Transportation Research Part A 76 (2015) 38–57

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Understanding time use: Daily or weekly data?

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ARTICLE INFO

Article history:
Available online 21 August 2014

Keywords:
Time use
Survey duration
Time value
Time diaries

ABSTRACT

The appropriate duration of time diaries as a source of time use data is analyzed in a structured way. Nine detailed European surveys based on seven-days diaries are used in order to study different dimensions of data quality, duration and variability of activities, and modeling capabilities. Pseudo diaries of 1, 2 (one week, one weekend) and 3 (one week, both weekend) days are constructed to further analyze these issues, selecting the seven-days diaries data as a benchmark. Comparative results show that two and three-days weighted surveys seem to be an adequate surrogate for the information obtained in weekly surveys that capture a basic work–leisure cycle.

1. Introduction

Time use surveys (TUS) provide information on how populations – described in terms of variables such as gender, age, ethnicity, socioeconomic status and household type – assign their time to perform all types of activities. The measurement of time use began relatively early in the twentieth century; some studies even mention a survey from 1924 in the former Soviet Union and others made in the United States and Japan. After World War II, this type of studies became recurrent. The international comparative time use studies designed and organized by Szalai (1972) are usually mentioned as the starting point of modern time use measurement in Western market economies, because of the explicit effort to standardize both the contents and the methodology of surveys. Although studies on time use have multiplied around the world, it is a common opinion that criteria for international harmonization should be established to allow comparability among different countries or regions. In this regard, Eurostat (Statistical Office of the European Communities) launched project HETUS (Harmonized European Time Use Surveys) in the nineties, to promote improvements in time use research and the development of standards to permit international comparisons within Europe. Presently, an external user can access harmonized summaries of processed information from 15 European countries through HETUS.

The magnitude of information regarding time use can be overwhelming. It can cover days, weeks, months, years and even a lifetime. To choose the period of observation properly is an issue that is intimately related with the research objective and whose relevance has been acknowledged in an extensive range of articles. In this paper we want to contribute to this discussion by creating a structured way of analyzing the proper duration of time diaries. The idea is to explore the effects of survey duration on the accuracy of reported activities (number, duration, exhaustiveness), on capturing activity patterns and on modeling time use and its values, in order to compare different observation periods and to draw a justified recommendation. The remainder of this section contains a description of the different sources to obtain time use information. In Section 2 we summarize the arguments around those issues related with the measurement of time use discussed in the

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http://dx.doi.org/10.1016/j.tra.2014.07.009
0965-8564/

literature. In Section 3 we identify appropriate data sets (multiday diaries) to analyze those issues comparatively using different periods of observation. The analysis is performed in Sections 4 (descriptive) and 5 (modeling). Section 6 concludes.

The first multi-national organization aimed at studying time use was created in the mid 70's: the International Association for Time Use Research (IATUR), aimed at fostering the development of time use studies and promoting time use studies at an international level. IATUR's objectives include the identification and promotion of methodological designs to ensure comparability between countries. In the late eighties, IATUR collected surveys on time use studies in 20 countries and generated a harmonized version of them to allow international comparison. The result is known as the Multinational Time Use Study (MTUS). Presently, the MTUS consists of 68 harmonized datasets collected since the early 1960s from 22 countries with common series of background variables and total time spent per day grouped into 41 activities; some surveys contain specific (additional) variables. Data contained in MTUS surveys are readily available from the Centre for Time Use Research (CTUR) website.

Another attempt to support TUS is the Research Network on Time Use (RNTU), a pilot project promoted by the University of Lüneburg, Germany, whose main objective is to build and provide a system of information on research into time use that can be accessed via Internet for anyone interested. The information system includes references to the researcher, links to databases, methods used, results, literature, discussions and suggestions. Besides these two groups dedicated entirely to TUS with an international scope, presently many countries conduct their own TUS (including the American Time Use Survey) aimed at satisfying their need for specific information. In our search for TUS sources, we came to the conclusion that the most complete one is the MTUS, kept and updated constantly by the CTUR.

There have been attempts to introduce some homogeneity regarding the period of observation in data collection in order to facilitate comparisons among surveys. However, there still are differences of opinion among time use researchers regarding this important problem. In the next section we present the most commonly addressed issues in the literature regarding the impact of different survey lengths.

2. Measurement issues

In the matter of measurement issues in evolving activity and social network patterns, the consideration of several days versus one, two or three for surveying has been discussed from various perspectives. The most relevant aspects in this discussion, in our opinion, are: response rate, quality of information, variability of data and modeling issues. Let us examine the views on each of these aspects.

Regarding response rate, without much rigorous empirical comparisons some authors claim that individuals may be reluctant to take part in a study if they are expected to complete more than one or two daily diaries; according to this, forcing responses during a longer period would lower the willingness to participate (Schlich and Axhausen, 2003; Shon, 1999; Pas and Harvey, 1997; Rydenstam, 1995; Bagatta, 1995; Harvey, 1993; Hedges, 1986; Gershuny et al., 1986, among others).

The length of the period surveyed has an influence on quality of information in two dimensions: richness of data and accuracy of the information recorded. Glorieux and Minnen (2009), Schlich and Axhausen (2003) and Gershuny et al. (1986) found that the number of activities reported did not decrease when going from 1 or 2-day diaries to 7-day diaries. Additionally, Ampt and Richardson (1994) showed that the degree of understanding of the survey methodology increases in time. On the other hand, longer periods might be associated with larger degrees of inaccuracy because of fatigue or diminished motivation, as mentioned by Väisänen (2009), Backor et al. (2007), Axhausen et al. (2002), Golob and Meurs (1986), Niemi (1983), Clarke et al. (1981) and Szalai (1972), among others. Note that time allocation may be accurately reported but the timing may be wrong, which can be occasionally detected when looking at joint activities reported by more than one individual in a household.

On the aspect of variability of data, the allocation of time of individuals to different activities can differ greatly across the days of the week and across seasons of the year. Activities that happen on weekend days are likely to be quite different from the activities that happen on a weekday; these differences occur because, among other things, the individuals do not experience the same pressures due to the usually exogenous organization of work activities. Besides, sources of day to day variability encompass various factors such as weather conditions, unexpected events – as well as expected ones – on certain days, such that a one-day, a two-day or a three-day diary might characterize atypical days for the individual interviewed. Day-to-day variability is somehow internalized in a multiday diary because intra-personal variation is captured in addition to inter-personal variation, grasping what can be called a "living cycle", a natural disposition among activities that occur during different periods (a week, a month, a year, a life); evidently, the minimum work–leisure cycle is a week. This factor is mentioned by Hejun and Darren (2010), Glorieux and Minnen (2009), Senbil and Kitamura (2009), Spissu et al. (2009), Habib and Miller (2008), Buliung et al. (2008), Stopher et al. (2008), Bhat et al. (2005, 2004), among others. Recently, Gershuny (2012) noted that in a number of cases researchers have in the past misused time diary materials by estimating population time-distributions directly from single-day diary samples. For example: the absence of free or discretionary leisure time on a given day has been presented, with questionable legitimacy, as evidence of time poverty. On the other hand, some authors found no real differences in average daily activity duration when comparing 2-day diaries against 7-day diaries, noting that richness of information was not lost in a shorter period if days were appropriately chosen (Hedges, 1986; Gershuny and Jones, 1986). Furthermore, and considering that variability of data can be looked upon using many approaches, like inter-individual, inter-household, temporal, spatial and intra-individual variations, Chikaraishi et al. (2010) examined the variation properties of time use behavior incorporating various variance components into a Multilevel Multiple Discrete

Continuous Extreme Value model. They came to the conclusion that the intra-individual variation accounts for more than 50% of the total variation and that most types of unobserved variations are still dominating in the total variation even after introducing the relevant observed information.

Finally, the duration of the period surveyed might have an impact regarding modeling issues when the modeler is dealing with time perception and its many values, as the revealed relative time assignment – which might depend on the period surveyed – is assumed to hide preferences and constraints (Jara-Díaz et al., 2008; Konduri et al., 2011; Munizaga et al., 2011; Glorieux and Minnen, 2009; Spissu et al., 2009; Glorieux et al., 2008; Habib and Miller, 2008; Habib et al., 2008; Bhat et al., 2005, 2004). From this viewpoint, time values inferred from the observation of one or two days could differ substantially from those inferred using models based on weekly assignment of time.

Presently, an international organization took a stand regarding most of these issues and released a formal statement. In the Guidelines on Harmonized European Time Use Surveys, the European Commission (2004), following Harvey (1993), proposed "*to use two diary days, i.e. one weekday (Monday–Friday) and one weekend-day (Saturday and Sunday). The use of only one diary day will also be acceptable, but with only one diary day it is impossible to get any idea of the intra-personal variation. The general rule from this point of view is that the more diary days the better. Considering also the problem of increasing non-response with increasing respondent burden a reasonable choice is two or three diary days.*" This recommendation has been critically examined by Glorieux and Minnen (2009) using ad-hoc data regarding accuracy of the reported activities (number, duration and missing time), concluding that a 7-days survey would be a better choice.

As seen in the introduction, there are sufficient sources of information such that the issues of response rate, quality of information, variability of data and modeling can be quantitatively analyzed to some degree across countries and periods, and this is what we will cover after describing the contents of the most appropriate surveys.

3. Describing multiday surveys

To analyze all of the measurement issues presented above we searched for – and examined – those databases that contain the basic work–leisure cycle, i.e. weekly data on time use for the same individual. Then, we extracted simulated 1-day, 2-day and 3-day diaries to construct pseudo-surveys for fair comparison regarding reported activities, missing time, variability (average duration and time patterns) and modeling results. Inspection of the many datasets available in MTUS showed that there are several differences regarding the degree of detail of variables such as main activity, simultaneous activities, socio-economic characteristics, activities with others, and so on. We searched for those that had the minimum data required to feed the comparative analysis of all dimensions that we had identified, and decided that seven Dutch surveys and two British ones for different years were the most appropriate. In order to examine the modeling capability as well, data was complemented with information regarding money budget and expenses when possible (British case). Note that these nine surveys have limitations: sample sizes are not particularly large, activity location is not included, eight surveys do not include "with whom" activities are performed. Also, the constructed 2 and 3 days pseudo surveys cannot capture the problems that might arise due to the effect of a discontinuity on the individuals' reports. These limitations, however, do not preclude the comparative analysis on the four dimensions we identified.

