UNIVERSIDAD DE CHILE
FACULTAD DE CIENCIAS FÍSICAS Y MATEMÁTICAS
DEPARTAMENTO DE INGENIERÍA INDUSTRIAL

TIME USE MODELING: TOWARDS AN EXTENDED FRAMEWORK

TESIS PARA OPTAR AL GRADO DE DOCTOR EN
SISTEMAS DE INGENIERÍA

JORGE AGUSTÍN ROSALES SALAS

PROFESOR GUÍA:

SERGIO JARA DÍAZ

MIEMBROS DE LA COMISIÓN
CHANDRASEKHAR BHAT
MARCELA MUNIZAGA MUÑOZ
ALEJANDRO TUDELA ROMÁN

SANTIAGO DE CHILE

2015

THESIS ABSTRACT FOR THE DEGREE OF:
Doctor of Philosophy in Engineering Systems
BY: Jorge Agustín Rosales Salas
DATE: 29/10/2015
TUTOR: Sergio Jara Díaz

TIME USE MODELING: TOWARDS AN EXTENDED FRAMEWORK

In this thesis we expand the understanding of the role of time in the analysis of individual behavior. First, we systematize, organize and classify time use modeling literature. Then, we analyze the role of the period of analysis in time use valuation. Finally, we explore the role of new variables in the analysis of individual time use, formulating and estimating an extended model that considers information about hiring external agents to perform certain activities (e.g. childcare).

In terms of the time use literature review, we summarize, address and examine different forms of looking at time use literature: by historical context, discipline and type of analysis. Within the latter one, we extend our exploration towards modeling. Our review concludes that there is hardly any interaction among disciplines, which limits the formulation, the explanatory power and interpretation of current models. This almost non-existent collaboration induces a research line based upon potential complementarities among approaches to solve existing modeling disadvantages.

Furthermore, we detected that there was a need for an adequate data analysis to estimate time use models. The appropriate duration of time diaries as a source of time use data is analyzed next. We study different dimensions of data quality, duration and variability of activities, and modeling capabilities using nine detailed European surveys based on seven-days diaries. Pseudo diaries of one day, two days (one week, one weekend) and three days (one week, both weekend) 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 seemed to be an adequate surrogate for the information obtained in weekly surveys that capture a basic work–leisure cycle.

Given the analysis on the period of data and the systematic review of time use models, we present an extended time allocation and valuation model. We formulate and estimate a model with the explicit introduction of other individuals' time, namely an external agent to perform certain activities without losing their intrinsic value, i.e. productive activities, in this case, childcare. Values of time are computed using three Dutch weekly time use and consumption datasets. Furthermore, we compare our results with those from two previous formulations that did not include the novelty. Present models yield values of leisure and work that are larger than the values of time when taking into account the possibility of hiring external agents for childcare. This overestimation of time values is lower for the model where childcare was considered as an unrestricted activity with uncommitted expenses. Finally, we compare the results of our new model with those drawn from a sub-sample with the same individuals in all waves. Results show no significant differences in values of leisure or work.

RESUMEN DE LA TESIS PARA OPTAR AL GRADO
DE: Doctor en Sistemas de Ingeniería
POR: Jorge Agustín Rosales Salas
FECHA: 29/10/2015
PROFESOR GUÍA: Sergio Jara Díaz

MODELAMIENTO DEL USO DEL TIEMPO: HACIA UN ENFOQUE EXTENDIDO

En esta tesis se expande el entendimiento del rol del tiempo en el análisis del comportamiento de los individuos. Primero se sistematiza, organiza y clasifica la literatura de modelamiento de uso de tiempo. Luego, se analiza el rol del periodo de análisis en la valoración del uso del tiempo. Finalmente, se explora el rol de nuevas variables en el análisis de la asignación de tiempo de los individuos, formulando y estimando un modelo extendido que considera información sobre la contratación de agentes externos para realizar ciertas actividades (e.g. cuidado de niños).

En términos de la revisión de la literatura de uso de tiempo, se resumen, analizan y examinan diferentes formas de ver esta literatura: por contexto histórico, disciplina y tipo de análisis. En la última categoría, se extiende la exploración hacia el modelamiento. En esta revisión se concluye que la interacción entre disciplinas es casi inexistente, lo que limita la formulación, el poder explicativo y la interpretación de los modelos actuales. Esta poca colaboración conlleva a una línea investigativa basada en las complementariedades potenciales entre perspectivas para resolver las desventajas de los modelos existentes.

Además se detectó la necesidad de un análisis adecuado de la información para estimar modelos de uso de tiempo. Se estudia posteriormente la duración apropiada de los diarios temporales como una fuente de información de uso de tiempo. Se analizan diferentes dimensiones, como la calidad de información, duración y variabilidad de actividades, y capacidades de modelación, usando nueve encuestas europeas detalladas basadas en diarios de siete días. Se construyen pseudo-diarios de un día, dos días (un día laboral, un día de fin de semana) y tres días (un día laboral, ambos días de fin de semana) para complementar el análisis de estos aspectos, seleccionando la información de diarios de siete días como base. Los resultados comparativos muestran que encuestas dos y tres días ponderados parecen ser una alternativa adecuada de la información obtenida en encuestas semanales que capturan un ciclo trabajo-ocio básico.

Dado el análisis del periodo de información y la revisión sistemática de modelos de uso de tiempo, se presenta un modelo extendido de asignación y valoración del tiempo. Se formula y estima un modelo con la introducción explícita del tiempo de otros individuos, llámese un agente externo para realizar ciertas actividades sin que se pierda su valor intrínseco, i.e. actividades productivas, en este caso, cuidado de niños. Se computan los valores del tiempo usando tres bases de datos semanales holandesas de uso de tiempo y consumo. Además, se comparan los resultados con aquellos de dos formulaciones anteriores que no incluyen esta novedad. Los modelos actuales entregan valores del ocio y trabajo más altos que los valores del tiempo que incluyen la posibilidad de contratar agentes externos para el cuidado de niños. Esta sobreestimación de los valores del tiempo es menor para el modelo donde el cuidado de niños es considerado una actividad irrestricta con gastos no comprometidos. Finalmente, se comparan los resultados del nuevo modelo con aquellos de una sub-muestra de los mismos individuos en todas las encuestas. Los resultados no muestran diferencias significativas en los valores del ocio y trabajo.

A mi madre y abuela, quienes me acompañaron
por este camino con una sonrisa y mucho amor.

Content

List of Tables

List of Figures

1. INTRODUCTION

1.1. Motivation

Time is inherently egalitarian and scarce. Everyone has 24 hours a day and not a minute more. However, because some people's projects are more time-consuming than others', time is a limited resource that carries a social valuation, and whose use is embedded in cycles set by biological and social organization.

We believe that the importance of time is strongly manifested in how people allocate it to their activities, resulting from the superposition of individual preferences with institutionalized frameworks and conditions collectively imposed. The resulting time use is closely related to levels of social satisfaction and overall well-being, measurements now becoming as important as national income and its distribution. These new measurements add to the conventional measures of market produced goods and services, in the form of the satisfaction drawn from the activities performed by individuals, and the overall well-being associated with household produced goods and services.

While the best known published time use studies are those that cover labor supply, leisure, unpaid work and transport, the study of the uses and values of time has multidisciplinary, multinational and multicultural dimensions.

An important direction for time-use research is to integrate the plethora of current theories from various fields to develop a comprehensive theory that integrates different aspects of time-use behavior. This effort needs to be much more than a detailed review of various ideas; it needs to juxtapose theories, highlight their consistencies, resolve their discrepancies and identify data requirements. We do not conceive such a comprehensive theory to be prescriptive; our intention is to provide a platform for multidisciplinary collaborative research. To this end, this theory must itself be the result of a collective effort involving researchers from several fields, with the level of cooperation among disciplines as a function of the purpose of this potential collaboration. Therefore, it is important to be clear about its purpose from the beginning.

Conceptual and theoretical contributions within time use modeling literature can be found among different disciplines, although these various approaches hardly interact. We believe that there is a proper way of classifying time use models and that there is space for multidisciplinary interaction, which should lead to a better understanding of individual time allocation. More specifically, we postulate that there are methodological and empirical gains if new elements are incorporated in the (microeconomic) time use framework, e.g. time hired from an external agent, which should have an impact on the values of leisure and work.

The motivation of this thesis is therefore, to analyze and integrate new modeling strategies that may explain some of the unexamined interactions of current time allocation models.

1.2. Objectives

The general objective of this thesis is to expand the understanding of the role of time in the analysis of individual behavior in three complementary directions: the organization and classification of time use modeling literature; the role of the period of analysis in time use valuation; and the role of new variables in the analysis of individual time use.

Specific objectives:

- To organize the contributions in the literature regarding time use models from different perspectives, identifying different analytical, quantitative and/or qualitative models, their characteristics and limitations.
- To analyze, in a structured way, the models' information requirements in terms of the data collection period needed for an adequate and interpretable estimation.
- To formulate and estimate a time allocation and valuation model that incorporates information about hiring another individual to perform certain activities.
- To discuss and compare our results with current modeling frameworks.

1.3. Research questions

Given that the objectives of this thesis are focused in three complementary directions, some questions are born:

In terms of the organization and classification of time use modeling literature:

- Is there a proper way to categorize time use literature?

In terms of the role of the period of analysis in time use valuation:

- Is there an adequate period of observation to estimate time use models?

Regarding the role of new variables in the analysis of individual time use:

- Can we better estimate individual time valuation considering information from external agents?

1.4. Thesis structure

This thesis has 5 chapters. In Chapter 2 we categorize and summarize different types of time use models. Time allocation literature encompasses a relatively large variety of approaches. Although there are many ways to systematize time use modeling literature, it is useful to establish the coexistence of two study groups: those in which the researcher is trying to study and understand a particular activity, and those whose object of study is the use of time as a whole.

Chapter 3 identifies and discusses, in an organized structure, different levels of information required by time use models in terms of precision, the period of observation, and the data available to estimate current and future models.

In Chapter 4 we formulate and estimate an extended time allocation and valuation model that considers the choice of hiring external agents to perform certain activities. We compare our results with those from current models in different scenarios.

Finally, in Chapter 5, the work is summarized, conclusions are made and ideas for further research are presented.

2. TIME USE MODELING: LITERATURE REVIEW

2.1. Introduction

Time use studies have been justified primarily by the need to understand how people make decisions about their activities, whose sum is by definition the total time available. The temporal limitation induces the existence of options, so that the decision on the use of time involves an implied and relative valuation of the time allocated to various activities; therefore, use and value are inextricably linked.

The importance of studying time allocation has many dimensions. Time use data can be used to improve the evaluation and creation of public policies to encourage some behaviors (e.g. work-leisure balance) and discourage others (e.g. physical inactivity). It can also be used to assess the characteristics of the allocation of time within different groups, detecting trends and their evolution.

Many analyzes can be performed with time use data, extending from purely descriptive studies to econometric modeling with thorough theoretical foundations from diverse disciplines and requirements of information involving different levels of detail.

Contributions to conceptual frameworks and theoretical bases in time use modeling can be found within different areas, such as leisure, transport, household production, work-life balance, among others. As we will argue later, research in those topics hardly interact, and we believe that capturing those contributions in a systematic way, and promoting their interaction, would help with the construction of a richer basis for time use modeling.

The goal of this thesis is to contribute to the study of individual time allocation decisions from a modeling approach. To accomplish that, in this chapter we study the possible perspectives in which time use literature can be reviewed and we present what we believe to be an organized and complete way of classifying the time use literature.

2.2. Describing Time Use Literature

2.2.1. Organizing Time Allocation Research

The allocation of time has been a topic of interest and research since the beginning of the twentieth century. While the main purpose of these studies is similar – trying to describe and understand how people use their time - the specific motivations behind this interest have changed over time, creating an overwhelming amount of literature that contributes to the understanding of people's time allocation from different approaches.

Time use literature has an extensive variety of focuses and perspectives in terms of the research being conducted. All of these approaches are collected in the literature in different ways. For example, there are authors that use the perspective of data collection to synthesize the research aimed at studying the most appropriate form of time use data acquisition (e.g. Jara-Diaz and Rosales-Salas, 2015; Bittman and Ironmonger, 2011; UN Economic Commission for Europe, 2010; Andorka, 1987). There are others that focus on data analysis to present a variety of descriptive studies in terms of how groups of individuals assign their time and how these decisions can be interpreted (e.g. Aguiar, and Hurst, 2009; Gershuny, 2003; Gershuny and Robinson, 1988; Gershuny and Jones, 1986). Moreover, there are the ones that look at the literature from the perspective of understanding agent behavior from a modeling approach (e.g. Jara-Diaz, 2007; Grossbard, 2001; Gonzalez, 1997; Heckman, 1993).

To incorporate all types of time use studies in an organized manner, we have identified three possible perspectives to describe the extent of time use literature: by historical context, by discipline and by analytical framework.

Concerning the **historical context**, time use studies have been changing their focus depending on the development of world issues over time. According to Pentland et al. (1999) and Bittman and Ironmonger (2011), the first time use studies were published in the second decade of the twentieth century (Bevans, 1913; Pember-Reeves, 1913), beginning as early studies of the living conditions of the working class. In the 1920s two political blocks of time use studies emerged. On one hand, soviet social scientists and policy makers conducted time use surveys as they were developing a centrally planned economy, based on an economic theory that rests on the view that the value of things depends on the time required for their production (Artemov and Novokhatskaya, 2004). On another hand, American time use studies concentrated in home economics and the analysis of domestic labor (Minge-Klevana, 1980; Sorokin and Berger, 1939).

Four decades later, in the 1960s, time use studies were still divided in two political blocks of analysis. Within the Eastern countries, the emphasis was on the measurement of progress towards a socialist structure, while Western analysts concentrated on the informal economy and patterns of leisure activities (Szalai, 1972). From the 1970s till the 1990s, the block division of time use studies diminished but still influenced the focus of studies being conducted. The leading studies using time use data in Eastern Europe centered on the informal economy, and in Western countries, studies focused on domestic economy, gender equity, valuing non-market production, monitoring trends and the tradeoff between domestic labor and leisure activities (Robinson et al., 1989).

Finally, the most recent time use studies (after the 2000s), have seen many of these topics continued but with a focus on more specific policy-oriented areas such as work-leisure balance, childcare, the social impact of digital technologies, the increase of sedentary behavior and more ecologically sustainable ways of living (Krueger, 2009).

Regarding the **disciplinary perspective**, the study of time and its allocation by individuals is a topic that has been covered in many areas of knowledge, being characterized as a multidisciplinary area of research.

Time allocation has a strong presence within the social sciences, where time use and its subjective perception relates with areas such as *sociology*, specifically the social construction of time patterns in different groups (e.g. Bergmann, 1992; Zerubavel, 1981); *psychology*, when dealing with cultural diversity and the understanding of individuals' time allocation (e.g. Brislin and Kim, 2003; Block, 1990); and *economics*, studying the necessity of incorporating time in traditional economic instruments (e.g. Hamermesh and Pfann, 2005; Hood, 1948).

Time use studies have also covered topics related to specific groups of the population, such as *gender studies*, studying differences between men and women in the labor market and in overall activities (e.g. Bryson, 2007; Aliaga and Winqvist, 2003); *gerontology*, when studying the relationship between productivity, leisure and personal care activities within elders (e.g.

McKinnon, 1992; Moss, and Lawton, 1982); and *occupational therapy* by dealing with the impact of well-being perception over adult care activities (e.g. Abdul-Rahman, 2008; Hasselkus, 1989).

Furthermore, time use analysis has even been covered in areas that, *a priori,* one would suspect have no relation to the importance of time allocation, such as *administration* and the impact of time perception in managerial decisions of corporate executives (e.g. Mulligan, 1997; Das, 1991); and *urban planning* with the inclusion of time in the organization of cities (e.g. Millward and Spinney, 2011; Gutenschwager, 1973).

Regarding the **analytical perspective**, we have identified four distinctive (but not mutually exclusive) types of methods used to examine time use studies: *conceptual-theoretical discussion*, *data collection methodologies*, *descriptive data analysis,* and *analytical modeling frameworks*.

Conceptual-theoretical discussion deals with the understanding and explanation of diverse time allocation issues. These discussions aim at interpreting the many ways that time can be allocated by individuals and households, each of them presented with distinctive and valid arguments, drawn from different theoretical and conceptual backgrounds (e.g. Abell, 2003; Block, 1990).

Data collection methodologies emphasize the appropriate ways time use information should be gathered, and the level of detail that should be encouraged, in order to answer questions asked by researchers, perform more complete analysis, and assist in the creation of adequate public policies (e.g. Gershuny, 2012; Munizaga et al., 2011).

Descriptive data analysis focuses on presenting organized ways of viewing time use data, in terms of trends, patterns, activity duration and other indicators. Overall, its main concern has been contributing to the analysis of the evolution of time allocation and how it relates to the trade-off among time spent in activities, by acknowledging the measurements of time as general indicators of living conditions (Aguiar and Hurst, 2009; Aliaga and Richardson, 1994).

Analytical modeling frameworks encompass an extensive area of research that contains diverse theoretical constructs representing the individual and/or household time allocation decision process by the use of models. Their main purpose is to understand the functioning and dynamics of individual's choice and the factors, variables and constraints that condition that behavior. (e.g. Bhat, 2008; Jara-Díaz et al. 2004). Because our focus is on the modeling aspect of time use, we need to understand how modeling literature has evolved and how it can be classified and expanded.

Most of the modeling literature has been built explicitly or implicitly on models based on the classical consumer theory, and its extension to incorporate the scope of time use (e.g. working time, leisure and/or consumption as a source of (dis)utility within a time constraint). The model that has been labeled by a large group of studies as the starting point is Becker's (1965), which was the first to explicitly point out that the classical consumer theory was unrealistic by not incorporating time as a determinant in an individual utility function. From that point forward, many studies from several disciplines have discussed and expanded his work by incorporating their own contributions, such as variables, constraints and theoretical frameworks.

Although time use modeling literature has a central point where all studies converge (the expansion of consumer theory), there are many ways to systematize it. We believe that the best form to organize the modeling literature is by paying attention to the type of activity being modeled. This is because we postulate that the strongest manifestation of the importance individuals attach to their time use is its allocation to activities, resulting from the superposition of individual preferences, institutionalized rhythms and collectively imposed conditions. Within this focus, it is useful to establish the coexistence of two study groups: those in which there is an attempt to study and understand a particular activity, and those whose object of study is time use as a whole.

In the first group it is possible to distinguish three large families of studies, each focused on the analysis of one type of activity: *paid work*, time spent in production on the market (e.g. Blundell et al. 2005; Card, 1991), *unpaid work*, activities that may be delegated to a paid worker without losing their intrinsic value, such as household production and childcare (e.g. Bryant and Zick, 2006; Chiappori, 1997) and *non-work activities*.

