prices used were the same as that for motorcycle.

Public transport

For both samples, a cost of zero was assumed if the person had public transport season ticket, otherwise a cost of 2.50 DEM (1.28 EURO) was used for the German sample and a cost of 2 CHF (1.31 EURO) for the Swiss sample.

Train

The reported cost was used in the German case. For the Swiss sample, a cost of zero was assumed if the person had some season ticket for the train, otherwise we used information on cost of tickets depending on the distance travelled.

Combined modes

For the combined modes with car driver, the travelled distance in this mode was calculated using the average speed observed in the pure mode and the time reported in this stage of the trip. With this distance, the assumptions mentioned earlier for the car driver were applied (without considering parking cost) and the costs of the other modes were added. For the Swiss sample, the same idea was used in combined modes with train and motorcycle where it was necessary to know the travelled distance in this mode to obtain the cost of this stage of the trip. The speeds used in this approach can be seen in the Table B. 1. For the rest of the combined modes, the same assumptions used for the pure modes were utilized.

Table B. 1 Average speeds by mode [km/hr]

Mode	Speed	
	Mobidrive	Thurgau
Car	32.0	45.1
Train	-	47.6
Motorcycle	-	35.0

Table B. 2 Types of season tickets for Switzerland, validity and prices

	Type of ticket	Price
1	General season ticket for public transport in Switzerland	
	Adult GA, 2nd class	275, per month
	Junior GA, 2nd class	205, per month
	Senior GA, 2nd class	210, per month
2	Halbtax	
	Adult	150, per year
3	Gleis 7	
	Gleis 7 combined with one-year Half-Fare Card	249, per year
4	Yearly or monthly ticket for train/bus (i.e. Ostwind)	
	Adult, 2nd class, 1-2 zones	73, per month
	Junior, 2nd class, 1-2 zones	53, per month
5	Yearly or monthly ticket for city bus Frauenfeld	
	Adult	52, per month
	Junior	39, per month
	Senior	39, per month
6	Multiple ticket (regular)	
	12 trips	18
7	Route pass	
	It depends on the route, which were identified in each case.	
8	Other season tickets	
	Adult	62.5, per month (average between the prices of 4 and 5)
	Junior	46, per month (average between the prices of 4 and 5)

Table B. 3 Insurance and tax costs for vehicles by income group for Thurgau [CHF/month]

Income	Number of observations	Average vehicle tax	Average vehicle insurance premiums
<= 2000	22	28.77	66.89
2001 – 3000	76	34.40	67.76
3001 – 4000	133	35.15	79.04
4001 – 5000	189	35.72	93.67
5001 – 7500	713	38.87	102.72
7501 – 10000	759	44.31	116.33
> 10000	1029	52.92	153.75
Total	2921	44.67	121.39