The two national British surveys are "The People's Activities and Use of Time" (PAUT), conducted by the BBC between 1974 and 1975 covering 1941 individuals (1304 workers), and the "Economic and Social Research Council Time Budget Survey 1983/84" (ETBS) conducted by the Stanford Center for Population Research (SCPR), the University of Bath and the University of Sussex, covering 1350 individuals (579 workers). Both of these surveys used a stratified national random sample of addresses, asking all household members aged 14 or more. The seven Dutch surveys were conducted every five years from 1975 till 2005 by the "Sociaal en Cultureel Planbureau" during October, under the name "En Week Tijd" from 1975 till 2000 and "Tijdsbestedingsonderzoek" (TBO) for 2005. A stratified random sample of 4200 addresses drawn from 300 regional clusters in the Netherlands was used in every survey, implicitly avoiding, as in the British case, self selection bias. Sample size varies from 1143 to 3157 individuals (and from 512 to 2176 workers). Both British and Dutch workers completed seven consecutive days' diaries. Data characteristics are shown in Table 1.

The average daily duration of activities reported by workers are shown in Fig. 1, grouped into five items: Sleep, Leisure, Committed, Childcare and Work. Sleep refers to all activities that involve sleeping; Leisure consider those activities to which the individual wishes to spend more time than the minimum required but cannot because the period ends (e.g. entertainment); Committed are those activities to which the individual wishes to allocate less time than observed but cannot because

Table 1
Data description of all surveys.

Country	United Kingdom		Netherlands						
Year of survey	1975	1985	1975	1980	1985	1990	1995	2000	2005
Sample size	1941	1350	1143	2381	2968	3157	2956	1693	1895
Number of workers	1304	579	512	1031	1938	2176	1739	891	1183
Gender (% men)	58.31	48.70	72.50	61.60	47.70	40.60	45.10	46.70	50.40
Age (% 26–40)	35.71	37.82	43.40	52.60	56.80	54.30	52.60	48.30	35.40
Household type (% cohabiting couple plus others)	69.20	57.86	63.10	66.80	58.20	54.50	48.50	42.50	54.60

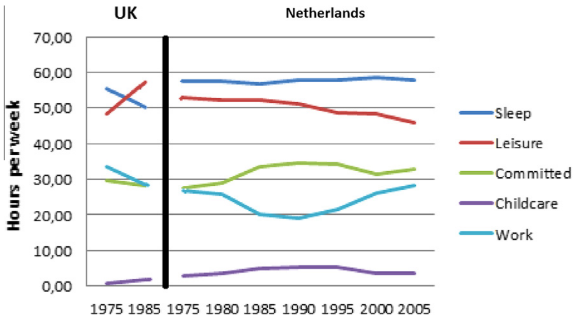


Fig. 1. Average duration of activities for all surveys.

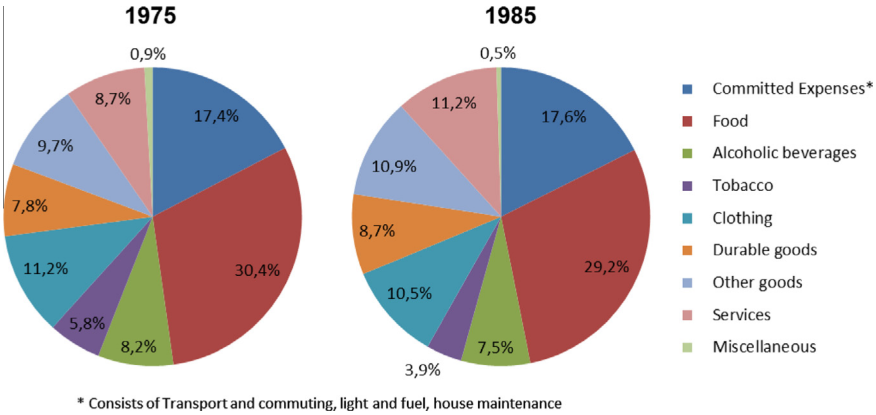


Fig. 2. Total expenses structure – British datasets.

the technological constraints impose an undesired minimum (e.g. travel and errands); Childcare are activities that involve spending time with children (but are not considered as work); finally, Work is understood as activities that report income to the individual; for a detailed description, see Appendix A. Data shows that, for the Dutch data, average time assigned to leisure activities diminished in time while sleep kept constant and committed time increased. Looking at the British data, one can see that work, sleep and committed time diminished while leisure and childcare increased over the span of 10 years.

To estimate the models for time assignment of the type we will use in Section 5, we collected additional data on income and expenses. As mentioned above, this was feasible only for the British data sets because the budget-income information available for the Netherlands was not detailed enough to match the information on time use at the individual level. This complementary information is available in the Family Expenditure Survey (FES), annually conducted on 10,000 homes. In Fig. 2 we show the structure of all expenses for both surveys. Most part of consumption goes to "food" and "committed expenses". In this latter item, transport has the largest share for both datasets and the rest is composed of house maintenance, light and fuel.

Using a matching procedure based on up to 8 socioeconomic characteristics (age, gender, household size, marital status, minors at home, car ownership, type of work and weekly hours worked) we were able to input expenses and income from the FES into the individuals in the British time use surveys.[1] The British sub-samples including income and expenses that were finally used to run the modeling analysis in Section 5 consist of 383 individuals for PAUT and 183 individuals for ETBS. All individuals are workers that live in a one-worker household, which facilitates handling income data and making inferences regarding preferences in the modeling exercise.

4. Analyzing multiday diaries

We aimed at investigating the arguments in favor and against of using different diary periods. To test the differences between a 1-day, 2-days, 3-days and a 7-days registration, we selected different sets of weekdays and weekend days out of the seven collected diary days, keeping in mind the guidelines proposed by EUROSTAT.

Regarding quality of information, in Table 2 we present the average number of reported activities per day. For the British data, the first day surveyed was a Wednesday while for the Dutch data was a Sunday. Looking at the results, the data shows

[1] For every individual in the time use survey we searched for an individual in the expenditure survey with the largest amount of equivalent characteristics.

Table 2
Average number of reported activities for all seven-day surveys.

Diary day	United Kingdom		Netherlands						
	1975	1985	1975	1980	1985	1990	1995	2000	2005
1st	19.06	22.38	21.76	21.61	23.21	23.14	23.04	21.73	22.58
2nd	19.14	22.13	24.15	24.46	26.80	27.05	26.48	24.54	23.78
3rd	19.24	22.39	23.98	24.51	26.67	26.50	26.06	24.12	23.12
4th	19.80	21.96	24.19	24.73	26.54	26.49	26.05	24.05	23.60
5th	19.35	21.85	23.95	24.62	26.68	26.63	25.97	23.81	23.35
6th	18.64	22.09	23.88	24.19	26.12	25.91	25.58	23.57	23.25
7th	18.49	22.37	22.17	22.74	24.19	24.31	24.06	22.88	23.08
Sample size	1304	579	512	1031	1938	2176	1739	891	1183

that the number of reported activities does not appear to diminish as the period of observation for surveying increases, except for Netherlands 1995 and 2000, but this can be seen only on week days, somehow showing a "week-day effect" rather than a survey duration effect. Note that, for the 1975 British data, the number of reported activities increases over the weekend (4th and 5th) but the opposite happens in Netherlands (7th and 1st) and United Kingdom in 1985.

Further on quality, in Table 3 we present the total amount of unspecified time per day (captured by the variable "no recorded activity"). The numbers show that as the survey progresses from the first diary day to the last, the amount of minutes not reported does not increase; however, one can see that the unreported time is a negligible fraction of the period, suggesting that this is not a particularly relevant issue.

Variability of data is an interesting topic by itself, as the whole idea of using a period of observation with less than seven days is based on the potential similarities among days. First we note that we should expect differences between working and weekend days but, are working days similar? Are weekend days different? Let us begin by analyzing time use patterns, which is a most demanding type of analysis.

In Fig. 3 we present time use patterns for 1975 and 1985 both in the United Kingdom and the Netherlands. The figure shows the percentage of workers that are performing each activity group at a given time. It is interesting to see the similarities among the five working days with respect to every activity group regardless of the country or year; it seems as if one day between Monday and Friday were sufficiently representative of working days. On the other hand, by observing the weekend days, one can see that there are evident differences between Saturday and Sunday in every country and year, particularly regarding committed time, work and leisure after eight in the morning (these comparisons hold for the rest of the surveys as well; see the remaining patterns in Appendix B).

To provide quantitative evidence on this observed similarity among working days we can use a *similarity index*. These type of indices are built on the assumption that individuals create routines over time, i.e. that the structure of activities is not decided on a daily basis. As Schlich and Axhausen (2003) mention, individuals will rather repeat an activity pattern that offers them a satisfying experience without carefully judging the alternatives.

There is no agreement on the superiority of a methodology to evaluate similarity of activity patterns. Different methods and indices have been advocated in the literature, as in Hanson and Huff (1982, 1986, 1988), Hanson and Burnett (1981, 1982), Huff and Hanson (1986, 1990), Pas (1980, 1983), Jones and Clarke (1988), Recker et al. (1985) and Joh et al. (2002). Here, we used a variant of the Jones and Clarke similarity index to compare activity behavior across our samples. The purpose of our variant is to analyze overall daily behavior by examining the percentage of people performing the same activity at the same time. We divided each day d in 10 min intervals and compared every day activities (grouped as in Fig. 1) against the working day average within the same interval. If the same activity a is performed within the same interval i by the same percentage of people (allowing a difference less than 2.5 %), the index increases by 1. The result is divided by the maximum possible value if all 144 intervals on a day were identical for all activities (720). The similarity index for day d, SI_d, is then calculated as:

Table 3
Total missing time (minutes/day) for all seven-day surveys.