Furthermore, because non-work is a much wider classification, it is useful to recognize two categories this family can be divided in: *leisure*, activities that the individual cannot pay other people to perform without losing their intrinsic value, and that have no minimum time requirement, such as entertainment (e.g. Jara-Díaz and Astroza, 2013; Johnson, 1966), and *tertiary activities*, activities that the individual cannot pay other people to perform without losing their intrinsic value, and that has a minimum time requirement, such as eating, sleeping, and personal care (e.g. Bhat and Koppelman, 1999b; Biddle and Hamermesh, 1990).

In the second modeling group, where time use is studied as a whole, the main focus is the understanding of time allocation as a structural phenomenon. It analyzes all, or a specific combination, of the activities the individual performs during a specific period (e.g. Jara-Díaz et al., 2008; Becker, 1965).

An organized view of the Time Use Literature classification can be seen in Fig. 2.1.

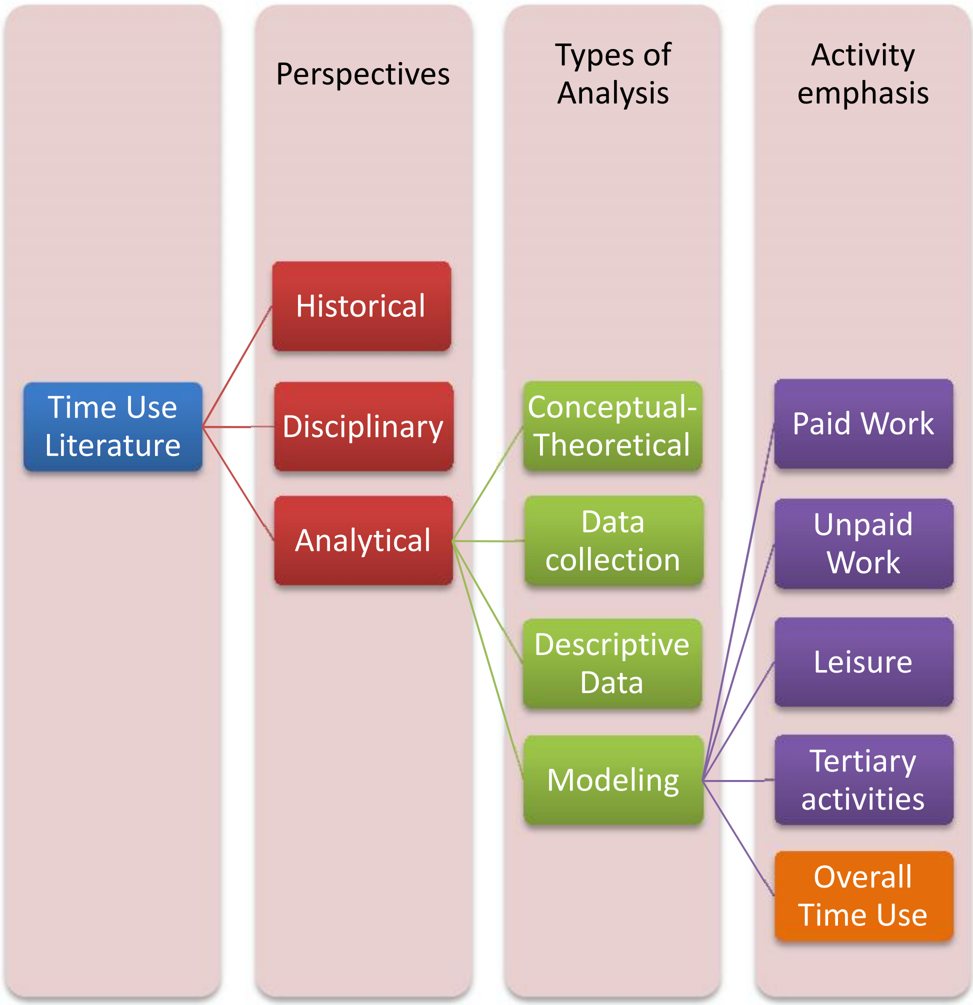

Fig. 2.1. Time Use Literature classification

2.2.2. Modeling Activities

There have been many attempts within the modeling literature to present revisions of past and current research developments and contributions. All of these efforts have concentrated in studying specific activities and have covered different aspects of time use modeling, such as purpose of the model, utility function, unit of analysis, temporal dimension, constraints used, among other factors. In what follows, a brief examination of reviews is presented by each categorized activity.

a) *Paid work*

Among the reviews of this area of research, Heckman (1993) stands out as a concise but comprehensive work with an overall approach, analyzing the evolution of labor supply regarding various issues, such as wages, taxes, intertemporal modeling and the limitations of available data. He concluded that the main advance in the study of labor supply between 1970 and 1990 has been recognizing and interpreting the variety of different labor supply functions that coexist in the empirical literature. Other inclusive reviews have presented additional focuses, such as gender segmentation. For example, Pencavel (1986), and Killingsworth and Heckman (1986) analyzed labor supply data and modeling for men and women, respectively.

More specific revisions of labor supply literature have been motivated by particular purposes. Within these, the temporal dimension has been an important topic of discussion, contrasting static and lifetime modeling. Studies such as Bargain (2009), Heckman (1993), and Card (1991) list the intertemporal approach as a key area within empirical labor supply work, offering an assessment of the intertemporal model ability to explain the main components of labor supply, and concluding that the life cycle model of hours worked has been a key aspect of both micro and macroeconomic research.

Another dimension comprehensively covered by labor supply reviews has been the unit of analysis. For instance, Blundell et al. (2005) and Laisney and Beninger (2002) present a comparison between unitary and collective models of household labor supply, analyzing taxation, and the presence of children and public consumption, respectively. By comparing collective and unitary models, they came to the conclusion that the use of a unitary model on collective data may distort the design of policy reforms.

b) *Unpaid work*

Unpaid work, more specifically domestic production, has been profoundly analyzed both as a related aspect of labor supply and in its own merit. Within this topic, New Home Economics – an approach to the study of consumption, labor supply, and other family decisions that centers on the household rather than the individual and emphasizes the importance of household production – has been the center of discussion and analyses since its creation in the 1960s by Gary Becker (1965) and Jacob Mincer (1962).

There are two studies that, to our opinion, stand out as comprehensive revisions of the evolution of domestic production research. On one hand, Grossbard (2001) studied forty years of New Home Economics presenting an account of its birth and early growth in the sixties, and discussing some aspects of its development since 1970. On another hand, Ironmonger (2000) presented an historical review of the literature, and a revision of different approaches to measure, model and estimate household economy. He concluded that the major scientific achievement of this field was the measurement of the magnitude of household production through surveys of the uses of time. Ironmonger claimed that household production is now recognized as an alternative economy to the market.

The fact that Becker and Mincer are considered the founders of New Home Economics has led to their research being considered the cornerstone and significant references of the area. To this matter, Pollak (2003) presented a revision of Becker' studies, discussing his contributions to family and household economics and studying the crucial role of auxiliary assumptions in Becker's family analysis in three contexts: preferences, household production, and household collective choice. He postulated that Becker's ideas have dominated research in the economics of the family, shaping the tools used, the questions asked, and the answers given.

On the specific issue of the unit of analysis within unpaid work modeling frameworks, Grossbard (2010) discussed the evolution of unitary models and the transition into collective ones, including bargaining and consensual approaches. She concluded that as a basis for econometric estimations, models that consider individuals in families as independent decision-makers may be preferable to models imposing the structure of a unique household welfare function.

c) *Non-work activities*

Regarding non-work activities, leisure and tertiary activities have evolved in completely different ways:

Within leisure research, because there are as many studies as specific leisure activities being examined, the majority of reviews that have focused on leisure have been descriptive ones (e.g. Aguiar and Hurst, 2009, 2006; Alesina et al., 2006; European Commission, 2008, 2007, 2005, 2003; Harvey, 1990; Shaw, 1982; Ferge, 1972), comparing trends in time allocation between countries, historical periods and specific groups, and contrasting their leisure time allocation with time assigned to other activities, such as work and travel.

Within the few studies that focus on leisure from a modeling approach, Jara-Diaz and Astroza (2013) and Jara-Diaz et al. (2008, 2004) stand out as significant contributions to the analysis of the impact of leisure in time allocation decisions, as they were based on and advanced from studies such as Becker (1965), Johnson (1966), Oort (1969), DeSerpa (1971), Evans (1972), Train and McFadden (1978), among others. They present new and improved structures for the valuation of time, specifically the values of leisure and work.

Jara-Diaz et al. (2004) presented an activity duration modeling approach to calculate the values of leisure and work, applying it experimentally to two datasets collected in Germany and Chile. Later, Jara-Diaz et al. (2008) improved this modeling framework and estimated the value of leisure for three populations, in Germany, Chile and Switzerland. Furthermore, in a pioneering research, Jara-Diaz and Astroza (2013) presented a new theoretical construct, called the *revealed willingness to pay for leisure*, as a link between two different types of time use models: the microeconomic theory approach and the structural equations model (SEM).

Tertiary activities, on another hand, encompass several activities performed to, among other reasons, satisfy basic human needs (e.g. eating, personal care and sleeping) and to allow the individual to perform other activities (e.g. transport).

The areas that have been covered with more emphasis in the literature are transport and sleep.

Transport literature is multifaceted and covers many issues, such as the generation (to travel or not) and distribution (where) of travel, mode choice (how) and the (re)location of activities. Reviews have usually focused on travel demand and behavior, and travel time values.

Regarding travel demand, individual behavior has been analyzed in work such as Wardman (1988), where he compared Revealed Preference (RP) and Stated Preference (SP) models of travel behavior. His results provide evidence that individuals' stated preferences among hypothetical travel scenarios are a reasonably accurate guide to true underlying preferences.

Furthermore, Axhausen and Garling (1992) presented different activity-based approaches to travel analysis. They compared and studied various frameworks, models and research problems, offering a state-of-the-art review of conceptualizations and models of activity scheduling and an examination of the validity of behavioral assumptions.

Timmermans and Zhang (2009) examined several modeling approaches to household activity travel decisions. They reviewed issues such as group decision theory, utility theory, latent class modeling, rule-based modeling and micro-simulation approaches.

Within travel time studies, one of the most complete revisions is Bhat and Koppelman (1999a). They reviewed theoretical and empirical research in activity time allocation and activity episode analysis. Their conclusions emphasized the need to focus on activity episode analysis rather than activity time allocation. Likewise, Wardman (1997) dealt with the topic of travel time value, reporting on a large scale review of British empirical evidence relating to the value of travel time.

Sleep literature, on another hand, has remained in the areas of biology and psychology, covering topics such as sleep disorders, biological clocks, and dream analysis (e.g. Ocampo-Garcés et al., 2000). This activity has been surprisingly absent from work-life balance debates and has remained largely under-researched within the time use literature. Time allocation models focused on sleep are just a few, so currently no reviews have been presented.

d) Overall time use

The study of time allocation as a structural phenomenon has provided many insights to time use literature, mostly from a descriptive approach. Within modeling literature, however, the theme that we believe stands out is the issue of the value of time.

The topic of the value of time has been presented from different perspectives, such as travel time values, the value of leisure, and the value of domestic production, among others. One of the reviews we believe to be a starting point into analyzing the value of time literature is Gonzalez (1997). She reviewed several models that study the subjective value of time emphasizing important aspects behind the microeconomic formulation of time allocation models, such as behavioral assumptions, the role of constraints, and relevant variables in the utility function. She analyzed the pioneering models of Becker (1965), DeSerpa (1971, 1973) and Evans (1972), which were one of the first to develop a general theoretical framework. She then goes on to review the models that extend and perfect the analysis to establish what may be considered as, by then, the actual position of research on the subject (e.g. Jara-Diaz, 1994, 1990; Jara-Diaz and Videla, 1989; Jara-Diaz et al. 1988; Bates, 1987). Jara-Diaz (2007) comprehensively reviewed the main contributions to the analysis of this issue and incorporated new research that has complemented the path for a more precise estimation of time values.

Now we will present a more detailed analysis by each activity identified.

2.3. Single-Activity Time Use Models

2.3.1. Paid Work

As stated above, the way people assign their time has been a subject of study since the early years of the twentieth century. This area of research began predominantly focused on the amount of time individuals allocated to work and the trade-off with non-work time, or leisure.

Work is the only activity that is present in all time use models (whether it is in the utility function or in budget and temporal constraints) and is taken as the pillar of every time assignment decision. It is understandable to acknowledge work as the most important activity people can undertake as it is the only one that can provide monetary income, which allows individuals to buy market goods, the only source of utility recognized at the time by economics.

In the beginning of the twentieth century, the main idea regarding the valuation of work was that the real cost of working time had to be measured by the activities the individual postponed because of work. This derives in the acknowledgment of non-work activities providing utility and the fact that resistance to work was not only due to displeasure of working but also due to satisfaction obtained from leisure time.

The first labor supply models were based on a structure where the individual was the decision agent and the only two relevant activities were work and non-work (or leisure), but only time assigned to the latter was source of utility. Most of the models that guide economists' analyses of labor supply are based on research conducted by Jevons (1871), Walras (1889), Marshall (1890), and Hicks (1946). The labor supply function is embedded in the neoclassical theory of individual consumer behavior.

The standard neoclassic labor supply model can be formulated as follows:

$$MaxU = U(G, L) \tag{2.1}$$
$$wT_w - G \geq 0 \tag{2.2}$$
$$T_w + L = \tau \tag{2.3}$$

The individual chooses to assign his total available time (τ) between paid work (T_w) and leisure or non-work activities (L). Given a wage rate (w), the individual spends his total income in goods consumption (G).

Note that working time has a double effect. On one hand, it allows higher consumption, but on the other hand, it diminishes the available time for leisure. This situation creates a trade-off between leisure and consumption. If a person decides that they want leisure, then they will work less, but this means that they will not be able to consume as many goods. If they decide that they want to consume, then they will work more, but this means that they will not have as much free time for themselves. Their preferences for leisure (free time) and all other goods (consumption), combined with their market wage, will determine what combination of leisure and all other goods they will choose. Even though workers are the suppliers of labor, they make their working decisions in a manner similar to the way they make their buying decisions: based on preferences and prices. The equilibrium point for the individual facing this trade off will occur when $\frac{\partial U}{\partial L} = w\frac{\partial U}{\partial G}$.

Within this structure, the most important evolution of these models, to our opinion, is the recognition that working time is not only important because of the market goods that can be bought with the associated income, but it is also a source of (dis)utility.

In time, the structure of time use models began to change. First, it was acknowledged that work by itself should be incorporated into the utility function rather than just being a time-consuming and income-providing activity. Second, time assignment started pondering more activities (other than paid work) as the focus of the research. To this purpose, Becker (1965) proposed that the individual draws utility from all activities and goods involved in the production and consumption of commodities. Therefore, both the utility function and the temporal constraint began incorporating specific activities drawn from the separation of "non-work" into specific categories, such as transport, unpaid work, childcare, and others.

This activity-oriented evolution came in parallel with other advances. With the consideration of other activities performed by the individuals came the change in the unit of study. Now, not only the individual could be the agent analyzed but also the household. Studying the decisions taken by all the members of the household took an important step into the analysis of the trade-off between work and leisure time. The time assigned to work by one individual is now dependent of the income needed both by the individual and by the household. And this household now faces the opportunity of having more than one breadwinner, a complementary work force.

The representation of the individual as a part of a decision-making group changes the emphasis of the research. Now there are multiple agents that have to decide multi-activity time assignments in order to maximize their own utility and the overall satisfaction of the household.

This change in modeling was complemented with the way the individuals interacted within the household. There could be cooperation among them, bargain, or even individuals who just consumed but did not take part in the decisions, such as children.

Because labor supply is an area of research that is immerse in a context of a family or household, the literature has acknowledged that labor supply behavior can only be understood within a family (collective) framework. The standard "unitary" family labor supply model treats the household as an individual. However, this is not realistic when considering that there are more family members involved in the decision-making process.

The generic collective labor supply model supposes a household with two working individuals with a model formulated as:

$$U(G, L_1, L_2, A) \quad (2.4)$$
$$G + w_1 L_1 + w_2 L_2 = w_1 \tau + w_2 \tau \quad (2.5)$$

Where families are assumed to maximize joint utility over consumption (G) and the leisure of each family member (L_1 and L_2), and to include children and other dependents in the vector of the household attributes (A).

Focusing in a static way of analyzing time allocation, over the years there has been many attempts to expand the traditional single-agent approach. The origins of this expansion can be traced back to research by Becker (1965, 1973, 1974a, 1976, 1981a, 1981b), which introduce several modeling innovations trying to solve for the need for an emphasis on the individual within the household rather than the family as the decision-making unit.

According to Wetzell (2002), Becker's generalization of the standard labor supply model presented in his 1965 paper, expanded the set of analytical possibilities for labor supply behavior. He showed that since all consumption requires time and money, if there are limitations to the extent to which time and money can be substituted for each other in production of final consumption goods then negatively-sloped labor supply behavior can be induced by the diminution of ability to transfer between time and money inputs. On later contributions, Becker presented a framework of a two member household, each one characterized by his/her own preferences. He introduced idea of "caring" by assuming that the preferences of one individual are influenced by the other member's utility function.

Expanding on Becker's work, Chiappori (1992) developed a general collective model of household labor where there are two stages in the internal decision process: agents first share non-labor income according to some given sharing rule; then each one optimally chooses his or her own labor supply and consumption. His model can be formulated as follows:

$$max U^i(L^i, G^i) \quad (2.6)$$
$$w_i L^i + G^i \leq w_i \tau + \varphi^i(w_1, w_2, I) \quad (i = 1,2) \quad (2.7)$$

In this model, w_i are the individuals´ wage rate, and non-labor income I is shared between the members and that $\varphi(w_1, w_2, I)$ is the amount received by member 1 and I - $\varphi(w_1, w_2, I)$ by member 2. Now each member independently chooses consumption and labor supply, subject to the corresponding constraint.

Blundell, Chiappori and Meghir (2005), extend the collective model of labor supply presented by Chiappori (1992) by the introduction of children in a specific context. Besides, they allow for the existence of public consumption and they analyze the changes in distribution of power within the household.

$$U^i(L^i, G^i, K) = W^i[u^i(L^i, G^i), K] \quad (2.8)$$
$$w_1 L^1 + w_2 L^2 + G^1 + G^2 + K = w_1 \tau + w_2 \tau + I \quad (2.9)$$

In this model there are three commodities: two individual leisure (L^1 and L^2), and a composite good G where $G = G^1 + G^2 + K$ and K is the level of expenditures for the public good. In the case of this paper, the public good considered is the amount spent on children.

Cherchye, De Rock and Vermeullen (2012) proposed a collective labor supply model with household production that generalizes the model of Blundell, Chiappori and Meghir (2005). They focus on a household with two adults and with children with no bargaining power of their own. Their formulation can be modeled as follows:

$$u^i = u^i\left(G^i, L^i, u^k(G^k, H_k^1, H_k^2; s^k), u^p(G^p, H_p^1, H_p^2; s^p)\right) \tag{2.10}$$

$$L^i + T_w^i + H_k^i + H_p^i = 1 \tag{2.11}$$

$$G^1 + G^2 + G^k + G^p = I + w^1 T_w^1 + w^2 T_w^2 \tag{2.12}$$

Where the adults *i* spent their time on leisure (L^i), market work (T_w^i) and two types of household work: parental time invested in children (H_k^i) and other household work (H_p^i), normalizing the time endowment to one. Consumption is divided into private consumption of the adult members (G^1 and G^2), expenditures on children (G^k) and expenditures on other public goods (G^p). Finally, vectors s^k and s^p contain production shifters associated with domestic goods u^k and u^p. A production shifter is a variable that affects individual preferences only through the household production technologies (e.g. average age of the children in the household).

With this, the authors observe the complete intra-household consumption allocation, not only observing how much of the household's resources go towards children and other public goods, but also how the household's private consumption ($G^1 + G^2$) is allocated to both adult members.

Although these studies have been presented as an expansion of the classical collaborative labor supply model, they have not been exempt of criticisms. Duguet and Simonnet (2003) consider that research such as Chiappori (1992) and most collective labor supply models are limited because they are restricted to the case where both household members work. Even though there are studies that analyze the cases where only one member of the household works, or where neither does (Blundell, Chiappori, Magnac, Meghir, 2005; Donni, 2000), these exclude public goods and therefore, as an example, they perform their analysis on married couples without children. Finally, these studies are restricted to the case where the man just decides whether to participate or not, while the woman can freely choose her working hours. The model presented by Duguet and Simonnet (2003) is constructed to calculate the incentives to work for each household member.

Furthermore, the modeling framework also evolved in terms of the period analyzed. Now the decision of time assigned to work is paired with the decision of what to do with the money. In a static model, goods consumption is the only choice that the individual can make but it is not a good representation of reality. A dynamic or multi-period model presents alternatives to consumption: investing or saving money to use it in another period. This is the main characteristic of the lifetime labor supply models.

The interest in lifecycle labor supply arose from two issues. Lucas and Rapping (1970) presented a lifecycle framework as a way to reconcile an elastic short-run labor supply curve with an inelastic or even backward-bending long-run labor supply curve. Their idea was to model cyclical hours' variation as a response to a temporary wage change. Therefore, much debate in the macroeconomics literature has focused on the size of this intertemporal wage elasticity (e.g. Card, 1991).

A second motivation for studying lifecycle modeling arose from human capital theory and the influence of the pattern of lifecycle wage rates in the pattern of lifecycle hours. On this issue, Heckman (1976) noted that a model with endogenous labor supply can potentially reconcile differences in the lifecycle profiles of earnings and hourly wage rates.

The generic single-agent lifecycle model starting at period *t* can be characterized as follows:

$$U_t = U(G_t, L_t, G_{t+1}, L_{t+1}, \dots, G_\tau, L_\tau) \quad (2.13)$$

$$A_{t+1} = (1 + r_{t+1})\left(A_t + I_t + w_t T_{w_t} - G_t\right) \quad (2.14)$$

Where A_{t+1} is the real value of assets at the beginning of period *t+1* and r_{t+1} is the real rate of return earned on assets between *t* and *t+1*.

2.3.2. Unpaid work

In general, the focus regarding unpaid work activities can be separated into three main activities: household production, care for others (mostly childcare) and volunteering; with the majority of research focused on the first two categories.

In the mid-1960s a major theoretical development took place, known as the “new household economics" (see Becker, 1981b; Ironmonger, 1972; and Lancaster, 1971). In this theory the household is regarded as a productive sector with household activities modeled as a series of industries (Ironmonger, 2000).

Within this approach, households produce commodities that are designed to satisfy separate wants such as thirst, hunger, warmth and shelter. The characteristics, or want-satisfying qualities, of the commodities used and produced can be regarded as defining the production and consumption technology of households. With changes in incomes and prices, households still alter expenditures as in the earlier theory. However, households adjust their behavior as they discover new commodities and their usefulness in household production processes.

Given that unpaid work was drawn from labor supply theory, domestic labor research has adopted the same framework but with a clear emphasis on how to evaluate and value the work performed inside the household. In addition to that, the presence of children appears as an important issue to consider when allocating individual and/or household time. Furthermore, there is a clear distinction between the consumption of market goods and household produced goods, distinction that is not present in labor supply literature.

While market economy produces goods that households cannot fabricate (e.g. cars and shoes), in many cases the market and households are in direct competition, producing identical or similar goods. Some examples to consider are: restaurant dinner versus home cooking; hotels versus homes; external versus home-based child care; commuting by taxi or by own vehicle. Market goods and services need an immediate pay while domestic goods and services are free but time-consuming.

Another characteristic in domestic labor models is that, as in the labor supply literature, they recognize that a realistic way to model household behavior is to consider the presence of more than one individual, that is why there has been an evolution from unitary models to cooperative and bargaining models with two-individual households.

Regarding the period studied and the unit of analysis, the majority of models categorized as unpaid work has a static structure and focus on domestic labor rather than childcare or volunteering. In order to present how a different point of view has been studied, here we will examine a dynamic childcare-focused model studied by Gronau (1973a, 1973b)):

He considered a model with two commodities (or activities): "standard of living" (S) and "child services" (C), each being produced by combining the household members' time (T_i) and market goods (X_i).

$$U = U(Z_1, \dots, Z_n) \tag{2.15}$$

$$\sum_{j=1}^{n} \alpha_j \left(X_{sj} + X_{cj}\right) = \sum_{j=1}^{n} \alpha_j \left(w_{mj} T_{wmj} + w_{fj} T_{wfj}\right) + I \tag{2.16}$$

$$T_{sij} + T_{cij} + T_{wij} = \tau \qquad i = m, f \qquad j = 1, \dots, n \tag{2.17}$$

$$S = S\left(X_s, T_{sm}, T_{sf}\right) \tag{2.18}$$

$$C = C\left(X_c, T_{cm}, T_{cf}\right) \tag{2.19}$$

$$Z_j = Z_j\left(S_j, C_j\right) \tag{2.20}$$

Where the household consists of two adults, male (m) and female (f), and children, who do not contribute to household production. The utility in any given period is a function of the quantities of S_j and C_j consumed during that period. T_{wij} denotes the time spent in work by person i in period j and w_{ij} is the wage rate person i in period j. α_j is a discount factor.

Regarding unit of analysis, the majority of models in this category represent a 2-members household as the unit of analysis. The most common model structure can be formulated as:

$$U^i\left(X_{ji}, Y_{hi}, T_{Li}\right) \tag{2.21}$$

$$T_{wi} + T_{hi} + T_{Li} = \tau \qquad i = 1,2 \tag{2.22}$$

$$\sum_i \sum_j X_{ji} \leq \sum_i (w_i T_{wi} + I_i) \tag{2.23}$$

$$\sum_i \sum_h Y_{hi} = Y \leq h(T_{h1}, T_{h2}) \tag{2.24}$$

Where U^i is the individual utility; X_{ji}, Y_{hi}, T_{Li} are the consumption of market purchased good *j*, household produced good *h* and time assigned to leisure by individual *i* respectively; $T_{wi}, w_i, I_i, T_{hi}, \tau$ are time assigned to market work, wage rate, non-work income, time assigned to household production and total time available for individual i respectively. Finally, Y is the total amount of household produced goods by both members and $h(T_{h1}, T_{h2})$ is the household production function that depends on time assigned to household production by both members.

As an overall characterization of these models, they are dependent mostly from consumption of market and household (home and/or childcare) goods, separation not existing in labor supply models, and time assigned to leisure and domestic labor (or childcare). Additionally, some studies explicitly incorporate the households and the individuals' socio-demographic characteristics. The majority of the models have the household as the unit of analysis, and when modeling the household, all of the models consider a two member household (husband and wife) independently of the presence of children.

In general, in a two-member household model, the individual's decision is influenced by not only his own income but his spouse's as well. Preferences can be altruistic, and there may be positive externalities from household production. The presence of children is a factor that can also alter the household decision making process (e.g. Bryant and Zick, 2006). Furthermore, Chiappori's (1997) collective models specify a resource sharing rule within household in terms of domestic labor and other activities.

The labor supply model of Cherchye, De Rock and Vermeulen (2012) presents an interesting approach by considering into the individual's utility function, two subutility functions, u^k and u^p. The subutilities represent two domestic goods of which the output is unobserved. The domestic good u^k is the children's utility that acts as a public good in the preferences of the adults in the household; the domestic good u^p can be seen as the satisfaction of a clean house. This model makes the assumption that the domestic goods are produced in a cost-minimizing framework.

There have been attempts to estimate a monetary value to domestic labor or household production (e.g. Murphy, 1978; Weinrobe, 1974; Sirageldin, 1973; Nordhaus and Tobin, 1972; Morgan et al., 1962; Clark, 1958). But so far this has not yet been included in official national accounts such as the Gross National Product (GNP) or even considered as a measure of household income and expenses.

The fact that GNP estimations ignore the value of goods and services produced within the household seriously underestimates its magnitude and produces a bias in national and international comparisons between domestic and market indexes. Ignoring the contribution of domestic labor into the household's real income draws an incomparable situation between two families. This is extremely relevant when contrasting two households with the same monetary income but one having a member with a full-time focus on domestic production and the other one needing to hire external domestic help.

There is however a problem when trying to estimate the value of household services. Three methods of imputing a value to the time used in household production have been used, all taking a wage per hour from the market economy (Ironmonger, 2000). The first is the "opportunity cost" wage that a person could be paid for doing an extra hour of work in a market job rather than an hour of unpaid household work. The cost of an hour of household work is the forgone opportunity to earn in the market. This method is usually rejected since it yields different values depending on who performed the task. The second method uses the wages of specialist paid workers who come to the household, e.g., a cleaner, a cook, a nanny, a gardener, to value the same tasks performed by household members. This "specialist replacement cost" method can be criticized because these workers work more efficiently than a usual household member can, taking less time to perform the same task. Finally, a "generalist replacement cost" method of valuation uses the wage rate for a generalist worker or housekeeper. This is regarded as more appropriate since the working conditions and range of activities are similar to those of household members.

Time use surveys provide only one source of information about household production since they omit the contribution from non-human capital (the land, dwellings and equipment owned by households). A more complete national accounting approach to measuring and modelling the household economy is required to cover all factors of household production, all intermediate inputs and all the principal outputs.

There is still work to be done. As pointed out by Ironmonger (1996), the role of households in building human capital resources needs much greater investigation. Education, nurturing and training are still classified as the delivery of consumption rather than investment goods, leading to the debate about the extent to which childcare is a community concern rather than just a private, parental responsibility. In addition to that, the effects of changing household technology on unpaid household work needs more analysis to understand changes in gender divisions of labor and capital-output ratios.

Furthermore, the movements through the business cycle of production and work between the household and the market needs more profound research to establish the extent of the trade-off between household production and market production.

Finally, an analysis of the effects that differences in social and economic policies across countries have on women's and men's time use would be helpful in determining which social and economic policies will promote gender equity and at the same time will minimize the negative impacts on family welfare.

2.3.3. Non-work activities: Leisure

In parallel with labor supply literature, time use modeling focused on the activities that had to be traded in order to assign time to work. Within non-work activities, the category that achieved the most notoriety is leisure.

Literature acknowledges the problem that there is no clear distinction or an agreement about a unique definition for leisure, so the activities classified as such are determined a *priori* by the researchers under their own conceptions.

Leisure can be defined in many ways. According to Feldman and Hornik (1981), economic analysis describes leisure as a normal good with a positive income effect (Gronau, 1977; Hall, 1970). Additionally, leisure implies consumption time, in contrast with work and domestic labor that can be categorized as production (Becker, 1976; Pollak and Wachter, 1975). Some sociologists define leisure as the time that is available after subsistence needs are covered (Parker, 1978). Moreover, the psychological definition of leisure emphasizes the self-development and achievements obtained through freely chosen activities (Williams, 1977; Neulinger and Crandall, 1976).

The two conceptions that we believe to be the most adequate definitions of leisure to our research categorizations are the following: the first one is derived from the third-party rule proposed by Reid (1934, p.11). She presented a test in order to separate production from consumption and social activities: "*if an activity is of such character that it might be delegated to a paid worker, then that activity shall be deemed productive*". Therefore, within the unproductive activities, one can define leisure as "*all activities that we cannot pay someone else to do for us and that we do not have to do at all if we do not wish to*" (Burda et al., 2007, p.5).

The second one was first introduced by DeSerpa (1971, p. 834). He stated that leisure is freedom from work, which derives in the allocation of more time than required to the consumption to any particular good. In his words:

"…the primary responsibility of the time resource is with respect to the consumption of goods. Given the solution vector of the n goods, $(X_1^*, \dots, X_n^*)$*, a minimum amount of time, specified by the parameters,* $a_1, \dots, a_n$*, must be allocated to their consumption. Freedom from this responsibility, which inheres in the choice to allocate more time to any particular good than is required, thus constitutes leisure."*

In general, the focus regarding leisure activities is in the consumption of goods related to a specific activity being performed. Besides, the emphasis relies on the specific activity executed so there has not been a clear evolution regarding time use modeling. Even though there is not a single line of research because there are as many studies as leisure activities performed, it is important to say that every model considers two main activities: the specific leisure activity, and paid work. Every study in the leisure literature has analyzed how the time assigned to that activity has affected the ability of the individual or the household to supply labor into the market.

Because there are as many leisure models as leisure activities examined, here we present a generic formulation of the general form adopted by leisure studies, where T_p is the time assigned to that particular leisure activity.

$$MaxU = U(G, T_p) \tag{2.25}$$
$$wT_w + I - G \geq 0 \tag{2.26}$$
$$T_w + \sum_{i \neq p} T_i + T_p = \tau \tag{2.27}$$

2.3.4. Non-work activities: tertiary activities

There are activities that are particularly interesting to analyze from a modeling standpoint, called tertiary activities. Burda et al. (2007, p.3) defined this sub-category when analyzing household production, leisure and the trade-off with work: "*One alternative to production is tertiary activities, those things that we cannot pay other people to do for us but that we must do at least some of*". Within this definition, this sub-category includes activities like eating, sleeping, personal care and transport.

On one hand, eating, sleeping and personal care are among the most basic and required human activities as they are fundamental in order to survive. They require minimum amounts of time consumption, and one cannot pay another individual to perform them for us. Transport, on another hand, is a special type of tertiary activity. The specific kind of transport activity we are referring to is the one needed to carry on other particular activities. Individuals who need to perform activities personally in another location, such as working or studying, require traveling to do so, and cannot delegate those trips to another person. Furthermore, there are technological constraints that pose a minimum time required by individuals to travel, such as maximum legal speed.

Within this category, the activities that have been covered with more emphasis in the literature are transport and sleep.

a) Transport

The object of study in transport analysis is multifaceted and covers the issues of the generation (to travel or not) and distribution (where) of travel, mode choice (how) and the (re)location of activities. This area has been supported explicitly or implicitly on models based on the classical theory of the consumer and its extension to the scope of time use.

Models of discrete choice of mode of transport were justified by Train and McFadden (1978) based on the approach of Becker (1965), who proposed a theory of time use in which the utility of individuals depends on commodities and time consumption and where time has a unique value given by the wage rate. Since then, many theories have been developed either trying to enrich the model proposed by Becker (DeSerpa, 1971; Evans, 1972; Gronau, 1977; Juster, 1990) or adapt it to the study of specific aspects of time use, including the pioneering contributions of Oort (1969), which includes travel time in the utility function, and Small (1982), which includes the time of the trip as an important decision variable. Later transport models known as "activity based", developed from the pioneering work of Kitamura (1984) to the most recent of Bhat et al. (2013). The main focus of these models is to understand the context of the trip decision, recognizing that the activity structure, for the individual or the household, is distributed in space and time, generating different types of travel. There are many perspectives to study activity-based models, which are: time equations, structural equations, and activity program generation (see Astroza, 2012).

In the last decade Munizaga et al. (2008), Jara-Díaz (2003, 2007) and Jara-Diaz et al. (2008, 2012), among others, have taken up and expanded DeSerpa's formulation by modeling activities and travel together to then concentrate on the study of time use and time values in general. The approach thus generated has allowed deriving time use models from which time values assigned to activities such as work or leisure have been obtained empirically.

Within travel decision-making at an individual level, mode choice is an area that has been covered extensively by the literature. One of the most known approaches aimed at understanding mode choice is the goods/leisure trade-off framework proposed by Train and McFadden (1978), where modal travel time T_{t_m} and cost c_m are variables that influence utility by means of goods consumption and time spent in leisure, both dependent of the mode *m* selected. For a single trip, this can be presented as:

$$Max\, U = U(G, L) \tag{2.28}$$

$$wT_w + I - G - c_m \geq 0 \tag{2.29}$$

$$T_w + \sum_{i \neq t} T_i + T_{t_m} = \tau \tag{2.30}$$

Train and McFadden's (1978) goods-leisure model can be acknowledged as the first model to understand discrete travel choices regarding a consumer behavior framework including both, goods consumption and time allocation. This model reproduces most of the properties of Becker's (1965) approach, including its limitations, particularly the fact that travel time savings are theoretically valued at the individual's wage rate.

As stated in Nerhagen (2000), the influence of comfort and convenience on travel mode choice, in addition to travel time and travel cost, has been an issue for a long time in transportation research. DeSerpa (1973), for example, acknowledges that "inefficient" choices might exist in a travel mode choice situation. In this case the individual chooses a travel mode that is at least as expensive as an alternative mode and also more time consuming. The reason for doing so would be that the individual derives additional utility at the margin from the chosen mode, sufficient to compensate him for allocating more resources than required. In one case, the individual would be willing to pay a positive sum of money to save time traveling, but he is not willing to travel by another means. It could also be the case that the individual might not be willing to pay to save travel time since the marginal utility derived from the chosen mode is equal to the marginal utility of alternative uses of time. In this case, the value of saving travel time should be zero. The problem with "inefficient" choices, according to DeSerpa (1973), is that the different travel activities involve no substitutability between commodities and time.

However, one problem with the inclusion of attributes such as comfort and convenience is that they are not objectively measurable. Therefore, efforts have been made to include attitudes in the analysis of travel mode choice. Hensher et al. (1975) is an attempt to incorporate these factors in a travel mode choice model. In this study the respondents were first asked about what they defined as comfort and convenience. They were then asked to rate how important various comfort and convenience factors were for their choice of travel mode. These importance ratings where then included in the model of travel mode choice. It was found that inclusion of comfort and convenience factors improved the mode choice model and that their inclusion gave the variables travel time and cost a more realistic perspective.