Diary day	United Kingdom		Netherlands						
	1975	1985	1975	1980	1985	1990	1995	2000	2005
1st	1020	7680	15	0	0	210	0	0	45
2nd	390	8280	0	0	0	45	0	0	15
3rd	930	10,485	0	0	0	45	0	0	15
4th	1800	10,260	0	0	0	75	0	0	0
5th	720	9090	0	0	0	90	0	0	15
6th	630	8640	0	0	0	45	0	0	0
7th	720	8490	15	0	0	180	15	0	0
Sample size	1304	579	512	1031	1938	2176	1739	891	1183

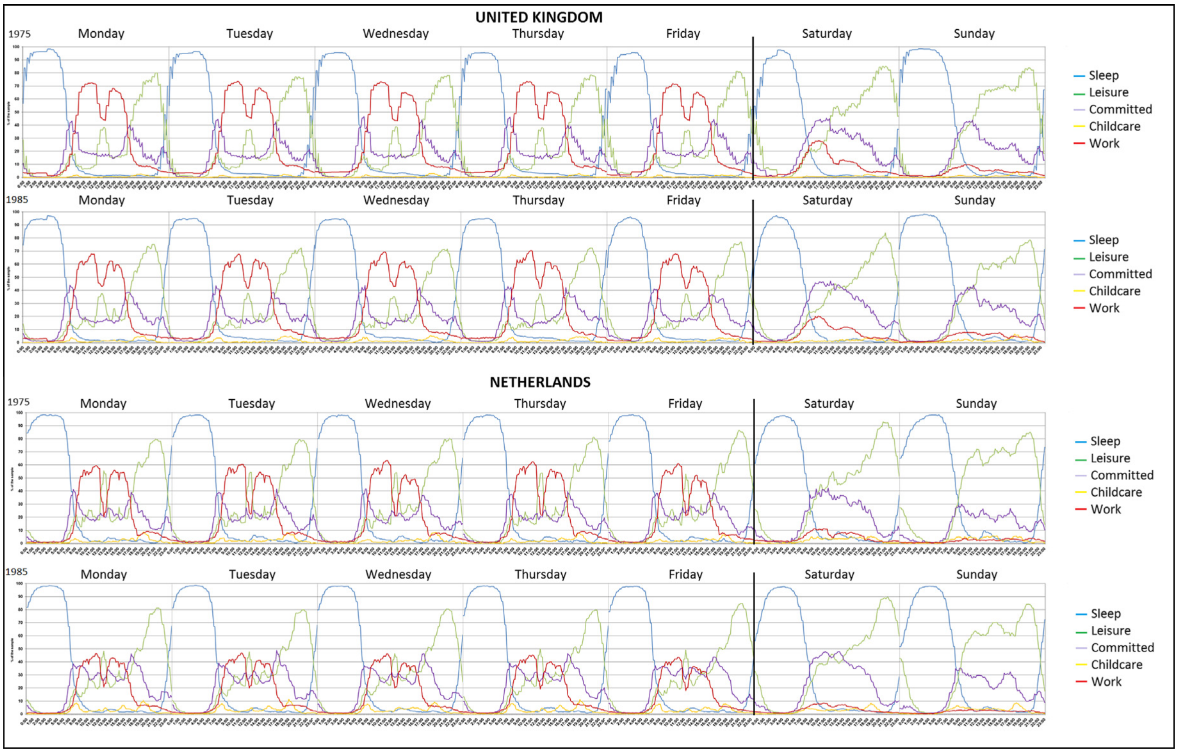


Fig. 3. Daily activity patterns – 1975 and 1985.

$$SI_d = \sum_{i=1}^{144}\sum_{a=1}^{5} f(x)/720 \quad d = 1,\ldots,7 \tag{1}$$

$$f(x) = 1 \text{ if } |p_{aid} - wap_{ai}| \leqslant 0.025 \text{ and } 0 \text{ otherwise}, \quad a = 1,\ldots,5;\ i = 1,\ldots,144$$

where p_{aid} is the proportion of people performing activity a on interval i on day d and wap_{ai} is the working day average proportion of people performing activity a on interval i.

As constructed, a value of 0 for SI_d indicates no similarity between day d and the average working day and a value of 1 indicates identical activity behavior. Note that this is a very demanding similarity measure such that a value above 0.75 can be regarded as "very similar". The results are shown in Table 4. All values from Monday to Friday for all surveys are larger than 0.77, confirming our visual observation regarding the similarity among working day patterns. Furthermore, all SI_d for each weekend day are lower than 0.51, indicating that weekend days are different from the average working day. The p-value shows that for every survey there is a significant statistical difference between working days and weekend days' similarity indices.

The activity patterns' analysis unambiguously indicates similarity across working days and differences with Saturdays and Sundays. This can be also examined through the comparison of the average durations of grouped activities as illustrated

Table 4
Similarity indices for all surveys.

Daily index against working day average	United Kingdom		Netherlands						
	1975	1985	1975	1980	1985	1990	1995	2000	2005
Monday	0.939	0.936	0.918	0.957	0.928	0.956	0.953	0.976	0.958
Tuesday	0.949	0.924	0.964	0.943	0.963	0.974	0.965	0.924	0.904
Wednesday	0.994	0.981	0.931	0.976	0.961	0.963	0.988	0.972	0.953
Thursday	0.965	0.967	0.935	0.950	0.963	0.958	0.983	0.925	0.967
Friday	0.879	0.843	0.865	0.881	0.861	0.879	0.842	0.776	0.783
Saturday	0.464	0.496	0.461	0.456	0.476	0.465	0.464	0.457	0.442
Sunday	0.492	0.508	0.447	0.446	0.472	0.479	0.464	0.460	0.426
Difference between day type (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000

Table 5
Daily average duration of activities for the 1975 British sample (hours).

United Kingdom – 1975								
Activity	Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Sleep	7.87	7.72	7.68	7.58	7.66	7.18	7.75	9.51
Childcare	0.13	0.12	0.10	0.14	0.12	0.11	0.13	0.18
Leisure	6.80	5.78	5.75	5.83	5.73	6.25	9.03	9.19
Committed	4.18	3.99	3.91	3.99	3.98	4.28	4.95	4.15
Work	5.02	6.38	6.55	6.44	6.50	6.16	2.12	0.97
Activity	Difference relative to week (%)							
Sleep		−1.86	−2.40	−3.67	−2.61	−8.74	−1.52	20.80
Childcare		−5.99	−21.96	9.27	−5.29	−14.69	−0.94	39.10
Leisure		−14.98	−15.44	−14.17	−15.60	−7.98	32.95	35.20
Committed		−4.56	−6.41	−4.44	−4.84	2.45	18.41	−0.61
Work		27.22	30.61	28.38	29.51	22.83	−57.78	−80.75

in Table 5 for the 1975 British database. The difference between working days, Saturday and Sunday is evident; this occurs in all the nine surveys selected.

Now we can analyze whether different sets of days can be used as adequate surrogates for a weekly period of observation (at least in terms of average duration of activities and variability). As the original surveys were conducted using a representative sample, we examined randomly selected disjoint groups of individuals (RDG) as if they were answering only one set of days: 1, 2 – one week, one weekend – or 3 – one week, both weekend – days diaries. For the 1-day set, we randomly selected 7 different groups of individuals and we extracted the information gathered from one day per group, covering the data from Monday to Sunday. For the 2-days set, we randomly selected 10 different groups of individuals and we extracted the information gathered from one pair of days per group (one weekday, one weekend day), covering data from "Monday–Saturday" to "Friday–Saturday" and from "Monday–Sunday" to "Friday–Sunday". Lastly, for the 3-days set, we randomly selected 5 different groups of individuals and we extracted the information gathered from one trio of days per group, covering data from "Monday–Saturday–Sunday" to "Friday–Saturday–Sunday". This is presented in columns 3, 4 and 6 of Table 6. In columns 5 and 7 we have considered exactly the same pairs just discussed for the cases of two and three days, but now we acknowledge that a weekday represents five days and, for the case of the two days sets, a weekend day represents two days. In the bottom part of Table 6 we present the difference – relative to the actually observed week – of the average duration of activities following the different grouping procedures.

Results in Table 6 show that the average duration of activities presents relevant variations relative to the week when considering 1, 2 and 3-day diaries. Simple inspection shows that the last column – three days (weekday weighted) – yields the smallest difference with the week. This procedure was applied to all nine surveys; a synthesis of average differences is presented in Table 7. Again, 3-day diaries (weighted) yield the lowest differences of average duration of activities relative to the week in most cases.

In order to test whether these pseudo weeks are adequate surrogates for the observed week, we have to perform an Analysis of Variance (ANOVA) to test the differences between the average activity duration of the four constructed periods taking into account their variances. We first need to know whether the variances are equal (homoscedastic, the main assumption of the simple ANOVA test) or not. Table 8 contains the standard deviation of the activity durations of the four periods of observation (1-day, 2-days weighted, 3-days weighted and a week) for all surveys and activity types: as the period of observation increases, the standard deviation decreases.

Table 6
Average weekly duration of activities for different pseudo-weeks obtained using Random Disjoint Groups.

United Kingdom – 1975						
Activity	Week	1 Day	2 Days Week + Weekend	2 Days Week + Weekend (weighted)	3 Days Week + 2 Weekend	3 Days Week (weighted) + 2 Weekend
	Average duration (h)					
Sleep	55.08	54.84	56.74	55.12	57.93	55.12
Childcare	0.89	0.84	0.91	0.86	0.97	0.87
Leisure	47.57	47.31	52.78	47.91	56.31	47.78
Committed	29.26	29.14	29.86	29.09	30.59	29.13
Work	35.13	35.80	27.63	34.94	22.10	35.02
Activity	Difference relative to week (%)					
Sleep		−0.45	3.00	0.07	5.17	0.06
Childcare		−5.49	2.65	−2.66	9.64	−1.43
Leisure		−0.53	10.95	0.72	18.39	0.45
Committed		−0.40	2.04	−0.58	4.54	−0.44
Work		1.92	−21.33	−0.53	−37.08	−0.29

Table 7
Average differences of the pseudo-weeks' activity durations relative to the observed week for all surveys (percentage).

Number of days to build the pseudo-weeks	United Kingdom		Netherlands						
	1975	1985	1975	1980	1985	1990	1995	2000	2005
1-day	0.80	1.29	1.87	1.47	0.33	0.88	0.89	1.34	0.68
2-days	8.91	9.03	7.23	7.70	5.95	6.23	6.04	7.59	8.38
2-days (weighted)	0.45	1.02	0.78	0.49	0.31	0.32	0.46	0.21	0.73
3-days	15.50	14.81	13.79	13.29	10.97	10.81	10.94	12.97	14.13
3-days (weighted)	0.29	0.57	0.69	0.40	0.23	0.29	0.58	0.27	0.60
Sample size	1304	579	512	1031	1938	2176	1739	891	1183

Table 8
Standard deviation of activity duration for all pseudo weeks, all surveys (hours).

Activity	Type of period	United Kingdom		Netherlands						
		1975	1985	1975	1980	1985	1990	1995	2000	2005
Leisure	1-day	20.15	19.53	20.06	20.87	19.01	20.18	18.95	21.24	20.80
	2-days (weighted)	13.29	14.63	15.37	14.65	13.97	14.74	14.58	14.94	14.43
	3-days (weighted)	12.98	14.27	14.81	14.54	13.50	14.30	14.31	14.42	13.99
	Week	9.99	10.98	12.63	12.10	11.07	12.05	11.50	11.51	11.39
Work	1-day	27.46	26.03	26.16	25.44	24.97	25.15	25.43	26.73	27.49
	2-days (weighted)	18.20	18.16	19.44	18.28	19.34	19.58	19.66	19.20	19.59
	3-days (weighted)	18.08	18.13	18.96	18.06	19.21	19.36	19.56	18.97	19.32
	Week	15.04	14.69	16.74	15.89	17.52	17.19	16.90	15.40	15.45
Committed	1-day	17.12	18.81	16.66	17.37	17.62	19.10	17.36	16.08	18.33
	2-days (weighted)	14.40	15.42	14.43	14.32	14.86	15.64	14.40	13.28	14.83
	3-days (weighted)	14.34	15.16	14.10	13.93	14.65	15.42	14.10	12.86	14.37
	Week	12.84	13.24	12.81	12.52	12.75	13.36	11.99	11.08	11.55
Sleep	1-day	12.16	14.34	12.22	11.78	10.54	12.55	11.43	14.28	12.27
	2-days (weighted)	8.80	10.65	9.36	9.19	8.24	9.86	9.37	10.99	9.31
	3-days (weighted)	8.25	9.85	9.04	9.08	7.91	9.49	9.02	10.61	9.14
	Week	6.40	8.03	7.57	7.50	6.92	8.09	7.90	8.65	7.76
Childcare	1-day	2.80	5.32	6.96	7.58	9.71	8.96	10.14	8.06	7.81
	2-days (weighted)	2.52	4.75	5.36	5.79	8.34	8.67	8.49	7.25	6.90
	3-days (weighted)	2.51	4.62	5.28	5.78	8.23	8.59	8.23	7.08	6.84
	Week	2.21	4.05	4.83	5.04	7.63	7.72	7.62	6.29	6.17

To examine whether variances are statistically different, we performed the Levene test applied to four cases: all four constructed periods; 2-days weighted versus week; 3-days weighted versus week; and 2-days weighted versus 3-days weighted. In all cases the null hypothesis was that the variances were equal, which is rejected if its significance value is lower than 0.05. Table 9 shows that for most databases equality of variances is rejected for the first, second and third cases, but it cannot be rejected when comparing 2-days weighted against 3-days weighted. Thus, according to variability, these results work in favor of either 2-days or 3-days.

Knowing that equality of the variances has been rejected for most cases we have to perform an alternative ANOVA test, called Welch ANOVA, where the means are weighted by the reciprocal of the group mean variances, disregarding the main assumption of the ANOVA test (equal variances). If the significance of the test between groups is lower than 0.05, the test rejects the hypothesis of equal means of the durations of activities between different periods of observation. Results are shown in Table 10. As the significance values of all Welch statistics (for all nine surveys and five activities) are larger than 0.05, we cannot reject the equality hypothesis. Therefore, the activity duration means of the 2-days weighted and the 3-days weighted pseudo-weeks are both statistically equal to the actual week.

For synthesis so far, on the one hand weekly observations do not seem to induce a loss of quality regarding number of reported activities (the fatigue effect) or amount of missing time (accuracy effect). On the other hand adequately chosen shorter periods of observations performed similarly in terms of point average duration of activities, such that choosing one working day (weighted times five) and both weekend days, seems the best surrogate. This conclusion does not change when examining the variance effect by simple inspection (it diminishes as the number of days increases). Finally, a Welch ANOVA shows that activity duration means for pseudo-weeks constructed with either two or three days (weighted) surveys are not statistically different from the actual week.

One additional issue to explore is the trade-off between survey duration and sample size when resources are limited, i.e. is it better to collect information from a few individuals during a week or from many individuals during shorter periods? Controlling for the number of individuals-days, say N, we examined the four periods previously identified: week, 3-days, 2-days and 1-day. For each data base analyzed we extracted different sample sizes n/i from the original pool, with $i = 1, 2,$

Table 9
Test of homogeneity of variances for all surveys.

Periods compared	Activities	United Kingdom				Netherlands													
		1975		1985		1975		1980		1985		1990		1995		2000		2005	
		Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.
All constructed periods	Leisure	174.225	0.000	47.636	0.000	43.081	0.000	103.882	0.000	181.047	0.000	192.653	0.000	135.554	0.000	113.150	0.000	142.782	0.000
	Work	357.239	0.000	153.604	0.000	95.702	0.000	253.574	0.000	236.886	0.000	290.628	0.000	281.364	0.000	270.215	0.000	393.065	0.000
	Committed	35.722	0.000	23.014	0.000	8.796	0.000	27.687	0.000	66.573	0.000	73.162	0.000	75.749	0.000	32.175	0.000	64.849	0.000
	Sleep	86.646	0.000	26.380	0.000	25.301	0.000	44.886	0.000	62.006	0.000	56.169	0.000	59.833	0.000	21.337	0.000	52.098	0.000
	Childcare	1.239	0.294	1.746	0.156	5.898	0.001	16.944	0.000	9.772	0.000	5.489	0.001	11.841	0.000	1.691	0.167	3.562	0.014
2-days weighted versus week	Leisure	69.388	0.000	33.799	0.000	12.464	0.000	28.993	0.000	74.158	0.000	70.848	0.000	82.639	0.000	46.391	0.000	58.586	0.000
	Work	25.776	0.000	23.587	0.000	13.846	0.000	34.019	0.000	46.083	0.000	95.523	0.000	95.711	0.000	89.087	0.000	133.346	0.000
	Committed	13.865	0.000	8.655	0.003	5.964	0.015	12.772	0.000	40.330	0.000	41.245	0.000	58.660	0.000	26.128	0.000	61.243	0.000
	Sleep	80.012	0.000	13.417	0.000	6.753	0.009	17.553	0.000	31.214	0.000	35.156	0.000	21.779	0.000	9.270	0.002	21.104	0.000
	Childcare	2.058	0.152	3.547	0.060	3.322	0.069	6.972	0.008	11.265	0.001	10.032	0.002	7.821	0.005	3.201	0.074	3.114	0.078
3-days weighted versus week	Leisure	53.739	0.000	25.713	0.000	7.599	0.006	24.325	0.000	54.602	0.000	54.954	0.000	66.385	0.000	34.357	0.000	39.968	0.000
	Work	28.544	0.000	25.390	0.000	11.975	0.001	34.665	0.000	49.441	0.000	93.112	0.000	105.527	0.000	86.304	0.000	127.929	0.000
	Committed	12.032	0.001	7.711	0.006	3.543	0.060	8.022	0.005	34.298	0.000	34.732	0.000	47.222	0.000	16.596	0.000	47.544	0.000
	Sleep	43.336	0.000	9.975	0.002	3.997	0.046	13.668	0.000	20.456	0.000	23.433	0.000	12.738	0.000	5.292	0.022	16.273	0.000
	Childcare	1.082	0.298	1.996	0.158	1.978	0.160	5.871	0.015	7.772	0.005	9.080	0.003	2.771	0.096	2.375	0.124	2.564	0.109
2-days weighted versus 3-days weighted	Leisure	0.884	0.347	0.481	0.488	0.582	0.446	0.170	0.680	1.593	0.207	1.171	0.279	0.819	0.366	0.945	0.331	1.618	0.203
	Work	0.029	0.866	0.016	0.899	0.114	0.735	0.007	0.934	0.007	0.934	0.118	0.731	0.059	0.808	0.076	0.783	0.158	0.691
	Committed	0.057	0.812	0.039	0.843	0.302	0.583	0.561	0.454	0.269	0.604	0.298	0.585	0.666	0.415	1.042	0.308	0.947	0.331
	Sleep	5.190	0.023	0.420	0.517	0.338	0.561	0.211	0.646	1.243	0.265	1.249	0.264	1.214	0.271	0.505	0.477	0.302	0.583
	Childcare	0.133	0.715	0.210	0.647	0.163	0.687	0.038	0.846	0.317	0.574	0.029	0.866	1.215	0.270	0.066	0.797	0.026	0.872

Table 10
Analysis of Variance (Welch ANOVA).