Koppelman and Pas (1980) went further and proposed a method of travel mode choice analysis that was based solely on consumers' perceptions, feelings and preferences. They argue that traditional models, which are based on the identification of relationship between observed travel behavior and engineering measures of travel characteristics (travel time and cost) and demographic characteristics, provide a limited understanding of the behavioral processes underlying travel decision making. Instead, their method focuses on the decision process and the importance of attitudes for modal choice. This method was empirically tested on work/school travel (Koppelman and Lyon, 1981). This model includes individuals' perceptions of factors such as convenience, general service and psychological stress and feelings measures. In addition, they include a variable that accounted for the effect of situational constraints (car availability). However, contrary to the modeling effort by Hensher et. al. (1975), this model does not include travel time and travel cost as separate factors influencing choice. The authors' conclusions are that perceptions and feelings are important determinants of preferences and modal choice behavior.

Research regarding individuals travel choice behavior has been performed under the heading of activity based travel analysis. Clarke et. al (1981a) describe this line of research. The focus in this study is individuals' activity schedule, the importance of spatial and temporal constraints and the interaction between household members. They propose a model that predicts changes in household's activity schedule where travel mode choice is one such activity. An important part of this model is the various constraints that limit an individual's choice set. Another one is that travel behavior is dependent upon household structure, such as different stages in a family life cycle (without children, with children or retired).

Other issues that have been currently explored are data and modeling. There are various papers that dealt with the links between transport systems analysis and the study of individual time use. They were presented in a special issue and brought together data requirements, modeling opportunities and needs in terms of information for a better understanding of users' behavior and time assignment and its valuation.

In terms of data, there are three contributions in this issue. First, Gerike et al. (2015) analyzed the collection of time use from Travel surveys and Time Use Surveys, considering both travel and non-travel activities. The authors recommended using continuous time intervals for activity diaries, besides other improvement recommendations for the design of Time Use Surveys and Travel Surveys, such as proxy reporting, survey coding instructions, multiple activities recording, and incorporation of data regarding the usage of information and communication technology (ICT). Second, Minnen et al. (2015) showed that multi-day time-diary data might help to identify temporal regularities, such as repetition and timing of transportation activities. They demonstrated that a breakdown of continuous time-use data in 10-minutes time intervals adhered most to the original data and that it made hardly any difference whether they included the activity on the first or last minute of the discrete time intervals. Finally, Jara-Diaz and Rosales-Salas (2015) analyzed the appropriate duration of time diaries as a source of time use data. The study discusses the advantages and limitations of different lengths of data capture on time-use. They found that a two-day weighted survey does seem to be an adequate surrogate for weekly time-use information in the context of a work-leisure cycle.

Regarding modeling issues, Frei et al. (2015) study the impact of information and communication technologies (ICTs) on the valuation of travel time and transit services. They found that travel attitudes and activity engagement have potential to influence travelers' value of time, and many transit riders consider transit a better use of time and/or money than driving. Furthermore, as time use has an influence on users' valuation of the transit mode, offering opportunities to conduct certain leisure activities could improve the perceived value of travel time. Bernardo et al. (2015) examines the time-use patterns of adults in dual-earner households with and without children, focusing on the possibility of mobility-related social exclusion. They found that the presence of a child in dual-earner households not only leads to a reduction in in-home non-work activity participation (excluding child care activities) but also a substantially larger decrease in out-of-home non-work activity participation (excluding child care and shopping activities), suggesting a higher level of mobility-related social exclusion relative to overall time-use social exclusion. Finally, Pawlak et al. (2015) study the participation of (rational) individuals in activities by mode of activity participation (physical versus equivalent tele-activity), mode and route of travel for physical activity participation, and the bundle of Information and Communication Technologies (ICT) used for tele-activity participation using a modelling framework grounded in time allocation theories and the goods–leisure framework. They demonstrate the means by which their framework could be linked to various data collection protocols (stated preference exercises, diaries of social interactions, laboratory experiments) and modelling approaches (discrete choice modelling, hazard-based duration models).

b) *Sleep*

The other activity that stands out within this group is sleep, where the emphasis is on the relationship between time assigned to sleep and the allocation of time for the rest of the activities. Even though sleep has vast implications for multiple aspects of everyday life, consuming a large amount of non-working time, time use researchers have largely ignored decisions about sleep, as if the supply of waking time is of fixed quantity and quality.

The first paper to address this topic was by Biddle and Hamermesh (1990). Their model assumed the utility of sleep is equal to the amount one enjoys plus the increased productivity that one gains from sleeping. The cost of sleep is equal to the opportunity cost of the time used during the period the individual slept. The implication of this model is that the more a person values wakefulness, the less that individual will sleep.

They found that the length of sleep varies between individuals and that higher wage rates are inversely correlated with sleep time among men. Here we present their formulation as the seminal paper for sleep related time use studies:

$$MaxU = U(G, T_s) \tag{2.31}$$
$$wT_w + I - G \geq 0 \tag{2.32}$$
$$T_w + T_z + T_s = \tau \tag{2.33}$$
$$w = w_1 + w_2 T_s \tag{2.34}$$
$$T_G = bG \tag{2.35}$$
$$X = aG \tag{2.36}$$

In their formulation, sleep is assumed to generate utility in addition to having a positive effect on wages. Utility is now dependent on sleep time assigned to sleep (T_s) and commodities consumption (G), which in turn is related to time assigned to their consumption (T_c) and market goods.

Biddle and Hammermesh (1990) show an inverse relationship between hourly wages and amount of time asleep. A negative association between years of schooling and sleep hours is interpreted as arising from the higher wage potential of those with more schooling. Further research comparing sleep between nations suggests that, in countries with higher per capita incomes, people tend to sleep less. In a South African study (Szalontai and Wittenberg, 2004), the authors report an inverse relationship between per capita income and time sleeping.

In Asgeirsdottir and Zoega (2011), they extend Biddle and Hamermesh (1990) formulation by modeling the decision to sleep as an investment decision in the level of alertness that the individuals enjoy during the day. They introduced the quality of sleep as a factor that can be influenced by individuals.

2.4. Overall time use modeling

The study of the use of time as a whole tries to understand time allocation as a structural phenomenon. This literature analyzes the relationships between activities, often described by its duration, and the characteristics of individuals and/or households who allocate their time to them. This literature can be analyzed in many ways. The most important issues are, to our opinion: the utility framework, and the unit of analysis.

Regarding the utility framework from which models are created, the most extensively discussed ones are: the microeconomic theory approach, and the activity-based modeling. On one hand, the models that are based on the microeconomic approach expand the basic consumer theory by including time in the utility function and a temporal restriction in addition to the budget constraint. The main characteristics behind these models are defined by how time is included in the utility function and how the relations between goods consumption and the allocation of time to activities are defined. On the other hand, the central conceptual framework of the activity-based approach exists as an integration of aspects of time geography and human activity analysis. The main focus of this type of models have been travel demand, studying the overall time allocation of the individuals in combination with their transport behavior. According to Pas (1985), this has "*required travel demand analysts to (a) reconsider the definition of the phenomenon being modeled, (b) give more explicit recognition to the derived demand nature of travel and (c) pay more attention to the sociodemographic characteristics of individuals and households that affect the demand for activity participation.., and that often constrain activity and travel choices*".

Regarding the unit of analysis, there is increasing consensus in the literature on household behavior that we cannot model the decisions of a multi-individual household as though the household had a set of stable and unique preferences (as if it were a black box), the so-called 'unitary' model. That is why a number of alternatives have been suggested, ranging from bargaining models to cooperative and non-cooperative models.

Now we will analyze each issue, their characteristics, advantages and limitations.

2.4.1. The Utility Framework

a) Microeconomic Models

The first general theory of time allocation was made by Becker (1965). This approach has been disputed and extended over the decades by many authors but most of them comply that individual time use is derived from the maximization of a household utility function subject to a time constraint and a budget constraint. Building on Becker's economic theory, Johnson (1966), Oort (1969), DeSerpa (1971), Evans (1972), and Train and McFadden (1978), among others, present new and improved structures for the valuation of time, specifically the values of leisure and work. Many reviews (for example, see Pas and Harvey, 1997; Gonzalez, 1997; and Jara-Diaz, 2007) have discussed the economic formulations of time allocation and we refer the interested reader to these studies.

The model proposed by Jara-Diaz (2003) formulated a conceptual structure to understand the technological relations between goods consumption and time assignment to activities. Later, Jara-Diaz and Guevara (2003) presented a simplified microeconomic model focused towards transport research, which was extended by Jara-Diaz and Guerra (2003) by including all activities, goods consumption and any discrete choice, to provide new econometric estimations of the value of leisure and time allocation to different activities.

The model is:

$$max\ U = \Omega T_w^{\theta_w} \prod_i T_i^{\theta_i} \prod_j X_j^{\eta_j} \tag{2.37}$$

$$\sum_j P_j X_j + c_m \leq w T_w + I \rightarrow \lambda \tag{2.38}$$

$$\sum_i T_i + T_w + T_{t_m} = \tau \rightarrow \mu \tag{2.39}$$

$$T_i \geq T_i^{min} \quad \forall i \rightarrow \kappa_i \tag{2.40}$$

$$X_j \geq X_j^{min} \quad \forall j \rightarrow \varphi_j \tag{2.41}$$

where U is the utility function, θ_i and η_j are parameters corresponding to activities and goods respectively, Ω is a utility constant, X_j is the market good *j* consumed with its price P_j, T_i is the time assigned to activity *i*, T_w corresponds to the time assigned to work, *w* is the wage rate, c_m is the travel cost of mode *m*, T_{t_m} is that mode's allocated time, τ is the length of the period considered, T_i^{min} corresponds to an exogenous minimum time restriction for activity *i*, and X_j^{min} corresponds to an exogenous minimum goods consumption restriction for market good *j*. The parameters λ, μ, κ and φ are the Lagrange multipliers that represent the change in utility when the corresponding constraint is relaxed in one unit. Therefore, λ is the marginal utility of income, μ is the marginal utility of available time, κ_i is the marginal utility of diminishing the minimum time of activity *i* in one unit, and φ_j is the marginal utility of diminishing the minimum consumption of good *j* in one unit.

The optimality conditions lead to the set of equations (2.42)-(2.44) 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 *w*, 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*). Note that the equations for goods consumption can be easily converted into expenditure equations by moving the price to the left hand side.

$$T_w^* = \left[(\tau - T_c)\beta + \frac{E_c}{w}\alpha\right] + \sqrt{\left[(\tau - T_c)\beta + \frac{E_c}{w}\alpha\right]^2 - \frac{E_c}{w}(2\alpha + 2\beta - 1)(\tau - T_c)} \tag{2.42}$$

$$T_i^* = \frac{\widetilde{\theta}_i}{(1 - 2\beta)}(\tau - T_w^* - T_c) \quad \forall i \in A^f \tag{2.43}$$

$$X_j^* = \frac{\widetilde{\eta}_j (w T_w^* - T_c)}{P_j (1 - 2\alpha)} \quad \forall j \in G^f \tag{2.44}$$

Where A^f is the set of freely chosen activities, G^f the set of freely chosen market goods, $\beta = (\Phi + \theta_w)/2(\Theta + \Phi + \theta_w)$ and $\alpha = (\Theta + \theta_w)/2(\Theta + \Phi + \theta_w)$. $\Theta > 0$ 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_j over all unrestricted goods.

The values of leisure and work for each individual can be obtained as:

$$Value\ of\ Leisure = \frac{\mu}{\lambda} = \frac{\Theta}{\Phi} * \frac{(wT_w^* - E_c)}{(\tau - T_w^* - T_c)} = \frac{(1-2\beta)}{(1-2\alpha)} \frac{(wT_w^* - E_c)}{(\tau - T_w^* - T_c)} \tag{2.45}$$

$$Value\ of\ Work = \frac{\partial U / \partial T_w}{\lambda} = \frac{\theta_w}{\Phi} * \frac{(wT_w^* - E_c)}{T_w^*} = \frac{(2\alpha + 2\beta - 1)}{(1-2\alpha)} \frac{(wT_w^* - E_c)}{T_w^*} \tag{2.46}$$

Creating the following relation:

$$Value\ of\ Leisure = \frac{\mu}{\lambda} = w + \frac{\partial U / \partial T_w}{\lambda} \tag{2.47}$$

Munizaga et al. (2008) provide an econometric approach to calibrate the model from Jara-Diaz and Guerra (2003) to activities and travel. They estimate it using a Chilean time use dataset.

Furthermore, Jara-Díaz et al. (2008), among others, have expanded the classical consumer theory formulation to concentrate on the study of use and time values in general. The approach thus generated has allowed the derivation of time use models from which time values assigned to activities such as work or leisure have been empirically obtained (more information about the estimation of this model can be found in the next chapter).

Recently, López-Orpina et al. (2015) extended the microeconomic approach of time allocation and goods consumption by explicitly including a temporal dimension in the choice-making process. They recognize that some activities such as a job or education, involve a long-term commitment while others, such as leisure and shopping, are modified in the short term. They define the time window or frequency of adjusting the variables of activities (duration, location and consumption of goods) and the magnitude of preference observations at the micro level, such as transport mode choice, are strongly conditioned the resources (time and money) spent by the means of a hierarchical temporal structure. Then, they specify and analyze a microeconomic model with two time scales, macro and micro, concluding that by the prevailing choices at the macro scale.

Even though a model of these characteristics presents many advantages, it also has certain limitations, both specific to the model and general limitation shared with all microeconomic frameworks.

One of the first limitations involves the utility function. The studies performed by Jara-Diaz and associates chose a Cobb-Douglas functional form based on the fact that it allows the estimation of optimal time allocation and the different values of time. Out of the system of equations one can obtain a labor supply function dependent on the wage rate, committed time and committed expenses.

There are two main disadvantages present within a Cobb-Douglas formulation. First, it assumes marginal utilities with a constant sign for each argument. There are authors that consider this to be a limitation. For example, Prasch (2000) states that, to leisure activities, it is reasonable to think that their marginal utility depends on goods consumption, and that for a certain group of people (e.g. unemployed individuals with low income), this marginal utility could even be negative. Second, given the multiplicative form of the Cobb-Douglas, no arguments can have a zero value.

Given that one of the modeling purposes of these microeconomic frameworks is to obtain different values of time, a utility functional form is needed. Besides the Cobb-Douglas, other forms were analyzed by Contreras (2010). A summary is presented next.

The CES functional form given by $\mathrm{U} = \sum_{\mathrm{k}} \alpha_{\mathrm{k}} \mathrm{x}_{\mathrm{k}}^{\gamma}$ with $\alpha_{\mathrm{k}} < 0$ and $0 < \gamma < 1$, does not overcome the limitations previously presented for the Cobb-Douglas. Additionally, it imposes a complementarity of grade 0 between two different goods.

The Stone-Geary form given by $\mathrm{U} = \sum_{\mathrm{k}} \alpha_{\mathrm{k}} \log(\mathrm{x}_{\mathrm{k}} - \mathrm{b}_{\mathrm{k}})$ with $\alpha_{\mathrm{k}} > 0$ and $\mathrm{x}_{\mathrm{k}} - \mathrm{b}_{\mathrm{k}} > 0$, allows the definition of a minimum subsistence range, that could be interpreted as the minimum goods consumption or time allocation mandatory required. However, this form presents other limitations: first, the marginal utility of each argument is positive; second, the model does not allow the complementarity analysis of its arguments.

The quadratic functional form given by $\mathrm{U} = \mathrm{a}_0 + \sum_{\mathrm{k}} \mathrm{a}_{\mathrm{k}} \mathrm{x}_{\mathrm{k}} + \sum_{\mathrm{j}} \sum_{\mathrm{k}} \mathrm{b}_{\mathrm{jk}} \mathrm{x}_{\mathrm{j}} \mathrm{x}_{\mathrm{k}}$ is quite flexible, allowing marginal utilities to change signs depending on *their evaluation point*, and allows zero value arguments. However, when the model is calibrated, it has parameter identification problems that do not permit the estimation of values of time.

Finally, the Translog, a generalization of the Cobb-Douglas, structured as the quadratic form but with its arguments within a logarithm, allows marginal utilities to change signs depending on their point but does not allow zero value arguments.

Due to all of these characteristics, the models presented by Jara-Diaz and his associates have stated that in order to estimate the different values of time, the appropriate functional form, under these circumstances, is the Cobb-Douglas.

Another important limitation of this type of formulation is the use of endogenous income. In general, most microeconomic models follow the framework of Train and McFadden (1978), in which individuals decide how many hours to work (T_w) at a pre-specified wage rate *w*. In reality, this situation does not occur for a large segment of the population in many developing countries. In 1987, Jara-Diaz and Farah presented a version of the goods/leisure model in which the hours of work (T_w) and the total income (I) are fixed within the relevant period. In the case of exogenous income, the individual can not diminish their hours of work even if it brings dissatisfaction, but he or she is not limited to work more hours (for free) if work is pleasurable. When working hours and income are fixed, what matters are the time available to spend it and the disposable income available.

Expanding the analysis of this study, Jara-Díaz (2002) concludes that if the individual works more than strictly required, then the value of leisure is equal to the subjective value of work, which has to be positive. This is equivalent to the case when the individual chooses the working hours but with a zero wage rate.

$$Value\ of\ Leisure = \frac{\mu}{\lambda} = \frac{\partial U / \partial T_w}{\lambda} \qquad if\ T_w > T_{w_{fixed}} \tag{2.48}$$

A third limitation is the modeling period used. Estimating the values of time in a one-period static model that does not consider individual long-term time allocation and budgeting decisions may finalize with conclusions that do not represent the real decision-making process the individuals underwent. An alternative to this type of framework are dynamic or life-time models. These structures represent the individual as an agent that conducts successive decisions in terms of time allocation to activities, goods consumptions, savings and investments.

A fourth type of limitation is the unit of analysis used by these models. Even though the individual is the agent that has the final decision on his or her time allocation, it has to be acknowledged that, in terms of the utility drawn from activities, there is a difference between performing an activity on their own or doing them as a couple or with friends. The motivation to allocate time to certain activities can be heavily influenced by the presence of other individuals and this is not included in the microeconomic models presented so far. This issue will be more comprehensively covered in point 2.4.2.

Besides the specific limitations shown above, microeconomic models share characteristics that have been criticized by some authors. One of the limitations of neoclassical economists, according to certain social sciences, is that they assume stable preferences of individuals (Pérez, 1997). It follows that if the behavior of an individual varies over time, it is assumed that the change was due to a variation in driving forces, not preferences. The new socio-economic paradigm opposes this argument even though accepts that the factors causing changes in preferences are multiple and may vary depending on the discipline studying them, having different hypothesis in areas such as psychology, anthropology, political science and sociology.

Perez (1997) also argues that the weakness of the neoclassical theory regarding fixed preferences is due to the fear that the variation in human preferences means having to constantly manipulate the theory and the assumption of individual autonomy and consumer sovereignty.

Another difference between economic studies and other social sciences is the argument of rationality (Abell, 2003). Neoclassical economic models argue that individuals are rational maximizers of what is useful to them; and if these people act differently, this may not be included in the study. Disciplines such as sociology, psychology and even branches of economics such as socioeconomics and behavioral economics have investigated the interaction of individuals under non-rational behavior (Turner, 1996).

b) Activity-based models

Activity-based modeling tries to understand the context in which the decision to travel is made, acknowledging that the demand for trips derives from the necessity to perform activities distributed across time and space. Instead of considering travel as a cost in time and money, activity-based models deal with the motivation to travel.