Periods compared	Activities	df	United Kingdom				Netherlands													
			1975		1985		1975		1980		1985		1990		1995		2000		2005	
			Welch	Sig.	Welch	Sig.	Welch	Sig.	Welch	Sig.	Welch	Sig.	Welch	Sig.	Welch	Sig.	Welch	Sig.	Welch	Sig.
All constructed periods	Leisure	3	0.351	0.788	0.319	0.811	0.435	0.728	0.205	0.893	0.024	0.995	0.461	0.710	0.108	0.955	0.455	0.714	0.021	0.996
	Work	3	0.321	0.810	0.194	0.901	0.206	0.892	0.385	0.764	0.044	0.988	0.087	0.967	0.119	0.949	0.029	0.993	0.199	0.897
	Committed	3	0.039	0.990	0.380	0.768	0.660	0.577	0.545	0.652	0.131	0.942	0.460	0.710	0.680	0.564	0.631	0.595	0.478	0.697
	Sleep	3	0.193	0.901	0.148	0.931	0.398	0.754	0.171	0.916	0.049	0.986	0.130	0.942	0.192	0.902	0.069	0.976	0.177	0.912
	Childcare	3	0.085	0.968	0.022	0.996	0.093	0.964	0.632	0.594	0.006	0.999	0.182	0.909	0.221	0.882	0.026	0.994	0.023	0.995
2-days weighted versus week	Leisure	1	0.548	0.459	0.046	0.830	0.161	0.688	0.478	0.489	0.072	0.788	0.056	0.813	0.007	0.933	0.005	0.942	0.017	0.898
	Work	1	0.080	0.777	0.522	0.470	0.285	0.594	0.003	0.956	0.023	0.879	0.058	0.810	0.032	0.858	0.043	0.836	0.527	0.468
	Committed	1	0.101	0.751	0.258	0.612	0.045	0.832	0.280	0.597	0.330	0.566	0.190	0.663	0.732	0.392	0.000	0.990	1.155	0.283
	Sleep	1	0.017	0.896	0.412	0.521	0.049	0.824	0.018	0.893	0.066	0.798	0.087	0.768	0.232	0.630	0.031	0.861	0.003	0.955
	Childcare	1	0.064	0.800	0.065	0.799	0.021	0.884	0.000	0.985	0.001	0.981	0.028	0.867	0.118	0.731	0.025	0.875	0.014	0.907
3-days weighted versus week	Leisure	1	0.221	0.638	0.013	0.909	0.169	0.681	0.269	0.604	0.007	0.931	0.020	0.887	0.017	0.895	0.078	0.780	0.057	0.811
	Work	1	0.025	0.875	0.257	0.612	0.201	0.654	0.003	0.955	0.035	0.852	0.038	0.845	0.047	0.829	0.003	0.957	0.276	0.599
	Committed	1	0.059	0.809	0.098	0.755	0.073	0.787	0.249	0.618	0.151	0.698	0.040	0.841	0.927	0.336	0.064	0.801	0.540	0.462
	Sleep	1	0.014	0.906	0.023	0.880	0.002	0.960	0.000	0.993	0.044	0.834	0.327	0.567	0.509	0.476	0.009	0.924	0.026	0.871
	Childcare	1	0.019	0.891	0.019	0.891	0.029	0.864	0.017	0.896	0.008	0.928	0.091	0.763	0.294	0.588	0.034	0.854	0.041	0.841
2-days weighted versus 3-days weighted	Leisure	1	0.061	0.804	0.086	0.770	0.000	1.000	0.026	0.871	0.028	0.866	0.008	0.928	0.038	0.846	0.033	0.856	0.009	0.923
	Work	1	0.014	0.907	0.039	0.844	0.008	0.931	0.000	1.000	0.001	0.974	0.002	0.965	0.001	0.973	0.020	0.888	0.035	0.852
	Committed	1	0.005	0.943	0.035	0.852	0.003	0.959	0.001	0.971	0.031	0.859	0.049	0.825	0.008	0.929	0.048	0.826	0.104	0.747
	Sleep	1	0.000	0.987	0.210	0.647	0.063	0.802	0.013	0.908	0.002	0.962	0.061	0.805	0.041	0.839	0.060	0.806	0.041	0.840
	Childcare	1	0.012	0.912	0.013	0.910	0.001	0.981	0.020	0.888	0.004	0.949	0.016	0.900	0.033	0.856	0.001	0.982	0.006	0.937

Table 11
Sample sizes for all pseudo-surveys covering equal individuals-days.

Type of period	United Kingdom		Netherlands						
	1975	1985	1975	1980	1985	1990	1995	2000	2005
1-day	1304	579	512	1031	1938	2176	1739	891	1183
2-days	652	289	256	515	969	1088	869	445	591
3-days	434	193	170	343	646	725	579	297	394
Week	186	82	73	147	276	310	248	127	169
Individuals-days (N)	1304	579	512	1031	1938	2176	1739	891	1183

Table 12
Standard deviation of activity duration for all pseudo weeks, all surveys with new sample sizes (hours).

Activity	Type of period	United Kingdom		Netherlands						
		1975	1985	1975	1980	1985	1990	1995	2000	2005
Leisure	1-day	20.03	20.07	20.69	20.18	19.58	20.03	19.16	20.75	20.29
	2-days (weighted)	13.11	13.32	15.10	14.21	14.48	14.41	14.05	14.34	13.69
	3-days (weighted)	12.86	14.98	13.49	14.93	13.40	15.09	15.33	14.09	13.65
	Week	9.70	12.88	10.97	11.99	11.11	12.01	10.49	11.49	11.26
Work	1-day	27.10	26.58	26.08	25.47	25.20	25.23	26.19	26.65	27.41
	2-days (weighted)	17.84	17.63	17.88	18.41	19.68	19.51	19.34	18.94	18.75
	3-days (weighted)	17.81	16.61	20.62	17.36	19.45	19.61	20.19	18.53	20.09
	Week	14.70	16.56	15.17	15.87	17.33	16.91	16.62	16.07	15.45
Committed	1-day	16.86	17.95	17.01	21.98	17.11	18.58	17.58	16.29	17.69
	2-days (weighted)	14.10	15.22	13.88	16.69	14.84	15.29	13.94	13.65	14.22
	3-days (weighted)	15.64	15.06	13.76	14.32	14.94	15.76	13.22	13.80	14.76
	Week	13.00	11.72	12.61	13.11	11.68	13.06	11.84	12.45	10.70
Sleep	1-day	11.84	13.83	11.37	12.27	12.07	12.81	12.48	13.32	12.50
	2-days (weighted)	9.02	9.30	8.30	11.62	10.41	10.36	8.81	10.12	8.49
	3-days (weighted)	8.15	9.37	7.29	8.73	8.17	9.58	9.13	9.33	8.81
	Week	5.80	9.18	5.66	10.14	6.12	8.16	7.47	8.49	6.49
Childcare	1-day	2.84	5.57	6.93	6.34	9.32	9.60	9.30	7.16	6.92
	2-days (weighted)	2.42	4.56	5.55	6.60	8.37	8.97	9.30	7.01	7.09
	3-days (weighted)	2.53	4.48	6.39	5.84	8.17	8.46	9.34	6.42	7.13
	Week	1.72	5.13	3.92	6.16	7.49	6.81	7.61	5.40	7.24

3 and 7, shown in Table 11. Using these different sample sizes for the construction of the pseudo surveys for the four periods, we analyzed the same issues (variability and means) by looking at the new standard deviations and by performing new tests (Levene and Welch ANOVA).

Table 12 shows the standard deviation of the four periods of observation for all surveys and activity types, constructed with the new sample sizes. Results show that in general (23 out of the 45 survey-activity category), the standard deviation decreases as the period of observation increases. The rest of the results display the same situation when comparing the shortest period (1-day) against the longest one (a week).

To test if these differences are statistically significant, we proceeded to perform the Levene test once again. Results in Table 13 show that most variances between these four new constructed periods are significantly different across activities and surveys. However, when comparing the variances of pairs of constructed periods, the variances of the 2-days weighted and the 3-days weighted periods are not statistically different for most activities and surveys but there are differences when compared against the week. Finally, the Welch ANOVA test reported in Table 14 shows that for most of the nine surveys and five activities we cannot reject the equality of means hypothesis. For synthesis, when analyzing the trade-off between survey duration and sample size results suggest that a week-long survey applied to relatively small representative population would do as well as a 2-days or a 3-days weighted survey applied to larger populations.

Overall we can conclude that, on one hand, when a week long survey is applied quality does not diminish and variances of activity durations are smaller. On the other hand, 2 or 3-days weighted surveys seem to do as well statistically in spite of larger variances. Let us now move to the last issue: data is collected not only to describe properly but also to model behavior and perceptions, which is what we inspect next.

5. Modeling

In this section we want to examine data collected during different periods as a source of information to estimate time use models. To do this, we will use the microeconomic model obtained and described in detail in Jara-Díaz et al. (2008) which we

Table 13
Test of homogeneity of variances for all surveys with new sample sizes.