The seminal work of activity-based modeling can be attributed to Kitamura (1984), which postulates a discrete choice model of activity participation (an activity can be performed on that day or not) and continuous in time allocation. The model can be formulated as:

$$maxU(T_1, \dots, T_n, q_1, \dots, q_n) = \sum_{i=1}^{n} U_i(T_i, q_i) \tag{2.49}$$

$$\sum_{i=1}^{n} T_i = \tau \tag{2.50}$$

where q_i is a vector of characteristics of activity *i*. Total utility *U* is the sum of the utilities obtained for each activity $U_i(T_i, q_i)$, following this function when time allocated is positive:

$$U_i = \epsilon_i \gamma_i f_i(q_i) \ln(T_i) \tag{2.51}$$

Here, $f(q_i)$ is a function that indicates each individual valuation of activities characteristics ϵ_i is a positive error term and γ_i is a positive parameter. Kitamura (1984) admits the fact that when the individuals do not allocate time to discretional activities, they do not generate utility from them. From this, the utility function U_i is generated as follows:

$$U_i = \begin{cases} \epsilon_i \gamma_i f_i(q_i) \ln(T_i) & if\ T_i > 0 \\ 0, & if\ T_i = 0 \end{cases} \tag{2.52}$$

The author shows that this discrete/continuous time allocation can be expressed as a Tobit model for parameter estimation.

There have been several advancements in the utility function formulation of these models, such as Munshi (1993), Kitamura et al. (1996a), Kim et al. (2002), Bhat (2005, 2008), among other, that have used a similar base as equation (2.49) of resources allocation to determine individual/household activity participation and duration. Note that this particular type of models within the activity-based family does not allow obtaining time values because it only uses a temporal constraint. However, a recent paper by Castro et al. (2013) advances in that direction interacting with a microeconomic formulation, incorporating several types of constraints, and considering the following discrete/continuous choice problem:

$$maxU = \sum_{k=1}^{K} \frac{\gamma_k}{\alpha_k} \psi_k(q^k) \left(\left(\frac{x_k}{\gamma_k} + 1 \right)^{\alpha_k} - 1 \right) \tag{2.53}$$

$$\sum_{k=1}^{K} p_k x_k = E, \quad (\lambda) \tag{2.54}$$

$$\sum_{k=1}^{K} g_k x_k = \tau, \quad (\mu) \tag{2.55}$$

where $\psi_k > 0$ is the marginal utility when consumption of x_k is zero, ψ_k is a function of the attributes vector q^k of activity *k*. γ_k is a positive parameter for each good *k*. *E* is the total expense of every good, relative to each price p_k. Given that τ is total time available for goods consumption, g_k is the time rate for which each unit of good *k* is consumed. In addition, $0 <$

$\alpha_k \leq 1$ captures satiety effects, where if $\alpha_k = 1$ for every k, there is absence of satiety, or equivalently, a constant marginal utility. When α_k decreases, the effect of satiety to good k increases. Finally, as with the microeconomic models presented previously, $\lambda\, y\, \mu$ are the Lagrange multipliers of income and time constraints respectively. This work manages to capture the value of time as a resource (λ/μ).

Another interesting contribution of this work is that it permits different comparisons between microeconomic and activity-based modeling results.

On another hand, within the activity-based family of models, the structural equations models try to capture the influence that certain exogenous variables have over endogenous variables, and the influence of endogenous variables among themselves. Their framework is a linear system of equations with as many endogenous variables as equations. An extended review can be read in Golob (2003).

The model can be represented as follows:

$$T = AT + BS + \epsilon \quad \Rightarrow \quad T = (I - A)^{-1}(BS + \epsilon) \tag{2.56}$$

Where T is a vector of time allocated to different activities (endogenous variables), A is a matrix of parameters associated with these times (null diagonal), S is a vector of socioeconomic characteristics of the individuals (exogenous variables), B is the matrix of parameters associated with the socioeconomic characteristics, ϵ is the vector of error terms associated with endogenous variables, and I is the identity matrix.

This linear system captures two effects: the direct one, (the effect of variable y_j on y_i) and the indirect one (the sum of the effects of variable y_j on other variables k that in turn have a direct effect on y_i). The total effect is the sum of these two.

Golob and McNally (1995) developed a structural equations model to analyze interactions in time allocated to out-of-home activities and travel in three categories (work, maintenance, and discretionary) between male and female heads in a household. They also studied the effect of socio-demographic characteristics on time allocations. Thus, while their study examines individual time allocation like those of Kitamura et al. (1996b), Kraan (1996), and Bhat and Misra (1999), it also explicitly accounts for inter-individual interaction effects within a household. Other research efforts to capture inter-individual interaction effects have been undertaken by Koppelman and Townsend (1987), van Wissen (1989), Stopher and Vadarevu (1995), and Lu and Pas (1997). The results from these studies provide extensive insights on interactions in time allocations among individuals in a household as well as among various activity/travel categories for each individual.

Konduri et al. (2011) extended this system by including expenditure equations to induce the calculation of time values. Furthermore, Jara-Diaz and Astroza (2013) presented the concept of *revealed willingness to pay for leisure,* a link between the microeconomic utility theory approach and the structural equations model (SEM). In their work, they improve the incorporation of expenses, activities and socioeconomic variables into the structural equations model and calculate the revealed willingness to pay for leisure, a concept theoretically different from the value of leisure that is the value of time as a resource, and one of the results from a microeconomic formulation.

They conclude that the SEM does not allow the calculation of the value of leisure and that the microeconomic approach needs an explicit constraint relating goods consumption and time use.

Finally, the models based on a multiple discrete-continuous extreme value (MDCEV) approach, consider that many consumer choice situations are characterized by the simultaneous demand for multiple alternatives that are imperfect substitutes for one another. Bhat (2005, 2008) formulated a model within the broader Kuhn-Tucker (KT) multiple discrete-continuous economic consumer demand model of Wales and Woodland (1983) that portrayed, for example, the individual's decision to participate in multiple kinds of maintenance and leisure activities within a given time period. Such multiple discrete situations may be modeled using the traditional random utility-based single discrete choice models by identifying all combinations or bundles of the "elemental" alternatives, and treating each bundle as a "composite" alternative (the term "single discrete choice" is used to refer to the case where a decision-maker chooses only one alternative from a set of alternatives). A problem with this approach, however, is that the number of composite alternatives explodes with the number of elemental alternatives. Another approach is to use the multivariate probit (logit) methods of Manchanda et al. (1999), Baltas (2004), Edwards and Allenby (2003), and Bhat and Srinivasan (2005). But this approach is not based on a rigorous underlying utility-maximizing framework of multiple discreteness; rather, it represents a statistical "stitching" of univariate utility maximizing models.

Bhat (2005) introduced a simple and parsimonious econometric approach to handle multiple discreteness, also based on the generalized variant of the translated CES utility function but with a multiplicative log-extreme value error term. Bhat's model, labeled the multiple discrete-continuous extreme value (MDCEV) model, is analytically tractable in the probability expressions and is practical even for situations with a large number of discrete consumption alternatives. In fact, the MDCEV model represents the multinomial logit (MNL) form-equivalent for multiple discrete-continuous choice analysis and collapses exactly to the MNL in the case that each (and every) decision-maker chooses only one alternative.

Even though activity-based models have made conceptual, theoretical and methodological contributions in the understanding of travel behavior, there are challenges that can still be addressed.

The main challenges, to our opinion can be grouped in three categories: Data requirements, theoretical drawbacks and areas not analyzed.

In terms of data requirements, Activity-based models require large amounts of detailed and accurate input data to estimate the characteristics of each individual and household, and to correctly evaluate accessibility across highway, transit and non-motorized networks. They often require more detailed information not readily available from general sources, most notably household and transit surveys. Without this greater level of detail, many of the advantages of activity-based models are negated.

In practice, overcoming or compensating for holes in data can be a major expense of model development. With the higher data requirements of activity-based models, the amount of time and effort needed for data gathering (travel survey, household survey) and quality control account for a major portion of the model development effort.

Regarding theoretical drawbacks, while activity-based models may improve upon some of the limitations of other models, there are also questions regarding their theoretical assumptions and whether the benefits promised by these models can be realized in practice.

One of the appealing aspects of activity-based models is that they appear to be modeling travel by "following people around", rather than by making gross a priori generalizations about broad classes of people and types of travel. Yet for any real population, each day is necessarily different. What is of interest to planners and policy makers are not the outcomes of a single day (or even many single days), but rather our expectations regarding the most common outcomes, and our understanding of how those expectations shift in response to changes in the population, and in response to the travel and activity opportunities available to that population. According to VDOT (2009), researchers need "precise" rather than "gross" generalizations, and reconciling the disaggregate specificity of the activity-based modeling project with the need to construct accurate generalizations about travel behavior and the factors that influence it, presents a number of theoretical and practical challenges.

Additionally, because population synthesis and certain other steps in activity-based models are based on drawing samples from random probability distributions, the results of all major calculations, including the generation of households, activity patterns, and trip tours, will potentially be different every time the model is run. The result is that final network assignments will also potentially be different, and perhaps very different, for every model run. And there is no statistical guarantee that any of the outcomes of the different model runs represents the "most likely" or "expected" outcome, nor even that the expected outcome corresponds to the average of multiple model runs. (VDOT, 2009).

Even though activity-based models have made significant progress on understanding how households and individuals make choices that drive their activity and travel patterns, there are some areas that need to be further analyzed. According to Bhat and Koppelman (1999b), one of those areas is the time unit of analysis.

According to the authors, the unit of analysis typically used in the activity-based travel models is the weekday. The implicit assumption is that there is little variation in activity-travel patterns across different days of the week. Research focusing even on simple aggregate measures of activity-travel behavior (such as trip frequency, and number and type of stops made during the morning/evening commutes) has indicated quite substantial intrapersonal variability across weekdays (see Jara-Diaz and Rosales-Salas, 2015). One can therefore expect substantial day-to-day variations when considering entire activity-travel patterns.

In addition, the focus on a single weekday does not allow the examination of the interaction in activity participation between weekends and weekdays. Of course, the use of an entire week as the unit of analysis will require the collection of time-use diary data over at least one week. This offers research opportunities for the development of data techniques that can collect time-use data over a week without being prohibitively expensive or appearing excessively intrusive. (Bhat and Koppelman, 1999b).

2.4.2. The Unit of Analysis

Besides the utility framework used, microeconomic or activity-based, there is another issue that can be analyzed regarding the evolution of time use modeling: the unit of analysis. One can say that the decision between a single individual or a multi-individual household has been a well discussed topic in the time use literature.

Models on household activity start with the contribution of Becker (1965), who assumed that family members behave as if they were maximizing a household utility function subject to a household budget constraint. This is called a unitary model. Unitary models consider household behavior as a result of a single individual's decision or a joint utility function for a multi-individual household, disregarding that when dealing with a multi-individual household, all individuals try to maximize their own individual utility, taking part in the decision-making process of the household.

Unitary models treat the household as a black box so that the decision making cannot be tracked back to the individuals who took it. Many studies have been presented either trying to enrich the model proposed by Becker (DeSerpa, 1971; Evans, 1972; Gronau, 1977; Juster, 1990) or adapt it to the study of specific aspects of the use of time, but all considering the individual or the "black box" household as the unit of analysis. More details on unitary models literature can be found in Juster and Stafford (1991), Gonzalez (1997), and Jara-Diaz (2007). This type of model presents several difficulties, but the main ones are aggregation of preferences (Hilderbrand, 1994) and of individual demands (Deaton and Muellbauer, 1980).

Since the unitary model considers the household as a single unit, different preferences among members of the family remain hidden. The potential for misinterpretation of the reality of multi-individual households by relying on unitary models has led to the proposal of different modeling frameworks that consider the household as a field of competition and struggle, as well as cooperation and caring.

The most important approach that deals with the shortcomings present in unitary structures, are multi-individual models. Samuelson (1956) and Becker (1974b, 1981a, 1981b) were among the first studies to address the issue of resource allocation within the family, an important limitation within unitary models. Samuelson (1956) was the first author that presented the idea of a household utility function based on distinct utilities of each family member. Since the individuals agree on a social welfare function, the household as a whole behaves as if it were maximizing the family welfare function. This would lead to an optimal redistribution of income among the household members according to the equality of all members' individual expenditures.

On the contrary, Becker (1974b) proposed a model where the family utility function is the same as an "altruistic" head of the family. His (or her) decisions determine the intra-family distribution of resources and the redistribution of utility among household members according to his (or her) marginal utilities.

This scenario of pure altruism within the families is contradictory with the main assumption of individuals as selfish decision-making units in the outside market. To maximize one household utility function and to represent the behavior of a whole family just by the decisions of the head of the household is subject to criticism. These models, although an advancement in the area of modeling resource allocation within the family, have been described as highly restrictive (Ben Porath, 1982; Bergstrom, 1989). Moreover, it has been postulated that allocation within the family can create conflict (Sen, 1984).

Within a multi-individual modeling framework, bargain models are, to our opinion, the most relevant decision-making processes studied. In this framework, the behavior of the household is represented by a process of bargaining that occurs among family members.

According to Beblo (2001), bargain models are characterized by the object of bargaining, the identification of the players' objectives, the set of feasible outcomes, the associated payoff for each player and the specification of rules by which outcomes are to be determined. Regarding household decisions, each family member bargain over the allocation of their time, particularly labor time, unpaid work, and leisure activities. Furthermore, they can argue regarding the distribution of resources, such as income and consumption goods. Therefore, every member seeks to maximize their own utility. Contrary to unitary models, individual within a household are considered to be autonomous decision-making units with their distinct, but interdependent, optimization problems.

The most important types of bargaining models are: Cooperative, non-cooperative and dynamic models, where the latter one can combine both cooperative as well as non-cooperative features.

Cooperative bargaining models, on one hand, assume that individuals form a multi-member household when the benefit of doing so is higher than remaining alone. These benefits can be obtained as a result of a more efficient way to produce household goods and/or economies of scale in the sharing of goods. The benefits drawn from forming a household need to be distributed among the members and it is the rule that oversees that distribution that differentiates bargain models from unitary ones (Alderman et al. 1995).

Cooperative models are based on the assumption of free communication between family members, symmetry of information and voice. The cooperative Nash solution replaces the Becker-type household utility function as a weighted average of the individual utility functions. Another important assumption of this type of model is Pareto efficiency of outcomes. According to this assumption, the bargaining process guarantees intra-family time allocation and distribution of resources where no family member's position could be improved without diminishing another member's welfare (Beblo, 2001). In general, cooperative models often deal with marriage and domestic decision making processes (e.g. Manser and Brown, 1980; McElroy and Horney, 1981; Woolley, 1988; Lundberg and Pollak, 1993).

This assumption led to the formulation of another type of non-consensus framework within cooperative models, the collective model (Chiappori, 1988, 1992). In this approach, household members have their own utility function and the household equilibrium is Pareto-efficient but there is not a specification of any particular bargaining or collective decision process. They behave as if the household optimizes a collective utility function, with the individual utilities of the members as arguments.

As examples of this subcategory of cooperative models, we have collective models of household consumption, leisure and labor supply (Chiappori, 1988, 1992; Apps and Rees, 1988) that allow the representation of multi-individual behavior inside the household. Regarding leisure and consumption of goods in an aggregate form, Chiappori (1988, 1992) shows a definition of collective rationality, which determines efficient allocation between household members and a set of restrictions on labor supply functions, which allows the modeler to identify individual preferences. As stated in Laisney and Beninger (2002), the basic model has been extended in several directions, including household production and children (Apps and Rees, 1996, 1997, 1999; Chiappori, 1997; Chiuri, 1999; and Bourguignon, 1999), and the presence of more than two decision makers in the household (Browning and Chiappori, 1998). More details on collective models literature can be found in the survey of Vermeulen (2002).

In contrast to the cooperative structure, non-cooperative models explicitly specify a bargaining process and model strategic behavior of the individuals involved. They do not require assuming symmetric information or Pareto-efficient outcomes. Moreover, each member optimizes his or her own utility function and takes the behavior of the other as given. This context will yield a non-cooperative Nash-equilibrium (e.g. Leuthold, 1968; Ashworth and Ulph, 1981; Kooreman and Kapteyn, 1990; Browning, 2000; and Cheng and Woolley, 2001). Although one member cannot coordinate his or her decisions with other members of the household, individual utility maximization depends on the decisions made by other members, for instance due to household public goods that only have to be produced by one member but can then be consumed by both.

Finally, dynamic models present a combination of elements from cooperative and non-cooperative modeling structures. They integrate the cooperative Nash-bargaining framework with the strategic component of non-cooperative models. For example, they are used to model the dynamic impacts of a time use decision on human capital formation (e.g. Ott, 1992; Konrad and Lommerud, 1996; Wells and Maher, 1996). These works account for the strategic behavior within the family in the form of sequential non-cooperation. Moreover, they consider intertemporal dependencies of household decisions in proposing dynamic bargaining models.

As presented by Beblo (2001), the dynamic framework seems to be most appropriate for explaining labor force participation of many women who not only consider actual wage income but also the human capital aspect of job experience as well as their future bargaining power within the household when making time use decisions.

The focus of intra-household interactions is not only directed towards paid work and domestic production as presented so far. There are numerous facets of group decision-making that have relevant implications in the area of travel behavior and unpaid work, more precisely maintenance activities such as household chores. For example, Srinivasan and Athuru (2005) examine maintenance activity allocation and participation of household members. They specifically model whether an activity is pursued alone or jointly with another household member, and the specific person in the household who pursues the activity (if it is a solo activity). Their model is used to investigate within-household effects and between household differences. Also, the model is used to analyze the differences in person allocation between different types of households. Their results indicate that life-cycle and household role, income, gender, employment status, and several types of constraints (activities including cost, time-availability, vehicle-availability, coordination constraints, and child-care obligations) affect person allocation decisions in the context of maintenance activities.

Gliebe and Koppelman (2005) dealt with the individual interactions with other household members within their daily activity-travel patterns in terms of joint activity participation and shared rides. They developed a structural discrete choice model that predicts the separate, parallel choices of full-day tour patterns by both persons, subject to the higher level constraint imposed by their joint selection of one of several spatial interaction patterns, one of which may be no interaction. Model estimation results indicate that significantly greater emphasis is placed on the individual utilities of workers relative to non-workers and on the utilities of women in households with very young children, when making joint activity-travel decisions.

Meister, Frick and Axhausen (2005) generate complete daily activity schedules based on the structure of a household and its members' activity calendars. Their model assumes that the household is another basic decision making unit for travel demand aside from individual mobility needs. Results of the model are schedules containing complete information about activity type and sequence, locations, and means of transportation, as well as activity start times and durations. The generated schedules are the outcome of a probabilistic optimization using genetic algorithms.

Finally, Bhat et al. (2013) develops and estimates a multiple discrete continuous extreme value model of household activity generation that jointly predicts the activity participation decisions of all individuals in a household by activity purpose and the combination of individuals participating. Their results reveal that, in addition to household and individual demographics, the built environment of the home zone also impacts the activity participation levels and durations of households.

2.5. Synthesis and conclusions

In this chapter we have seen that time use literature is overwhelmingly diverse and disorganized. The evolution of time use research has been developed through different and independent approaches, thus producing isolated studies and not recognizing the effort generated in other disciplines.

Capturing the contributions existing in the literature in a systematic way is an important step towards the creation of a richer basis for time use modeling, identifying advantages, limitations and potential connections. This would allow closing the gaps of autonomous viewpoints by making it more manageable for time use researchers to acknowledge what has been done and allowing to focus future efforts to be conducted towards appropriate tasks and eliminating possible overlapping of analyses.

Here we have summarized, addressed and examined different forms of looking at time use literature: by discipline, historical context and type of analysis. For our purposes, the most important analysis is time use modeling by activity (Fig. 2.1). From this process some conclusions can be drawn.

From a modeling perspective, the main gap present in current research is that time use modeling has been developed independently among disciplines, providing almost no interaction and collaboration. This compartmental evolution has not allowed the overcoming of limitations that could be solved by integrating the advantages of multiple frameworks, such as the formulation, the explanatory power and interpretation of current models.

The analysis conducted in this chapter led us to identify two distinct paths to study further: data analysis and the extension of current time use models. The potential richness of combining time use data analysis and disciplinary interaction within time use modeling is overwhelming but has not been explored exhaustively.

First, we propose that an appropriate data analysis to estimate time use models is required. Time use data collection allows measuring the various ways in which people assign their time. There are several forms of data collection, which differ from each other in their specific objectives and scope, but coincide on their main purpose: providing information on individual time allocation.

However, different modeling structures present distinct information needs that are not necessary gathered by the available data collection techniques used in such studies. Because models differ from each other in terms of the period studied, unit of analysis, and type of model, they involve different levels of time use data. It is important to acknowledge that the information on how individuals allocate their time is abundant and diverse, but data collection aspects such as the period of observation are known to be controversial.

Second, we believe that there is a need for the formulation of more complete time use models, integrating contributions from different theoretical perspectives and the unification of different disciplinary approaches. In this chapter we found that there are several approaches that can be complemented with characteristics from other modeling structures.

The most important interaction improvement of the twentieth century was, to our opinion, the acknowledgement of unpaid/domestic work as a separate discipline of research from labor supply. This activity has been an important topic of discussion in areas such as official national accounts, in terms of the valued added to current measurements; gender studies and household production valuation.

This activity approach, however, has not been properly considered in time use models, even though there have been some efforts to acknowledge home economics as a source of improvement in the modeling and understanding of the value of time, both individual and social (Jara-Diaz, 2008).

To our opinion, accounting for the value of household production and domestic work, and the effect of the trade-off between work and non-work activities such as leisure should allow a better estimation and improve the interpretation of the value of time. Furthermore, this expansion of current time use model could also benefit from the introduction of (i) explicit domestic production technical constraints and (ii) the possibility of hiring external agents to perform certain activities.

These topics, data analysis and the extension of current time use models, will be covered in a deeper level in the next chapters.

3. TIME USE DATA REQUIREMENTS

3.1. 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 chapter 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 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 Lünenburg, 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.

3.2. 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. (1981b) 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-Diaz 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; Bhat et al., 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's (1993) recommendation, 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.

3.3. 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, socioeconomic 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 4,200 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 3.1.

Table 3.1. 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

The average daily duration of activities reported by workers are shown in Fig. 3.1, 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 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.

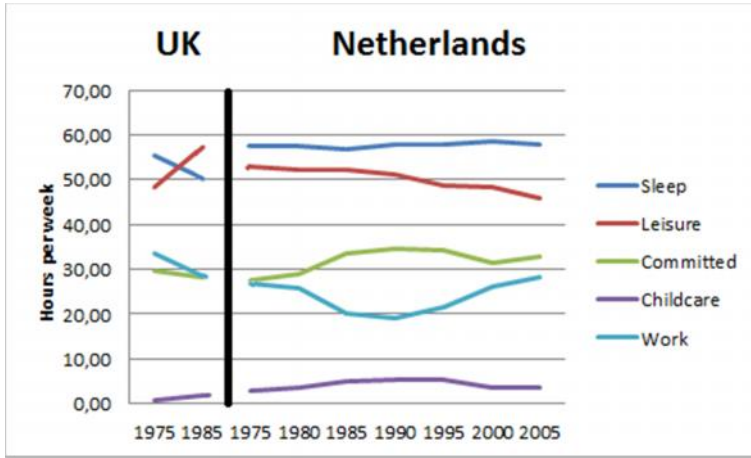

Figure 3.1. Average duration of activities for all surveys

To estimate the models for time assignment of the type we will use in the modeling section, 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. 3.2 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.

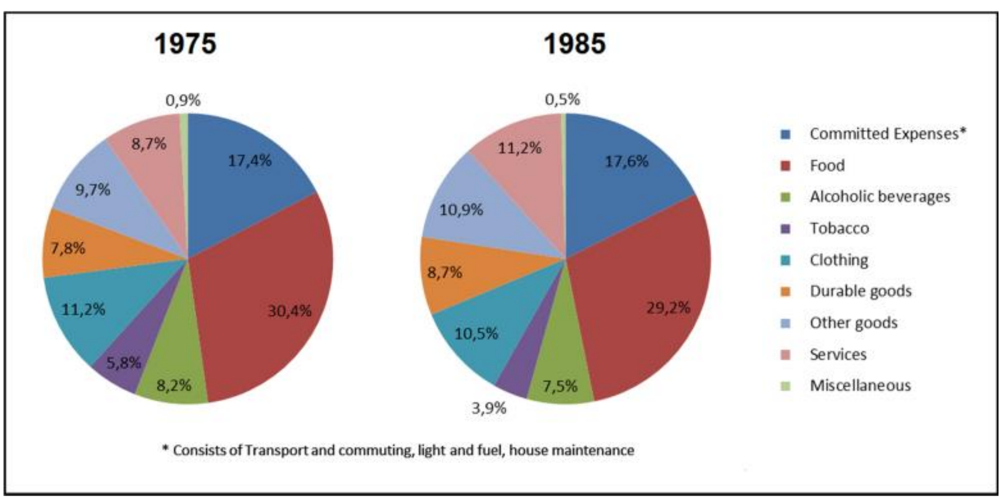

Figure 3.2. Total expenses structure – British datasets

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.

3.4. 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-day, 3-day and a 7-day 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 3.2 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 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 British data, the number of reported activities increases over the weekend (4th and 5th) but the opposite happens in Netherlands (7th and 1st).

Table 3.2. 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

Further on quality, in Table 3.3 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.

[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 3.3. 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	10485	0	0	0	45	0	0	15
4th	1800	10260	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

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. 3.3 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).

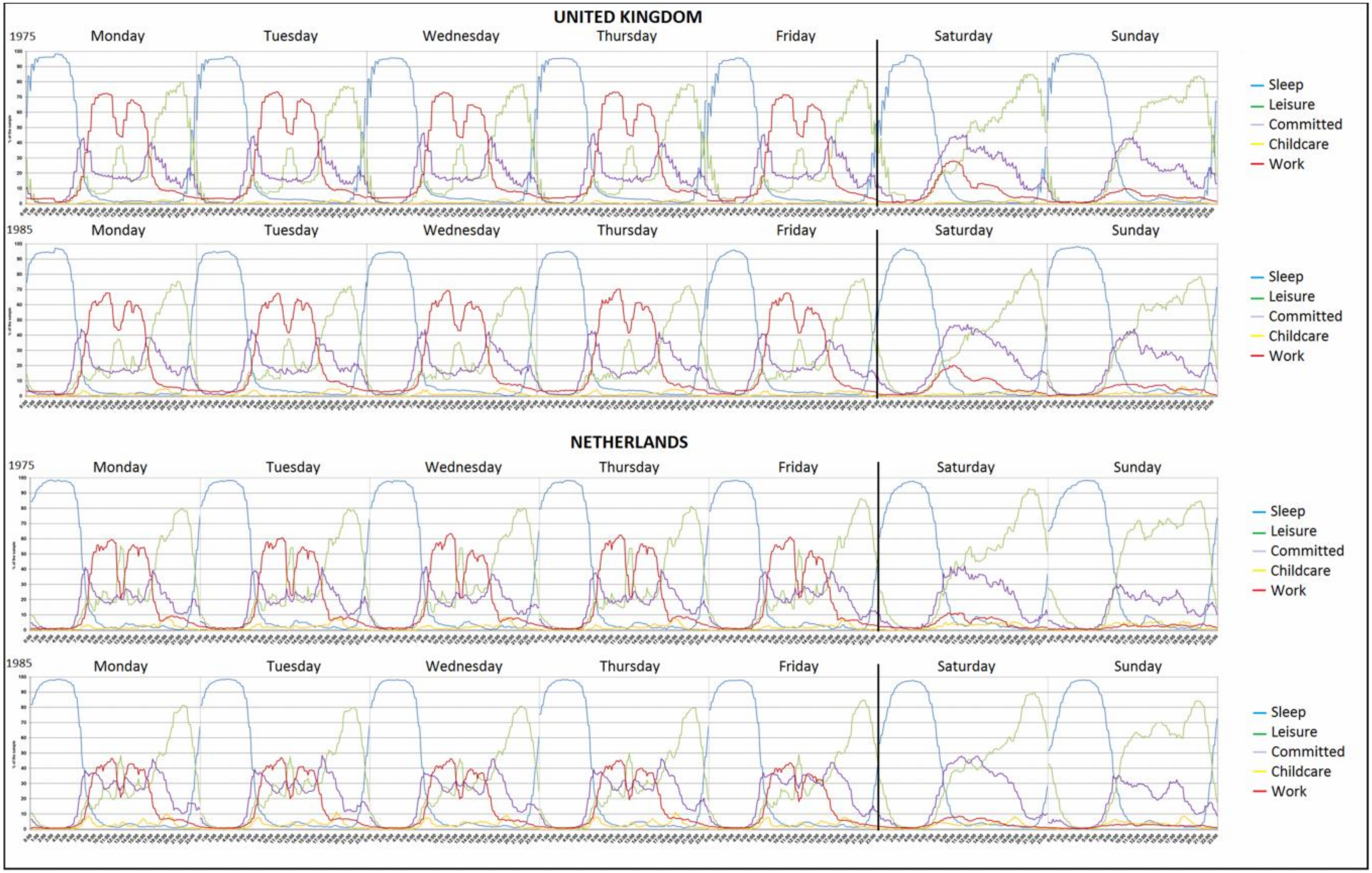

Figure 3.3. Daily activity patterns – 1975 and 1985

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 will use 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 divide each day *d* in 10 minutes intervals and compare every day activities (grouped as in Fig. 3.1) 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:

$$SI_d = \sum_{i=1}^{144} \sum_{a=1}^{5} f(x) \Big/ 720 \qquad d = 1, \ldots, 7 \tag{3.1}$$

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

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 3.4. 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.

Table 3.4. 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**

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 in Table 3.5 for the 1975 British database. The difference between working days, Saturday and Sunday is evident; this occurs in all the nine surveys selected.

Table 3.5. 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

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-day 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-day 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 3.6. 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 3.6 we present the difference – relative to the actually observed week – of the average duration of activities following the different grouping procedures.

Table 3.6. 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

Results in Table 3.6 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 3.7. Again, 3 day diaries (weighted) yield the lowest differences of average duration of activities relative to the week in most cases.

Table 3.7. 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 1975	United Kingdom 1985	Netherlands 1975	Netherlands 1980	Netherlands 1985	Netherlands 1990	Netherlands 1995	Netherlands 2000	Netherlands 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

In order to test whether these pseudo weeks are adequate surrogates for the observed week we have to bring the variances into the picture and perform an Analysis of Variance (ANOVA) in order 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 3.8 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 3.8. 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 3.9 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 3.10. 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, 3 and 7. Results can be seen in Table 3.11. 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 3.9. 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 3.10. 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 3.11. 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 3.12 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).

Table 3.12. 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

To test if these differences are statistically significant, we proceeded to perform the Levene test once again. Results in Table 3.13 show that most variances between these four new constructed periods are significantly different across activities and surveys. However, when just comparing pairs of variances of the four periods instead of all of them together, the variances of the 2-days weighted period and the 3-days weighted period are not significantly different for most activities and surveys but are statistically different when those shorter periods are compared against the week. Finally, the Welch ANOVA test reported in Table 3.14 shows that for most of the nine surveys and the five activities, we cannot reject the equality of means hypothesis.

Table 3.13. 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 3.14. 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

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.

It is essential to recognize that this analysis is being performed in an aggregate level and not for specific segments of the population. Note that it is possible that certain groups have much more variation across weekdays than others; however these differences across segments are not acknowledged in the aggregate.

To know that some segments of the population may have more variation across days can be of use for data collection procedures and analyses. This is because then it would be feasible to have a single weekday collected to cover the entire week for those segments that do not show much variation, and multiple days for those segments that do show more substantial variation. Further research should study the multi-day behaviors of different sociodemographic segments (e.g. per gender and/or age).

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.

3.5. 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-Diaz et al (2008) which we 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:

$$\max_{s.a.} U = \Omega T_w^{\theta_w} \prod_i T_i^{\theta_i} \prod_k X_k^{\eta_k} \tag{3.2}$$

$$I_f + wT_w - \sum_k P_k X_k \geq 0 \rightarrow \lambda \tag{3.3}$$

$$\tau - T_w - \sum_i T_i = 0 \rightarrow \mu \tag{3.4}$$

$$T_i - T_i^{min} \geq 0 \quad \forall i \rightarrow \kappa_i \tag{3.5}$$

$$X_k - X_k^{min} \geq 0 \quad \forall k \rightarrow \varphi_k \tag{3.6}$$

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 equations (3.7)-(3.9) for the time assigned to work (a labour 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.

$$T_w^* = \left[(\tau - T_c)\beta + \frac{E_c}{w}\alpha\right] + \sqrt{\left[(\tau - T_c)\beta + \frac{E_c}{w}\alpha\right]^2 - \frac{E_c}{w}(2\alpha + 2\beta - 1)(\tau - T_c)} \tag{3.7}$$

$$T_i^* = \frac{\widetilde{\theta_i}}{(1 - 2\beta)}(\tau - T_w^* - T_c) \quad \forall i \in I \tag{3.8}$$

$$X_k^* = \frac{\widetilde{\eta_k}(wT_w^* - T_c)}{P_k(1 - 2\alpha)} \quad \forall k \in K \tag{3.9}$$

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 (3.7)-(3.9) can be used as the basis for the estimation of the parameters involved ($\alpha, \beta, \widetilde{\theta_i}$ and $\widetilde{\eta_k}$) 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

$$Value\ of\ Leisure = \frac{\mu}{\lambda} = \frac{\Theta}{\Phi} * \frac{(wT_w^* - E_c)}{(\tau - T_w^* - T_c)} = \frac{(1 - 2\beta)}{(1 - 2\alpha)}\frac{(wT_w^* - E_c)}{(\tau - T_w^* - T_c)} \tag{3.10}$$

$$Value\ of\ Work = \frac{{\partial U}/{\partial T_w}}{\lambda} = \frac{\theta_w}{\Phi} * \frac{(wT_w^* - E_c)}{T_w^*} = \frac{(2\alpha + 2\beta - 1)}{(1 - 2\alpha)}\frac{(wT_w^* - E_c)}{T_w^*} \tag{3.11}$$

As explained in Jara-Diaz et al. (2008), the definitions of Θ, Φ and θ_i provide intuition for equations (3.10) and (3.11), as the value of leisure in (3.10) 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 equations (3.12) and (3.13). Equation (3.12) shows that μ/λ is the value assigned to all leisure activities (for which κ_i/λ is zero) and equation (3.13) 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).

[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.

$$\frac{\kappa_i}{\lambda} = \frac{\mu}{\lambda} - \frac{\partial U / \partial T_i}{\lambda} \quad (3.12)$$

$$\frac{\mu}{\lambda} = w + \frac{\partial U / \partial T_w}{\lambda} \quad (3.13)$$

In order to compare time values across populations controlling for differences in income equation (3.13) can be rewritten as in equation (3.14), 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.

$$\frac{\mu / \lambda}{w} - \frac{\partial U / \partial T_w / \lambda}{w} = 1 \quad (3.14)$$

As explained previously, 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 3.15 and 3.16 show the parameter estimates for every random disjoint group (RDG) as defined formerly, and the values of leisure and work, both in absolute value (obtained from equations 3.10 and 3.11) 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 before[3].

The estimation procedure follows the framework presented in Jara-Diaz et al. (2008). We must assume an error structure to estimate the system comprised by equations (3.7)-(3.9). These errors can come from four different sources: measurement errors in all the observed variables, differences among individuals, specification errors and the randomness inherent to human nature.

Furthermore, these errors can be assumed to add to a Normal additive error term for each equation, because they arise from different independent sources (Jara-Diaz et al., 2008). We believe there are no reasons to assume homoscedasticity among equations, so we included the standard deviations of the error terms for each equation, σ. Moreover, because of the presence of common error sources among equations, we also included a correlation coefficient ρ within a Multivariate Normal error structure.

[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.

As in Jara-Diaz et al. (2008), we calibrated the model with a full information maximum likelihood procedure, allowing for both correlation and heteroscedasticity, which were included in the multivariate normal likelihood function.

Table 3.15. 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 + 2 Weekend Weighted	
	Value	t-est	Value	t-est	Value	t-est	Value	t-est	Value	t-est	Value	t-est
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
Θleisure	0.34	92.26	0.28	44.26	0.37	79.23	0.33	74.60	0.41	88.29	0.33	76.79
σwork	10.44	27.60	2.28	24.28	3.58	26.91	11.29	26.91	5.27	26.94	11.18	27.01
σleisure	9.19	27.60	2.12	24.28	3.42	26.91	11.52	26.91	4.90	26.94	11.18	27.01
ρwork-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/corrrelations	107.15		92.17		51.83		53.69		163.42		132.55	
ρα-β	0.61		0.56		0.56		0.56		0.58		0.58	
Average time values (£/hr)												
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	

Table 3.16. 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 + 2 Weekend Weighted	
	Value	t-est	Value	t-est	Value	t-est	Value	t-est	Value	t-est	Value	t-est
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
Θleisure	0.32	59.41	0.28	30.47	0.35	47.10	0.31	44.47	0.38	54.29	0.31	45.16
σwork	10.19	18.87	1.91	16.24	3.30	18.44	10.83	18.44	5.12	18.55	11.21	18.55
σleisure	9.53	18.87	2.09	16.24	3.64	18.44	12.33	18.44	5.07	18.55	12.24	18.55
ρwork-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/corrrelations	68.18		46.00		29.33		12.65		48.63		79.06	
ρα-β	0.65		0.66		0.66		0.64		0.64		0.63	
Average time values (£/hr)												
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	
(1-2β)/(1-2α)	24.6913		8.4794		15.3765		20.0444		30.2482		34.6538	

To test if the values of time are statistically different among the constructed weeks, we calculated their confidence interval and conducted an independent t-test, shown in Tables 3.17 and 3.18.