Periods compared	Activities	United Kingdom		Netherlands															
		1975		1985		1975		1980		1985		1990		1995		2000		2005	
		Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.	Levene Statistic	Sig.
All constructed periods	Leisure	78.817	0.000	19.611	0.000	23.847	0.000	53.360	0.000	78.349	0.000	79.950	0.000	59.265	0.000	41.205	0.000	68.708	0.000
	Work	211.315	0.000	91.371	0.000	57.104	0.000	142.097	0.000	125.205	0.000	130.273	0.000	144.256	0.000	122.654	0.000	182.240	0.000
	Committed	11.355	0.000	9.627	0.000	5.977	0.000	12.159	0.000	26.436	0.000	27.275	0.000	39.158	0.000	10.366	0.000	16.484	0.000
	Sleep	34.301	0.000	9.617	0.000	15.429	0.000	16.615	0.000	23.357	0.000	22.843	0.000	27.969	0.000	15.656	0.000	26.479	0.000
	Childcare	1.911	0.126	0.798	0.495	2.103	0.098	1.354	0.255	3.672	0.012	7.113	0.000	2.050	0.105	2.598	0.051	2.075	0.101
2-days weighted versus week	Leisure	10.993	0.001	0.300	0.584	6.414	0.012	4.781	0.029	16.596	0.000	17.773	0.000	18.375	0.000	6.659	0.010	4.793	0.029
	Work	4.234	0.040	0.502	0.479	4.880	0.028	6.673	0.010	15.077	0.000	22.822	0.000	21.812	0.000	15.400	0.000	17.756	0.000
	Committed	0.299	0.585	5.847	0.016	0.260	0.610	2.700	0.101	21.230	0.000	7.535	0.006	13.687	0.000	3.363	0.067	12.572	0.000
	Sleep	12.305	0.000	0.159	0.691	7.386	0.007	7.265	0.007	12.821	0.000	8.857	0.003	4.164	0.042	1.789	0.182	10.670	0.001
	Childcare	4.110	0.043	0.457	0.500	2.904	0.089	1.156	0.283	3.711	0.054	17.755	0.000	5.000	0.026	6.437	0.011	3.172	0.075
3-days weighted versus week	Leisure	10.685	0.001	1.351	0.246	2.869	0.092	6.751	0.010	9.309	0.002	16.530	0.000	36.166	0.000	5.021	0.026	2.193	0.139
	Work	7.982	0.005	0.050	0.823	5.140	0.024	3.107	0.079	16.044	0.000	20.229	0.000	35.534	0.000	9.505	0.002	27.199	0.000
	Committed	5.872	0.016	5.414	0.021	1.247	0.265	0.869	0.352	23.401	0.000	13.096	0.000	6.273	0.012	1.515	0.219	14.501	0.000
	Sleep	7.543	0.006	0.035	0.851	2.686	0.103	3.691	0.055	8.615	0.003	3.960	0.047	6.480	0.011	0.780	0.378	5.614	0.018
	Childcare	4.528	0.034	1.968	0.162	1.971	0.162	0.591	0.442	2.480	0.116	8.674	0.003	6.244	0.013	4.514	0.034	2.940	0.087
2-days weighted versus 3-days weighted	Leisure	0.007	0.934	1.099	0.295	1.566	0.211	0.650	0.420	2.320	0.128	0.170	0.680	7.188	0.007	0.132	0.716	0.554	0.457
	Work	0.862	0.353	0.443	0.506	0.838	0.360	1.418	0.234	0.010	0.921	0.000	0.987	4.341	0.037	0.718	0.397	3.679	0.055
	Committed	7.112	0.008	0.004	0.949	0.542	0.462	1.111	0.292	0.214	0.644	1.727	0.189	2.383	0.123	0.355	0.551	0.425	0.514
	Sleep	1.665	0.197	0.631	0.427	2.354	0.126	0.045	0.832	3.366	0.067	1.888	0.170	0.729	0.393	0.427	0.514	0.452	0.502
	Childcare	0.104	0.747	1.406	0.236	0.005	0.943	0.077	0.781	0.177	0.674	2.753	0.097	0.173	0.677	0.478	0.489	0.001	0.971

Table 14
Analysis of variance (Welch ANOVA) with new sample sizes.

Periods compared	Activities	df	United Kingdom		Netherlands															
			1975		1985		1975		1980		1985		1990		1995		2000		2005	
			Welch	Sig.	Welch	Sig.	Welch	Sig.	Welch	Sig.	Welch	Sig.	Welch	Sig.	Welch	Sig.	Welch	Sig.	Welch	Sig.
All constructed periods	Leisure	3	0.284	0.837	0.432	0.730	0.254	0.858	0.307	0.820	0.349	0.790	0.627	0.597	3.774	0.010	0.291	0.832	0.834	0.475
	Work	3	0.818	0.484	0.621	0.602	0.093	0.964	0.631	0.595	0.308	0.819	0.535	0.659	3.278	0.020	1.874	0.133	0.260	0.854
	Committed	3	0.618	0.603	3.171	0.024	0.097	0.962	0.192	0.902	0.393	0.758	0.362	0.781	0.412	0.744	0.400	0.753	0.050	0.985
	Sleep	3	1.532	0.205	0.215	0.886	0.909	0.437	1.188	0.313	1.651	0.176	0.429	0.732	0.829	0.478	0.967	0.408	0.939	0.421
	Childcare	3	0.392	0.758	0.625	0.599	0.164	0.921	1.863	0.135	0.457	0.713	1.389	0.245	1.567	0.196	0.939	0.421	2.089	0.100
2-days weighted versus week	Leisure	1	0.820	0.366	1.274	0.261	0.022	0.883	0.103	0.748	0.967	0.326	1.321	0.251	3.072	0.080	0.356	0.551	0.670	0.414
	Work	1	0.018	0.893	0.961	0.329	0.048	0.826	1.077	0.300	0.894	0.345	0.007	0.932	0.351	0.554	3.004	0.084	0.032	0.858
	Committed	1	0.817	0.367	6.016	0.015	0.101	0.751	0.003	0.956	0.979	0.323	0.261	0.609	0.471	0.493	0.250	0.618	0.143	0.705
	Sleep	1	0.234	0.629	0.081	0.777	1.214	0.272	1.219	0.270	2.987	0.084	0.856	0.355	0.311	0.578	0.513	0.475	0.003	0.955
	Childcare	1	0.581	0.447	0.706	0.403	0.072	0.788	5.301	0.022	0.233	0.629	4.094	0.043	0.149	0.700	2.440	0.120	2.583	0.109
3-days weighted versus week	Leisure	1	0.176	0.675	0.804	0.371	0.047	0.828	0.759	0.384	0.249	0.618	0.751	0.386	9.231	0.002	0.019	0.890	0.234	0.629
	Work	1	1.502	0.221	1.017	0.315	0.017	0.897	0.004	0.947	0.533	0.466	0.017	0.895	6.456	0.011	0.000	0.996	0.303	0.583
	Committed	1	0.011	0.916	7.439	0.007	0.277	0.599	0.335	0.563	0.885	0.347	0.000	0.994	0.076	0.783	0.004	0.952	0.039	0.843
	Sleep	1	2.344	0.126	0.047	0.828	2.703	0.102	0.429	0.513	0.035	0.852	0.014	0.906	0.381	0.537	0.406	0.525	0.552	0.458
	Childcare	1	1.080	0.299	1.610	0.207	0.392	0.532	3.203	0.074	1.167	0.280	1.207	0.272	0.668	0.414	1.938	0.165	2.501	0.115
2-days weighted versus 3-days weighted	Leisure	1	0.248	0.619	0.031	0.861	0.179	0.673	0.519	0.472	0.286	0.593	0.055	0.815	2.942	0.087	0.736	0.391	2.411	0.121
	Work	1	1.878	0.171	0.008	0.928	0.158	0.691	1.446	0.229	0.044	0.833	0.074	0.786	6.373	0.012	4.375	0.037	0.763	0.383
	Committed	1	1.457	0.228	0.281	0.596	0.090	0.764	0.468	0.494	0.001	0.977	0.347	0.556	0.237	0.626	0.491	0.484	0.029	0.864
	Sleep	1	1.371	0.242	0.464	0.496	0.427	0.514	3.283	0.070	4.204	0.041	0.894	0.344	2.027	0.155	2.894	0.089	0.669	0.414
	Childcare	1	0.161	0.688	0.513	0.474	0.196	0.658	0.207	0.649	0.677	0.411	0.970	0.325	0.322	0.570	0.017	0.895	0.007	0.934

Table 15
Microeconomic model results – 1975 British.

United Kingdom – 1975	Week		1 Day		2 Days Week + Weekend		2 Days Week + Weekend (weighted)		3 Days Week + 2 Weekend		3 Days Week (weighted) +2 Weekend	
	Value	t-stat	Value	t-stat	Value	t-stat	Value	t-stat	Value	t-stat	Value	t-stat
α	0.3968	14.26	0.3943	7.23	0.4643	23.57	0.4454	18.15	0.4585	26.20	0.4351	16.72
β	0.1370	55.00	0.1786	45.16	0.1174	41.03	0.1455	56.76	0.0910	30.73	0.1434	55.36
Θ leisure	0.34	92.26	0.28	44.26	0.37	79.23	0.33	74.60	0.41	88.29	0.33	76.79
σ work	10.44	27.60	2.28	24.28	3.58	26.91	11.29	26.91	5.27	26.94	11.18	27.01
σ leisure	9.19	27.60	2.12	24.28	3.42	26.91	11.52	26.91	4.90	26.94	11.18	27.01
ρ work–leisure	−0.75	−33.01	−0.76	−30.97	−0.67	−0.23	−0.67	−23.27	−0.72	−27.98	−0.68	−23.89
Log-likelihood	−6.99		−3.98		−5.05		−7.41		−5.73		−7.36	
LR w/correlations	107.15		92.17		51.83		53.69		163.42		132.55	
$\rho\alpha - \beta$	0.61		0.56		0.56		0.56		0.58		0.58	
Average time values (£/h)												
VST leisure	1.52	3.77	1.84	1.96	3.39	1.82	2.80	2.24	2.29	2.39	2.34	2.52
VST work	0.36	0.88	0.72	0.77	2.30	1.23	1.70	1.36	1.18	1.23	1.24	1.33
w	1.17		1.11		1.10		1.10		1.10		1.10	
VST leisure/w [%]	130.65		164.98		308.87		254.71		207.01		212.36	
VST work/w [%]	30.65		64.98		208.87		154.71		107.01		112.36	
Sample size	381		295		362		362		363		365	
(1−2β)/(1−2α)	3.5174		3.0407		10.7171		6.4927		9.8554		5.4946	

now synthesize. This model is based on the framework proposed by DeSerpa (1971) in which individuals derive utility from time assigned to activities and from goods consumed. Three types of restrictions are considered: a money budget constraint, a total time constraint for the corresponding cycle (day, week, month), and technical constraints that deal with goods consumption and minimum time assignments. Let T_i be the time assigned to each activity i, X_k the amount of good k consumed, T_w the time assigned to work and I_f the income from other sources but work during period τ. Let P_k be the price of good k and w the wage rate. Let activities and consumption have minimum requirements given by T_i^{min} and X_K^{min}, respectively, which represent simplified forms of the technical relations (Jara-Díaz, 2003). The model is:

$$\begin{aligned}
&\max_{s.a.} U = \Omega T_w^{\theta_w} \prod_i T_i^{\theta_i} \prod_k X_k^{\eta_k} \\
&I_f + \mathrm{wT}_w - \sum_k P_k X_k \geqslant 0 \rightarrow \lambda \\
&\tau - T_w - \sum_i T_i = 0 \rightarrow \mu \\
&T_i - T_i^{min} \geq 0 \ \forall i \rightarrow \kappa_i \\
&X_k - X_k^{min} \geq 0 \ \forall k \rightarrow \varphi_k
\end{aligned} \tag{2}$$