Table 3.17. t-test and confidence intervals – 1975 British

UNITED KINGDOM - 1975													
		Week		**1 Day**		**2 Days**		**2 Days weighted**		**3 Days**		**3 Days weighted**	
		t-stat	p-value	t-stat	p-value	t-stat	p-value	t-stat	p-value	t-stat	p-value	t-stat	p-value
VST leisure	Week			3.136	0.001	5.980	0.000	8.041	0.000	3.477	0.000	6.631	0.000
	1 Day	3.136	0.001			4.814	0.000	5.434	0.000	1.920	0.028	3.437	0.000
	2 Days	5.980	0.000	4.814	0.000			1.713	0.043	2.916	0.002	3.187	0.001
	2 Days weighted	8.041	0.000	5.434	0.000	1.713	0.043			1.930	0.027	2.421	0.008
	3 Days	3.477	0.000	1.920	0.028	2.916	0.002	1.930	0.027			0.204	0.419
	3 Days weighted	6.631	0.000	3.437	0.000	3.187	0.001	2.421	0.008	0.204	0.419		
VST work	Week			6.525	0.000	19.482	0.000	20.040	0.000	15.232	0.000	17.330	0.000
	1 Day	6.525	0.000			14.280	0.000	11.887	0.000	6.364	0.000	7.425	0.000
	2 Days	19.482	0.000	14.280	0.000			5.132	0.000	10.184	0.000	9.768	0.000
	2 Days weighted	20.040	0.000	11.887	0.000	5.132	0.000			6.376	0.000	5.781	0.000
	3 Days	15.232	0.000	6.364	0.000	10.184	0.000	6.376	0.000			0.870	0.192
	3 Days weighted	17.330	0.000	7.425	0.000	9.768	0.000	5.781	0.000	0.870	0.192		
Confidence Interval (95%)													
		Lower B	**Upper B**	**Lower B**	**Upper B**	**Lower B**	**Upper B**	**Lower B**	**Upper B**	**Lower B**	**Upper B**	**Lower B**	**Upper B**
VST leisure		1.43	1.61	1.66	2.02	2.78	4.00	2.50	3.10	1.87	2.71	2.12	2.56
VST work		0.32	0.40	0.62	0.82	2.11	2.49	1.57	1.83	1.08	1.28	1.15	1.33

Table 3.18. t-test and confidence intervals – 1985 British

UNITED KINGDOM - 1985													
		Week		**1 Day**		**2 Days**		**2 Days weighted**		**3 Days**		**3 Days weighted**	
		t-stat	p-value	t-stat	p-value	t-stat	p-value	t-stat	p-value	t-stat	p-value	t-stat	p-value
VST leisure	Week			3.716	0.000	4.132	0.000	0.924	0.178	1.908	0.029	1.578	0.058
	1 Day	3.716	0.000			0.815	0.208	3.038	0.001	1.280	0.101	3.291	0.001
	2 Days	4.132	0.000	0.815	0.208			3.525	0.000	1.705	0.045	3.469	0.000
	2 Days weighted	0.924	0.178	3.038	0.001	3.525	0.000			1.139	0.127	2.079	0.019
	3 Days	1.908	0.029	1.280	0.101	1.705	0.045	1.139	0.127			2.594	0.005
	3 Days weighted	1.578	0.058	3.291	0.001	3.469	0.000	2.079	0.019	2.594	0.005		
VST work	Week			9.581	0.000	11.576	0.000	2.403	0.008	6.309	0.000	4.132	0.000
	1 Day	9.581	0.000			1.757	0.040	7.325	0.000	4.646	0.000	8.457	0.000
	2 Days	11.576	0.000	1.757	0.040			9.357	0.000	7.489	0.000	9.017	0.000
	2 Days weighted	2.403	0.008	7.325	0.000	9.357	0.000			3.794	0.000	5.360	0.000
	3 Days	6.309	0.000	4.646	0.000	7.489	0.000	3.794	0.000			7.056	0.000
	3 Days weighted	4.132	0.000	8.457	0.000	9.017	0.000	5.360	0.000	7.056	0.000		
Confidence Interval (95%)													
		Lower B	**Upper B**	**Lower B**	**Upper B**	**Lower B**	**Upper B**	**Lower B**	**Upper B**	**Lower B**	**Upper B**	**Lower B**	**Upper B**
VST leisure		24.18	39.30	13.51	19.29	11.86	17.56	20.83	33.39	14.23	28.81	29.33	66.33
VST work		25.12	30.62	10.96	14.02	10.13	11.75	20.87	25.81	16.11	19.25	36.86	51.14

Results show that, at the mean, 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. Furthermore, the t-test showed that, for 1975, the values of leisure and work for the observed week are significantly different from the five constructed weeks. For 1985, the values of leisure for the observed week are not significantly different from the 2-days weighted and 3-days weighted constructed weeks, and the values of work for the observed week are significantly different from the five constructed weeks. Finally, just among the constructed weeks, we can see that, for 1975, the only pair that is not statistically different are the 3-days and 3-days weighted; for 1985, we have that for the values of leisure, the 1-day constructed week is not different from 2-days and from 3-days pseudo weeks, and 2-days weighted week is not different from 3-days pseudo week, and for the values of work all the pairs are significantly different.

The results shown from Table 3.15 to Table 3.17 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 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 equation 3.10); 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).

3.6. Synthesis and conclusions

The information on how individuals allocate their time is both rich and varied, however the means of generating and collect these data is a subject that has generated much controversy in the specialized literature, particularly regarding the duration of the period of observation. 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 chapter 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, given the amount of available information, 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 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 chapter. 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. Furthermore, we should perform sensitivity analysis on our results given our several assumptions and the imputation procedure we had to conduct due to separate time and money sources.

Moreover, further research should study the multi-day behaviors of different sociodemographic segments. Due to the fact that the analysis of this chapter is being performed in an aggregate level, it is possible we are not acknowledging that certain groups could have much more variation across weekdays than others.

Finally, there is the need to obtain more current data to perform our analysis and model estimations. A proper motivation could be to analyze the evolution of time allocation and values of time over these decades. Up to the moment of the writing of this thesis, the only 7-day surveys were the ones used in this chapter.

Given this recommendation on the period of data recollection, in addition to the systematic review of time use models presented in the previous chapter, we can now continue with the formulation of an integrated and multidisciplinary time allocation and valuation model.

4. TIME ALLOCATION MODEL WITH DATA FROM EXTERNAL AGENTS

4.1. Introduction

The formulation of a more complete time use modeling framework needs the collaboration among different conceptual backgrounds and the incorporation of various disciplinary contributions. This would improve the understanding of individual time allocation and possibly lead to a better evaluation of the decision-making process involving economic activities that so far have not been explicitly incorporated into official accounts, such as household production.

The most important disciplinary interaction improvement of the twentieth century was, to our opinion, the acknowledgement of unpaid/domestic work as a separate discipline of research from labor supply. This activity has been an important topic of discussion in areas such gender studies and household production valuation.

This activity approach, however, has not been properly considered in time use models, even though there have been some efforts to acknowledge home economics as a source of improvement in the modeling and understanding of the value of time, both individual and social (Jara-Diaz, 2008).

To our opinion, accounting for the value of household production and domestic work, and the effect of the trade-off between work and non-work activities such as leisure, should allow a better estimation and improve the interpretation of the value of time. Furthermore, this expansion of current time use model could also benefit from the introduction of (i) explicit domestic production technical constraints and (ii) the interaction among individuals, more specifically, between members of a household and external agents to perform certain activities.

Within the domestic production literature, studies covering collaboration among individuals within a household have presented improvements on current individual modeling frameworks. However, we believe multi-individual interaction lacks an important aspect of time use decisions: time allocated by hired market agents to the individuals' activities.

Some examples of research aimed towards multi-individual collaboration can be found in activity-based transport studies and structural equations models. On one hand, activity-based models have made great progresses in modeling activity and travel interactions between household members (Bhat and Pendyala, 2005). On another hand, structural equations models are applied to examine the interactions in activity participation and travel between household heads (Golob and McNally, 1997) and time allocation to in-home and out-of-home joint activities with family members and non-family members (Fujii et al., 1999). A number of models have been developed to analyze the interactions between household members in activity participation and trade-offs between joint and individual engagement in activities. These include time allocation models of adult household members' participation in and time allocation to independent and joint activities (Gliebe and Koppelman, 2002; Scott and Kanaroglou, 2002); group decision-based models for time allocation to independent, shared and allocated activities (Zhang et al., 2002, 2004); models for the allocation of maintenance activities to household members in terms of who and how (jointly or independently) the maintenance activities are conducted (Bradley and Vovsha, 2005; Srinivasan and Athuru, 2005; Srinivasan and Bhat, 2005, 2006); and tour-based discrete choice models accounting for interactions between household heads (Gliebe and Koppelman, 2005).

All these models have an underlying assumption: there is no external help for household maintenance tasks, household members are supposed to take all these responsibilities. In reality, however, households may hire domestic helpers to take some or most of the household maintenance activities including childcare (Wang and Li, 2009). It is reasonably to believe that if some or most household maintenance responsibilities are taken by domestic helpers, the activity patterns of household members, in particular household heads will be adjusted, if not drastically changed. Some studies have tried advancing in this area but with limited results. For example, Wang and Li (2009) studied households' decision of hiring domestic helpers and the impacts of hiring domestic helpers on time allocation to daily activities, but without considering an income constraint.

We believe the current literature on modeling household activity–travel interactions should be extended to consider the external helps for household maintenance. To the best of our knowledge, no such model is reported yet in the time use model literature. The major objective of this chapter is to develop such a model to analyze how households trade-off between hiring domestic helpers for household maintenance and taking these responsibilities by household members.

Hiring domestic helpers has implications for household income, expenditure and family life. On the one hand, the availability of a helper will release household members, in particular the head, from household maintenance and make it possible for them to spend more time for working to earn more income for the household. They may also enjoy more leisure time and their quality of life may be improved. On the other hand, the presence of a helper may affect the privacy of family life. It may also influence households' spending patterns because hiring a domestic helper can be an important household expenditure commitment.

In order to incorporate this decision on current time use models, one should rely on a base model that can be somehow regarded as a comprehensive framework from which the new model formulation can begin.

4.2. Choosing a base model

Although time use modeling literature has a central point where all studies converge (the expansion of consumer theory), there are many ways to systematize it. In chapter 2 of this thesis we presented an organized way of categorizing time use models, e.g. by their focus on activities. Within this focus, we established the coexistence of two study groups: those in which there is an attempt to study and understand a particular activity and those whose object of study is the use of time as a whole.

If we want to choose a base model from which a contribution can be made to better capture how individuals assign their time, we believe the adequate way is to search within the models that treat time as a whole. This is because the theoretical foundation of these types of models assigns the same importance to every activity and there is no bias towards a focused understanding to a particular time allocation.

Within this group there has been an important evolution of models. The first significant general theory of time allocation was proposed by Becker (1965). This approach has been analyzed, disputed and extended over the decades by many authors, although most of them comply that individual time allocation is derived from the maximization of a household/individual utility function subject to a time constraint and a budget constraint. His model is built from the idea that those constraints are not independent and can be combined into one because the individual can trade leisure time for consumption by working more.

In his formulation, the utility is expressed in terms of commodities, modeled as market goods and time household production functions. Households are at the same time goods producers and utility maximizers. They combine time and market goods through the production function to generate the basic commodities and choose the combination that maximizes their utility. Becker concludes that the value of time is the opportunity cost of working time so is equivalent to the wage rate.

In 1971, DeSerpa proposes an important change from Becker's work. The essential aspects of this new model are: (1) utility is a function of commodities and the time allocated to them; (2) the individual decision is subject to 3 types of constrains: temporal, monetary and technological, which manifests that the choice to consume a specific quantity of any commodity requires a minimum amount of time but the individual can allocate more if wanted. To DeSerpa, the value of time is divided into three concepts: the value of time as a resource, the value of allocating time to an activity and the value of saving time in a restricted activity.

As presented in the previous chapters, in the last decade many studies have expanded the classical consumer theory formulation to concentrate on the study of use and time values in general. After an extensive time use modeling literature review, we chose to consider Jara-Díaz et al., (2008), expanded in Jara-Díaz and Astroza (2013), as our base model because the approach generated by this paper has allowed deriving models of time use from which time values, assigned to activities such as work or leisure, have been empirically obtained. The most interesting property of this model is that it allows estimating the value of leisure and value of work from an explicit system of equations depending on committed expenses, committed time and the wage rate.

4.3. Proposed model

We believe the direction of this new model should head towards two goals: the incorporation of time allocation decisions that go beyond the individuals' own time and overlaps with another individual's time use (i.e. hiring an external agent); and the trade-off between time and money derived by that choice.

The area that best allows us to incorporate these two goals is unpaid work, e.g. domestic production. Although the literature has extensively discussed the relationship between paid work and domestic work, it has mostly limited to conceptual and practical perspectives, and has not been framed in a formal economic model with a clear distinction between domestic work as production input and as a potential source of (dis)utility by itself.

The seminal work of Becker (1965) was the first to introduce the household's allocation of time as an additional constraint into the traditional household utility maximization problem. However, Pollak and Wachter (1975) recognized some limitations of his analysis: namely, that Becker neglected the role of household work at home in his model and did not model the direct disutility of work at home. In addition, Becker assumed that the household could provide market labor supply and this enabled Becker to consolidate the budget constraint and the time constraint into a single constraint and enabled him to value household time in an unambiguous way. In addition, models of domestic production that follows Becker's line, suggest an opportunity cost approach as the most appropriate valuation of this activity.

In Becker's model of consumer behavior, a household purchases X_j units of market commodity j and combines it with a household input of time, T_j, to produce $Z_j = f_j(X_j, T_j)$ units of a finally demanded commodity Z_j for j=1,2,…,N, where f_j is the household production function for the nth finally demanded commodity. Some examples of such finally demanded "produced" commodities are:

- Cooking a meal:
  - Inputs: clean utensils, stove, ingredients, time required to make the meal.
  - Output: prepared meal.
- Reading a book:
  - Inputs: physical or online book, time assigned to reading the book.
  - Output: book read.
- Cleaning the house:
  - Inputs: cleaning utensils and time.
  - Output: clean house.
- Childcare:
  - Inputs: diapers, games, food, time assigned to accompanying children.
  - Output: assisted children.

The model we propose incorporates all activities engaged by the individual, differentiating between market work, domestic work and the rest of activities. We will modify Becker's use of commodities by following Reid's third-party rule (1934) and acknowledging two types of activities that produce finally demanded commodities:

- *Unproductive activities:* Activities that cannot be done by an external agent hired in the market without losing their intrinsic value, such as eating a meal or listening to music.
- *Productive activities*: Activities that can be done either by the individual or by an external agent hired in the market without losing their intrinsic value, such as cleaning the house or childcare. We will refer to this type of activity as ***domestic work***.

Following this terminology, the novelty of our proposed formulation in comparison with the current models in the time use literature, is that we incorporate productive activities (e.g. childcare) and the production of domestic goods within these activities. This might carry a series of challenges:

- First, the potential incorporation of such activity in the utility formulation. Is the time allocated by another agent a source of utility? Should we consider both the own productive time and hired time in the same way in the utility function? How can we incorporate the domestic goods and the intermediate goods used to produce them in the utility function?

- Second, the addition of the time assigned to the productive activity in the monetary and temporal constraints. Is time assigned by another agent just an expense or should we consider the direct time allocated?
- Third, the addition of technological constraints in the model formulation. In terms of adding a domestic goods production function, should the input of hired time be weighted differently from the individual's own time?

Within the first challenge, to consider another individual's time as a source of utility could imply several problems. One might derive pleasure out of another individual's time if we have an appreciation for that person and want them to be satisfied by allocating time to that activity. But this type of formulation is not our current focus. Furthermore, the incorporation of another individual's time could lead to a multi-individual utility function, which is not our goal. In terms of domestic goods, we believe they should be incorporated in the utility function without the distinction if they were produced by the individual or the hired agent. The utility from the goods is drawn from their consumption and not from their generation.

The second challenge covers the topic of budget constraints, temporal and monetary. We believe time allocated by market agents should be an input rather than a part of the analysis. We want to study the decision process of the individual who hires domestic help, not the choice of the market agent to provide such activity. Therefore, time allocated by the external agent should be incorporated as an expense only in the monetary constraint.

Finally, the incorporation of a technological constraint, in this case a production function for domestic goods, leads to the consideration of assessing the contribution of the individual's own productive time, the external agent's time, and the consumption of intermediate goods. We think that the individual and the agent contribute differently in the production of domestic goods, in terms of time and intermediate goods consumed.

With all of these considerations, the proposed model can be formulated as:

$$Max U = \Omega \mathrm{T_w^{\theta_w}} \prod_i T_i^{\theta_i} \prod_d \left(T_d + T_{d_0}\right)^{\theta_d} \prod_j X_j^{\varphi_j} \prod_d Z_d{}^{\varphi_d} \tag{4.1}$$

$$I + wT_w - \sum_d P_d\left(\sigma_d\left[T_d + T_{d_0}\right] + o_d H_d\right) - \sum_j P_j X_j - \sum_d s_d H_d - c_f \geq 0 \leftarrow \lambda \tag{4.2}$$

$$\tau - T_w - \sum_d T_d - \sum_d T_{d_0} - \sum_i T_i = 0 \leftarrow \mu \tag{4.3}$$

$$T_i - T_i^{min} \geq 0 \quad \leftarrow \kappa_i \quad \forall i \tag{4.4}$$

$$X_j - X_j^{min} \geq 0 \quad \leftarrow \eta_j \quad \forall j \tag{4.5}$$

$$\left(\epsilon_d\left[T_d + T_{d_0}\right] + \psi_d H_d\right) - Z_d = 0 \quad \leftarrow \gamma_d \quad \forall d \tag{4.6}$$

In this model, the individual can assign his time to three types of activities: remunerated work, T_w, with its wage rate, w; domestic work (productive activities), T_d; and other activities (unproductive activities), T_i. This last category has a subdivision: those activities that the individual assign more time than the minimum required (leisure activities) and those that stick to the minimum required (restricted activities). Furthermore, we proposed a minimum time assigned to domestic work by the individual, T_{d_0}.