As shown below, the choice of a Cobb–Douglas utility form is quite useful and not as restrictive as thought. The optimality conditions lead to the set of Eq. (3) for the time assigned to work (a labor supply model), for the time assigned to leisure activities and for the consumption of freely chosen goods, where the independent (explanatory) variables are the wage rate, the committed time T_c (the sum of constrained activities) and the committed expenses E_c(sum over expenses in constrained goods minus fixed income I_f). Note that the equations for goods consumption can be easily converted into expenditure equations by moving the price to the left hand side.

$$\begin{aligned}
&T_w^* = \left[(\tau - T_c)\beta + \frac{E_c}{w}\alpha\right] + \sqrt{\left[(\tau - T_c)\beta + \frac{E_c}{w}\alpha\right]^2 - \frac{E_c}{w}(2\alpha + 2\beta - 1)(\tau - T_c)} \\
&T_i^* = \frac{\tilde{\theta}_\iota}{(1 - 2\beta)}(\tau - T_w^* - T_c) \ \forall i \in I
\end{aligned} \tag{3}$$

Table 16
Microeconomic model results – 1985 British.

United Kingdom – 1985												
	Week		1 Day		2 Days Week + Weekend		2 Days Week + Weekend(weighted)		3 Days Week + 2 Weekend		3 Days Week (weighted) + 2 Weekend	
	Value	t-stat	Value	t-stat	Value	t-stat	Value	t-stat	Value	t-stat	Value	t-stat
α	0.4851	15.42	0.4612	5.93	0.4745	14.93	0.4820	12.76	0.4863	21.79	0.4896	13.41
β	0.1321	37.12	0.1710	31.86	0.1079	25.09	0.1392	36.25	0.0856	19.53	0.1396	35.99
Θ leisure	0.32	59.41	0.28	30.47	0.35	47.10	0.31	44.47	0.38	54.29	0.31	45.16
σ work	10.19	18.87	1.91	16.24	3.30	18.44	10.83	18.44	5.12	18.55	11.21	18.55
σ leisure	9.53	18.87	2.09	16.24	3.64	18.44	12.33	18.44	5.07	18.55	12.24	18.55
ρ work–leisure	−0.63	−13.87	−0.67	−13.96	−0.55	−10.42	−0.60	−12.36	−0.63	−13.87	−0.67	−15.73
Log-likelihood	−7.16		−3.92		−5.14		−7.51		−5.84		−7.47	
LR w/correlations	68.18		46.00		29.33		12.65		48.63		79.06	
$\rho\alpha - \beta$	0.65		0.66		0.66		0.64		0.64		0.63	
Average time values (£/h)												
VST leisure	31.74	0.48	16.40	0.50	14.71	0.81	27.11	0.48	21.52	0.62	47.83	0.28
VST work	27.87	0.42	12.49	0.38	10.94	0.60	23.34	0.41	17.68	0.50	44.00	0.26
w	3.87		3.90		3.77		3.77		3.84		3.83	
VST leisure/w [%]	819.56		419.97		390.39		719.68		560.76		1247.92	
VST work/w [%]	719.56		319.97		290.39		619.68		460.76		1147.92	
Sample size	178		132		170		170		172		172	
$(1-2\beta)/(1-2\alpha)$	24.6913		8.4794		15.3765		20.0444		30.2482		34.6538	

$$X_k^* = \frac{\tilde{\eta}_k (wT_w^* - T_c)}{P_k(1-2\alpha)} \; \forall k \in K$$

In these equations $\beta = (\Phi + \theta_w)/2(\Theta + \Phi + \theta_w)$ and $\alpha = (\Theta + \theta_w)/2(\Theta + \Phi + \theta_w)$, where $\Theta > 0$ is the summation of the positive exponents θ_i over all unrestricted (leisure) activities and $\Phi > 0$ is the summation of the positive exponents η_k over all unrestricted goods. It can be shown that both α and β should be less than 0.5. It is worth noting that, as shown by Contreras (2010), the presence of E_c and T_c makes the resulting equation for T_w fairly flexible in terms of the signs of the first and second derivatives with respect to w in spite of the limitations regarding marginal utilities.[2]

Equations in (3) can be used as the basis for the estimation of the parameters involved (α, β, $\tilde{\theta}_i$ and $\tilde{\eta}_K$) provided that T_c, E_c and w, are known for every individual in a sample. Most importantly, the values of leisure and work for each individual can be obtained as

$$Value\ of\ Leisure = \frac{\mu}{\lambda} = \frac{\Theta}{\Phi} * \frac{(wT_w^* - E_c)}{(\tau - T_w^* - T_c)} = \frac{(1-2\beta)}{(1-2\alpha)} \frac{(wT_w^* - E_c)}{(\tau - T_w^* - T_c)} \tag{4}$$

$$Value\ of\ Work = \frac{\partial U/\partial T_w}{\lambda} = \frac{\theta_w}{\Phi} * \frac{(wT_w^* - E_c)}{T_w^*} = \frac{(2\alpha + 2\beta - 1)}{(1-2\alpha)} \frac{(wT_w^* - E_c)}{T_w^*} \tag{5}$$

As explained in Jara-Díaz et al. (2008), the definitions of Θ, Φ and θ_i provide intuition for Eqs. (4) and (5), as the value of leisure in (4) increases with the relative importance of leisure activities in utility and with what the authors have called the expenditure rate within the goods/leisure framework, defined as the ratio between uncommitted income and uncommitted time available to spend it.

One important property regarding time values of DeSerpa's type models is represented by Eqs. (6) and (7). Eq. (6) shows that μ/λ is the value assigned to all leisure activities (for which κ_i/λ is zero) and Eq. (7) shows that the value of leisure has to be equal to the total value of work, given by the wage rate plus the value of the time assigned to work (value of the marginal utility of work).

$$\frac{\kappa_i}{\lambda} = \frac{\mu}{\lambda} - \frac{\partial U/\partial T_i}{\lambda} \tag{6}$$

$$\frac{\mu}{\lambda} = w + \frac{\partial U/\partial T_w}{\lambda} \tag{7}$$

In order to compare time values across populations controlling for differences in income, Eq. (7) can be rewritten as in Eq. (8), such that the values of leisure and time assigned to work (with a minus sign) relative to the wage rate should add up to one.

$$\frac{\mu/\lambda}{w} - \frac{\partial U/\partial T_w/\lambda}{w} = 1 \tag{8}$$

As explained in Section 3, because of data availability only the British surveys for 1975 and 1985 could be complemented with expenses in order to estimate the time use model just presented; as only one-worker households were considered, samples sizes reduced to roughly one third of the originals. This is indeed a limitation of the analysis below; nevertheless it is useful as a fifth element of comparison.

To adequately estimate this microeconomic model, we imposed that the actual time assigned to work generated income large enough to cover committed expenses, which slightly reduced sample size from 383 to 381 workers for PAUT and from 183 to 178 workers for ETBS. Tables 15 and 16 show the parameter estimates for every random disjoint group (RDG) as defined in Section 4, and the values of leisure and work, both in absolute value (obtained from Eqs. (4) and (5)) and relative to the wage rate. Results show that all leisure values are positive, as theoretically required. As all values of leisure are larger than the wage rate, the corresponding values of work are positive. This suggests that individuals not only work for money, but also for pleasure at the margin. The values of parameters α and β are lower than 0.5, as theoretically required. To judge the degree of accuracy of the different pseudo-surveys behind each RDG, time values were compared against the results obtained using the weekly data, which is always the benchmark in spite of the sample sizes constructed because of the theoretical reasons given in Section 2.[3]

For the 1975 survey the values of leisure and work with the least variation relative to the week are obtained for the one day estimation. This result is very interesting because one could think that gathering information from just one day per individual would not grasp the inter-day variation that should be present when assigning time to activities. On the other hand, for the 1985 survey, the best representation of the week is obtained for the two days weighted group.

The results shown in Tables 15 and 16 are very interesting for two reasons: first, it shows that one or two days are a sufficiently adequate period of observation for time use diaries when a weekly database cannot be collected; second, when

[2] The Cobb–Douglas form assumes marginal utilities with constant sign for each of its arguments, which is considered a limitation by some authors (e.g. Prasch, 2000). Also, given the multiplicative form of a Cobb–Douglas, this utility form does not allow any argument to be zero, which is not an empirical problem when using aggregate descriptions for activities.

[3] Sample sizes of the different RDGs are slightly different because of the income-committed expense constraint. Note that the estimates reported are indeed those that would be obtained if surveys were conducted the way the RDGs are constructed.

comparing the results across years, one can see that time values for the 1985 British database are between 5 and 20 times the corresponding results for the 1975 British database (VST leisure). When normalizing by the wage rate one can see that now the relative time values (VST leisure/w) for the 1985 British database are between two and six times the corresponding results for the 1975 British database. With these results it can be inferred that the results varied not only because of the time frame between the years considered (and the average increase in wage rates) but the values of time also changed because of the individual behavior of the respondents.

These results are reinforced when looking at the ratio $(1-2\beta)/(1-2\alpha)$ that equals Θ/Φ (see Eq. (4)); this ratio commands the calculation of the values of leisure and work and corresponds to the relative importance of leisure activities in utility: for the 1975 survey the minimum difference is obtained for the one day estimation (3.5174 against 3.0407) and for the 1985 survey the best representation is obtained for the two days weighted group (24.6913 against 20.0444).

6. Synthesis and conclusions

The duration of Time Use Surveys (TUS) is a subject that has generated much controversy in the specialized literature. One, two, three or seven days (weekly) surveys have been supported as optimal from different viewpoints. Arguably, a weekly survey applied to a single sample would represent more precisely the variation of time use across individuals and for a single individual during a complete work–leisure cycle. However, various shortcomings have been pointed out to prevent its application. Besides the obvious objection related with cost, there are issues regarding the danger of a low response rate and diminishing quality of information when long surveys are attempted; moreover, variability of data is claimed to be sufficiently well captured in shorter surveys. To these, we add the importance of the possible effect of survey duration on modeling results regarding time use and its values. In this paper we have summarized, addressed and empirically examined those issues in a systematic way in order to contribute to this relevant discussion. After describing the presently available sources of data regarding time use in the world, we concluded that there is a potential for an empirical analysis to enlighten the discussion. Then we identified from the literature five issues to address: response rate, richness of data, accuracy of the information, variability of data and modeling impact. Then we selected appropriate data sets to analyze all those issues comparatively.

Inspection of the data suggests that there is no reduction of reported activities after the first days of the survey. Also, unreported periods do not seem to increase with time. Regarding intra variability of data, we begun by analyzing similarity among days of the week; this was done by looking at time use patterns and average duration of aggregated activities. A similarity index calculated for all surveys showed that working days behave alike and that weekend days should be treated differently. Then, we analyzed the data in terms of activity duration means, their differences and their variances; this was conducted by performing two statistical tests (Levene and Welch ANOVA) among all activities, constructed period of observation and surveys. Results showed that in terms of activity duration means, there are no significant differences among periods of observations but the variability diminishes as the period increases. In addition we examined the trade-off between survey duration and sample size to draw a recommendation to follow when resources are limited; this was done by realizing the same previous tests (Levene and Welch ANOVA) but now controlling for the number of individuals-days. Results suggest that both 2-day and 3-day diaries are a sufficient surrogate for a weekly period of observation. Finally, applying a microeconomic approach to model time use and to calculate values of time for different groups of the sample for the British data, different estimates were obtained; nevertheless, using the week data and results as a benchmark, the best alternatives in this modeling analysis were one day and two days (week and weekend weighted). Because of the variety of results obtained for the different analyses performed, different recommendations can be inferred.

Considering the results obtained by analyzing the average difference of activity duration relative to the week, one can infer that three weighted day diaries are a sufficiently adequate period of observation for time use diaries when a weekly database cannot be collected. On the other hand, considering the results of the analysis of variance, one can see that all periods of observation performed alike in terms of means of activity duration but their variance diminishes with period length, which makes the week a preferred choice. If a resource constraint induced a choice between sample size and survey length, we would recommend either 2-day diaries or 3-day diaries because the aforementioned property of equal durations and the fact that variances diminishes with period length but are equal between 2-days and 3-days. Finally, when considering the modeling analysis, one can infer that one or two days are the adequate alternatives.

Given that the modeling analysis could only be carried out on two of the nine datasets while the variability analysis was performed on all surveys, there is a sufficient amount of information to postulate that our conclusion from this fair empirical examination of issues is that, given that a weekly survey is a better source of information but may be hard to collect, two or three days weighted surveys do seem to be an adequate surrogate for the information obtained in a weekly survey that captures a basic work–leisure cycle, contrasting with the recommendation made by Glorieux and Minnen (2009). It should be noted that this recommendation applies only for surveys that would serve analyses of the same nature and specific purpose as the ones performed in this research. We acknowledge that different types of analyses require different types of information; while a comparative analysis of total duration of activities would need only the total amount of time assigned to each activity and not the time of day the activity was performed, a more detailed analysis of time assignment would not only require activities' characteristics (number, duration, exhaustiveness), or time allocation patterns over a week, but would also need a much longer period of observation than the ones compared in this paper. Even if one can agree on a proper period of observation, given a resource constraint one should also consider the trade-off between survey duration and sample size as in the case analyzed here.

We believe that some of the issues examined here could be looked at empirically using larger data sets. The rather strange phenomenon of a good modeling result for the one day estimation in the 1975 British survey should be studied further.

Acknowledgments

This research was partially funded by Fondecyt, Chile, Grant 1120316, the Institute for Complex Engineering Systems, grants ICM: P-05-004-F and CONICYT: FBO16 and the ACTUM Project. Jorge Rosales-Salas acknowledges Conicyt's Doctorate fellowship. We thank the comments of the unknown referees, particularly those regarding a deeper look at the variability issue. Remaining errors are, of course, our responsibility.

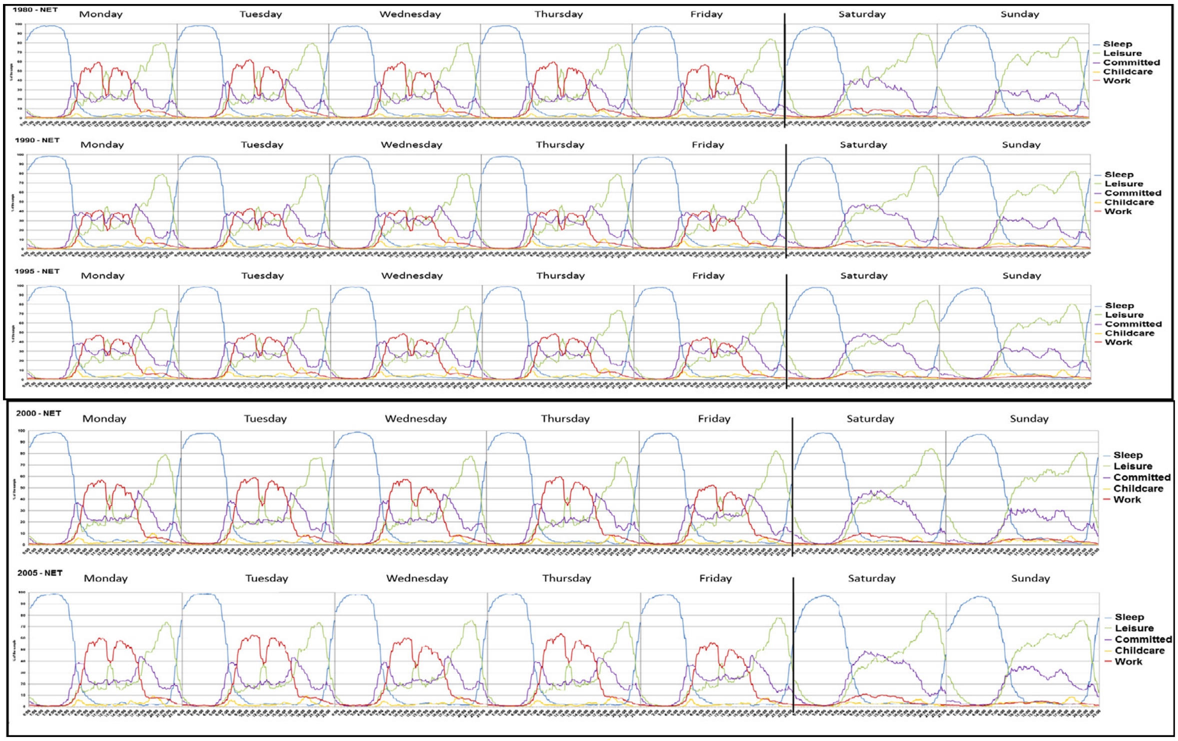
Appendix A

Activity classification in the MTUS.

Leisure	Committed
Meals at work or school	Imputed personal or household care
Other meals or snacks	Wash, dress, care for self
Work breaks	Travel as a part of work
Leisure/other education or training	Look for work
Consume personal care services	Regular schooling, education
Consume other services	Homework
Voluntary, civic, organisational act	Food preparation, cooking
Worship and religion	Set table, wash/put away dishes
General out-of-home leisure	Cleaning
Attend sporting event	Laundry, ironing, clothing repair
Cinema, theater, opera, concert	Maintain home/vehicle
Other public event, venue	Other domestic work
Restaurant, café, bar, pub	Purchase goods
Party, social event, gambling	Pet care (not walk dog)
Imputed time away from home	Correspondence (not e-mail)
General sport or exercise	No act but recorded transport mode
Walking	Travel to/from work
Cycling	Education travel
Other outside recreation	Voluntary/civic/religious travel
Gardening/pick mushrooms	Child/adult care travel
Walk dogs	Shop, person/household care travel
Receive or visit friends	Other travel
Conversation (in person, phone)	**Childcare**
Other in-home social, games	Physical, medical child care
General indoor leisure	Teach, help with homework
Art or music	Read to, talk or play with child
Knit, crafts or hobbies	Supervise, accompany, other child care
Relax, think, do nothing	Adult care
Read	**Work**
Listen to music etc	Paid work-main job (not at home)
Listen to radio	Paid work at home
Watch TV, video, DVD	Second or other job not at home
Computer games	Unpaid work to generate household income
E-mail, surf internet, computing	**Sleep**
Other time at workplace	Sleep and naps
	Imputed sleep

Appendix B

Daily activity patterns – 1980, 1990, 1995, 2000, 2005 Dutch.



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