In terms of goods, the individual consumes final goods purchased at the market, X_j, at their respective price, P_j. These goods have a subdivision: those which consumption is greater than the minimum required (free goods), and goods that are consumed at their minimum (restricted goods). Furthermore, there is production and consumption of domestic goods, Z_d, that can be produced using intermediate market goods, Y_d, at their price P_d; time allocated by the individual for the production that good, $(T_d + T_{d_o})$; and/or time assigned by a hired market agent, H_d, with a wage rate of s_d. Moreover, the consumption of these intermediate market goods (Y_d) can be formulated as a function depending on the time allocated by the individual and/or the hired agent to the production of the domestic good d, $Y_d = g_d([T_d + T_{d_0}] + H_d)$[4]. Incorporating this function into the domestic production function and the budget constraint, the generation of domestic goods Z_d can now be presented as being dependent of only time variables (equation 4.6), with ϵ_d being the proportion of domestic good d produced with respect to the time allocated to domestic work by the individual $(T_d + T_{d_0})$, and ψ_d being the proportion of domestic good d produced with respect to the time allocated to domestic work by the external agent (H_d). Additionally, in equation (4.2), σ_d is the proportion of intermediate good d bought with respect to the time allocated to domestic work by the individual $(T_d + T_{d_0})$, and o_d is the proportion of intermediate good bought to produce the domestic good d, with respect to the time allocated to domestic work by the external agent (H_d). I is the income from other sources different than market work and c_f represents the total fixed expenditures, those that do not depend on the goods or services purchased in the period.

The parameters $\lambda, \mu, \kappa, \eta$ and γ are the Lagrange multipliers that represent the change in utility when the corresponding constraint is relaxed in one unit. Therefore, λ is the marginal utility of income, μ is the marginal utility of available time, κ_i is the marginal utility of diminishing the minimum time of activity i in one unit, η_j is the marginal utility of diminishing the minimum consumption of good j in one unit, and γ_d is the marginal utility of the consumption of domestic good d.

Let A^f be the set of freely chosen activities, A^r the set of restricted activities, G^f the set of freely chosen market goods, G^r the set of restricted market goods, and D the set of domestic goods. Following the value of time derivation, and model estimation, first introduced by Jara-Díaz et al. (2015), and presented in Appendix C, we can form a system of $|A^f| + |D| + |G^f| + 1$ equations.

$$\frac{\theta_w}{T_w} + \frac{w * \Phi}{(wT_w - E_c - \sum_d P_d(\sigma_d[T_d + T_{d_0}] + o_d H_d) - \sum_d s_d H_d)} - \frac{\Theta}{(\tau - T_w - \sum_d T_d - T_c)} = 0 \qquad (4.7)$$

$$\frac{\theta_i}{T_i} - \frac{\Theta}{(\tau - T_w - \sum_d T_d - T_c)} = 0 \quad \forall i \in A^f \qquad (4.8)$$

$$\frac{\theta_d}{(T_d + T_{d_0})} + \left(\frac{\epsilon_d}{\psi_d}(s_d + P_d o_d) - P_d \sigma_d\right)\frac{\Phi}{(wT_w - E_c - \sum_d P_d(\sigma_d[T_d + T_{d_0}] + o_d H_d) - \sum_d s_d H_d)} - \frac{\Theta}{(\tau - T_w - \sum_d T_d - T_c)} = 0 \;\forall d \in D \qquad (4.9)$$

[4] This function is not explicitly added in the model because it was incorporated into the budget constraint and the domestic function as an input (see Appendix C).

$$\frac{\varphi_j}{P_j X_j} - \frac{\Phi}{\left(wT_w - E_c - \sum_d P_d\left(\sigma_d\left[T_d + T_{d_0}\right] + o_d H_d\right) - \sum_d s_d H_d\right)} = 0 \; \forall j \in G^f \tag{4.10}$$

Once the system is solved, the value of time as a resource, or value of leisure can be obtained as:

$$\frac{\mu}{\lambda} = \frac{\Theta}{\Phi}\frac{\left(wT_w - E_c - \sum_d P_d\left(\sigma_d\left[T_d + T_{d_0}\right] + o_d H_d\right) - \sum_d s_d H_d\right)}{\left(\tau - T_w - \sum_d T_d - T_c\right)} \tag{4.11}$$

Similarly, the value of work can be formulated as:

$$\frac{\partial U/\partial T_w}{\lambda} = \frac{\mu}{\lambda} - w \tag{4.12}$$

It is worth noting that in the case of not hiring external help to perform any domestic activity $(H_d = 0 \; \forall d)$ and considering intermediate goods $(Y_d \; \forall d)$ and domestic activities $\left(T_d + T_{d_0} \; \forall d\right)$ as committed expenses and committed time respectively, the value of time as expressed in equation (4.11) collapses to the value of time expressed in equation (3.10).

$$\frac{\mu}{\lambda} = \frac{\Theta}{\Phi}\frac{\left(wT_w - E_c - \sum_d P_d\left(\sigma_d\left[T_d + T_{d_0}\right] + o_d H_d\right) - \sum_d s_d H_d\right)}{\left(\tau - T_w - \sum_d T_d - T_c\right)} = \frac{\Theta}{\Phi} \cdot \frac{(wT_w - E_c)}{(\tau - T_w - T_c)} \tag{4.13}$$

4.4. Data

In the previous chapter we performed an inspection of the many datasets available online and focused on those that contained the basic work-leisure cycle, i.e. weekly data for the same individual (7-days diaries). However, these datasets did not contain the minimum data required regarding income and expenses, so we had to perform an imputation process with complementary information. To properly estimate our proposed model we searched for databases with overall time allocation data, and detailed information regarding income and expenses.

The information used for the analysis is drawn from the LISS panel data. The LISS panel is a representative sample of Dutch individuals who participate in monthly Internet surveys (households that could not otherwise participate are provided with a computer and Internet connection). The panel is based on a true probability sample of households drawn from the population register, and its first wave was conducted on 2008. A longitudinal survey is fielded in the panel every year, covering a large variety of domains including work, education, income, housing, time use, political views, values and personality.

The LISS panel also includes specific questionnaires designed by researchers with the purpose of identifying specific behavioral conducts or preferences. Among these studies, Cherchye *et al*. (2012) designed a survey on time use and consumption. The first wave of these questionnaires was implemented on September 2009. A second wave was conducted on September 2010, and a third on October 2012. In this study, we will analyze all waves. Respondents reported (1) the time allocated to 13 activities (including work) during the past seven days before the survey, and (2) the average monthly expenditure (in euros) in 30 categories, considering as reference the past 12 months. The time use and consumption data was complemented with socio-demographic information drawn from the LISS panel.

The 13 activities available in the original database were grouped into the 11 following activities (three activities –helping parents, helping family members and helping non-family members– were combined into one –assisting friend and family– due to low participation):

1) Work: includes any type of paid work as an employee or as a self-employed worker. The reported time includes over hours.
2) Commute: travel to and from work.
3) Household chores: includes cleaning, shopping, cooking, gardening, etc.
4) Personal care: includes washing, dressing, eating, visiting the hairdresser, seeing the doctor, etc.
5) Education: includes day or evening courses, professional courses, language courses or other course types, doing homework, etc.
6) Activities with children: any activity with own children aged less than 16 years, such as washing, dressing, playing, taking child to see doctor, taking child to school/hobby activities, etc.
7) Entertainment: includes in-home and out-of-home recreational activities, such as watching TV, reading, practicing sports, hobbies, computer as hobby, visiting family or friends, going out, walking the dog, cycling, sex, etc.
8) Assisting friends and family: assistance to friends and family members (not children). For example: helping with administrative chores, washing, dressing, seeing the doctor, voluntary work, babysitting, etc.
9) Administrative chores and family finances.
10) Sleeping and relaxing: includes sleeping, resting, thinking, meditating, being ill, etc.
11) Other activities: any activity not considered above.

Furthermore, because of the model's requirement of hired time for domestic work activities, we imputed a last category. For this case, the only domestic activity with available information on external market agents was childcare.

12) Hired Childcare: includes children's external daycare.

This last activity was calculated dividing the weekly expense on children's external daycare by the average hourly cost of external childcare in Netherlands. This is about 6.5 Euros in average according to several sources (Expatica, 2015; Expats Amsterdam, 2015; Passionate Parenting, 2015), and has been constant during the analyzed period (2009-2012).

The first wave of surveys on time use and consumption was delivered to 9,030 households. Out of these households, 38% did not answer the survey and 3% returned incomplete surveys. As a result, the number of individuals available for the analysis with a complete response is 5,337. The second wave was provided to 7,540 households, where 29.2% did not answer the survey and 3.1% returned incomplete surveys. The number of individuals with a complete response is 5,103. The third wave was distributed to 6,874 households. From these households, 20.5% did not answer the survey and 2.3% returned incomplete surveys. Finally, the number of individuals with a complete response is 5,306.

The sample used to estimate our model considered individuals who worked at least half an hour during the survey week and who reported expenditure in at least one of the expenditure categories. Further, we selected workers who live in one-worker households (with its income being the same as the household's income). This last criterion allows assigning all personal and household expenditures to the only worker in the household, without making assumptions regarding how the household expenditures are shared among income producers. Because the timeframe of our study is a week, we selected datasets where time allocation is reported on a weekly basis. Monthly expenditures and monthly income are divided by four to obtain weekly expenditures and weekly income, respectively.

The database includes the worker's monthly average gross and net income. For the analysis, only net income is considered. Henceforth, net income is referred as income. Income is disaggregated into salary (wT_w) and non-work income (I): salary is obtained from working (for an employer or independently) and it is used to compute the wage rate w. Non-work income corresponds to the earnings received from pensions, investments, annuities, governmental support, scholarships, tax reimbursement and others non-work related sources drawn from another database in the LISS panel.

Several consistency checks were performed to obtain the estimation sample removing workers following this criterion regarding data reported:

- Relevant missing data (such as income and time allocation).
- More than 168 hours declared on their week.
- Total expenses higher than total income.
- Less than 4 hours average sleep time per day.
- Extremely high activity duration reported (e.g., some people reported working 168 hours per week).
- Wage lower than 3 euros/hour (the minimum hourly wage in Netherlands was about 8.4 euros in 2012).
- No child living at home. This was done because, due to the available information, the only domestic work activity that allowed the option of hiring external help was childcare.
- No time allocated to activities with children.

After this selection process, the estimation sample has 101 workers for the first wave, 86 workers for the second wave and 114 workers for the third one.

To incorporate the novelty constraint in our model, we need the expenditure allocated to each activity purpose during the survey week. The LISS panel database contains detailed information about expenditure in 30 distinct categories, but these categories do not directly relate to the activity purposes listed above. Consequently, we needed to associate the expenditures to activities. For this purpose, the expenditure categories were studied in detail to assess those that matched the description of the activities. In addition, we computed the fixed expenditures (c_f) as those expenditures not related with any activity purpose. Details about the association procedure and the definition of c_f can be found in Appendix D.

To better estimate the model it is necessary to classify the 11 non-work activities into the sets defined beforehand. This classification is presented in Table 4.1. The set of activities restricted in expenses and time, therefore conforming the *committed time* (T_c) and *committed expenses* (E_c) items, comprises the following 6 activities: commute, household chores, personal care, education, assisting friends and family, and administrative chores and family finances. The set of unrestricted activities can be further divided into unproductive and productive activities (according to the classification previously proposed). Entertainment, sleeping and relaxing, and other, are considered *unproductive* (leisure activities), while childcare is the only *productive* (domestic work) activity that presents information on hired market agents according to the database used. This classification is based on the fact that, as mentioned in the previous section, the novelty of our proposed model is the introduction of the choice to hire external help to assist in the production of domestic goods. In this case, the domestic good produced is childcare.

Table 4.1. Classification of activities

Sets	Activities
Restricted Activities - *Committed* (A^r)	Commute
	Personal Care
	Education
	Household Chores
	Assisting friends and family
	Administrative chores and family finances
Unrestricted Activities - *Unproductive / Leisure* (A^f)	Sleeping and relaxing
	Other activities
	Entertainment
Unrestricted Activities - *Productive / Domestic* (*D*)	Activities with children (own childcare)
	Activities with children (hired childcare)

The descriptive statistics of time use and expenditure for all individuals who participated in the activity are presented in Tables 4.2, 4.3 and 4.4. By construction, all individuals allocate time to work, and sleeping and relaxing: on average, individuals work between 6.8 and 7.8 hours per weekday and sleep/relax between 7.8 and 8.2 hours per day. In addition, all workers spend time in personal care activities (recall that this activity type includes eating and dressing) and activities with children (all workers live with at least one child at home). Most workers allocate some time to commute, entertainment, and household chores, while education and hired childcare present the lowest participation rates. Regarding expenditure, personal care and activities with children presents the highest values. Although people spend a relatively large amount of money in entertainment activities, these represent only an expenditure rate of between 1.2 and 1.4 euros/hour, which is considerable lower than the average wage of between 13 and 16 euros/hour.

Table 4.2. Descriptive statistics for the first wave (2009)

Activity	Participation (%)	Duration (hours/week)				Participation (%)	Expenditure (euros/week)			
		Mean	St. Dev.	Min	Max		Mean	St. Dev.	Min	Max
Work	**100.00**	**38.82**	**13.37**	**6.00**	**75.00**	-	-	-	-	-
Committed	**72.61**	**45.00**	**7.85**	**0.25**	**71.00**	**53.96**	**29.50**	**30.55**	**0.90**	**157.50**
Commute	*93.45*	*6.45*	*8.10*	*0.25*	*71.00*	*64.36*	*13.87*	*16.03*	*0.90*	*108.00*
Household Chores	*95.05*	*9.98*	*8.39*	*0.50*	*36.00*	*45.54*	*12.68*	*16.17*	*1.25*	*75.00*
Personal Care	*100.00*	*8.10*	*5.83*	*1.00*	*28.00*	*98.02*	*48.52*	*32.94*	*1.75*	*157.50*
Education	*23.43*	*11.28*	*14.38*	*2.00*	*64.00*	*7.92*	*17.66*	*17.20*	*1.25*	*50.00*
Assisting family and friends	*51.58*	*6.56*	*8.06*	*0.50*	*40.00*	-	-	-	-	-
Administrative chores and family finances	*72.16*	*2.62*	*2.33*	*0.50*	*14.00*	-	-	-	-	-
Leisure	**82.51**	**97.75**	**21.01**	**1.00**	**90.00**	**93.07**	**35.97**	**34.11**	**2.50**	**167.50**
Entertainment	*100.00*	*25.29*	*14.62*	*2.00*	*66.00*	*93.07*	*35.97*	*34.11*	*2.50*	*167.50*
Sleeping and Relaxing	*100.00*	*54.74*	*11.54*	*30.00*	*90.00*	-	-	-	-	-
Other Activities	*47.54*	*17.72*	*15.73*	*1.00*	*59.00*	-	-	-	-	-
Own childcare	**100.00**	**12.10**	**8.58**	**1.00**	**40.00**	**20.79**	**43.13**	**30.75**	**13.75**	**125.00**
Hired childcare	**5.94**	**6.57**	**7.10**	**0.96**	**20.38**	**5.94**	**43.75**	**45.21**	**12.50**	**132.50**
Fixed expenditures	-	-	-	-	-	81.19	303.45	327.39	2.50	2642.00
Non-work income	-	-	-	-	-	43.56	153.45	226.74	2.88	1142.31
Wage	-	-	-	-	-	100.00	13.22	6.52	3.68	41.67
Number of observations	**101**									

Table 4.3. Descriptive statistics for the second wave (2010)

Activity	Participation (%)	Duration (hours/week)				Participation (%)	Expenditure (euros/week)			
		Mean	St. Dev.	Min	Max		Mean	St. Dev.	Min	Max
Work	**100.00**	**34.26**	**15.09**	**4.00**	**84.00**	**-**	**-**	**-**	**-**	**-**
Committed	**76.69**	**48.88**	**7.00**	**0.17**	**45.00**	**48.55**	**31.04**	**30.02**	**0.90**	**125.00**
Commute	*93.02*	*6.77*	*6.32*	*0.25*	*30.00*	*53.49*	*10.17*	*7.35*	*0.90*	*31.50*
Household Chores	*93.05*	*11.17*	*8.76*	*1.00*	*45.00*	*40.70*	*13.09*	*14.74*	*1.25*	*75.00*
Personal Care	*100.00*	*7.78*	*4.77*	*1.00*	*28.00*	*95.35*	*51.10*	*30.16*	*3.75*	*125.00*
Education	*24.76*	*12.14*	*10.58*	*1.00*	*31.00*	*4.65*	*16.88*	*17.37*	*2.50*	*37.50*
Assisting family and friends	*61.63*	*7.67*	*5.75*	*0.42*	*21.00*	-	-	-	-	-
Administrative chores and family finances	*87.70*	*3.36*	*3.89*	*0.17*	*25.00*	-	-	-	-	-
Leisure	**80.39**	**102.25**	**22.18**	**0.75**	**115.75**	**90.70**	**31.01**	**33.31**	**2.50**	**187.50**
Entertainment	*98.33*	*26.11*	*15.61*	*2.00*	*84.00*	*90.70*	*31.01*	*33.31*	*2.50*	*187.50*
Sleeping and Relaxing	*100.00*	*56.70*	*13.08*	*30.00*	*115.75*	-	-	-	-	-
Other Activities	*42.84*	*19.44*	*17.93*	*0.75*	*67.00*	-	-	-	-	-
Own childcare	**100.00**	**10.78**	**9.81**	**0.50**	**55.00**	**51.16**	**94.59**	**17.10**	**10.00**	**100.00**
Hired childcare	**3.49**	**2.82**	**3.13**	**0.38**	**6.35**	**3.49**	**22.92**	**18.13**	**5.00**	**41.25**
Fixed expenditures	-	-	-	-	-	70.93	263.95	143.27	13.25	659.50
Non-work income	-	-	-	-	-	44.19	119.03	106.61	1.92	371.25
Wage	-	-	-	-	-	100.00	16.06	11.66	3.25	70.37
Number of observations	**86**									

Table 4.4. Descriptive statistics for the third wave (2012)

Activity	Participation (%)	Duration (hours/week)				Participation (%)	Expenditure (euros/week)			
		Mean	St. Dev.	Min	Max		Mean	St. Dev.	Min	Max
Work	**100.00**	**37.54**	**12.57**	**2.00**	**82.00**	**-**	**-**	**-**	**-**	**-**
Committed	**76.03**	**44.59**	**7.22**	**0.25**	**50.00**	**55.92**	**33.93**	**39.33**	**0.45**	**325.00**
Commute	89.55	4.94	3.97	0.50	25.00	66.67	13.20	10.33	0.45	49.50
Household Chores	96.54	10.05	8.70	0.58	50.00	49.12	10.18	10.32	1.25	45.00
Personal Care	100.00	8.56	6.06	1.00	30.00	97.37	61.29	44.88	2.50	325.00
Education	33.91	10.60	11.54	1.00	48.50	10.53	23.08	28.24	2.50	100.00
Assisting family and friends	56.14	7.27	7.07	0.25	34.00	-	-	-	-	-
Administrative chores and family finances	80.03	3.16	4.02	0.25	30.00	-	-	-	-	-
Leisure	**82.42**	**97.55**	**21.86**	**1.00**	**87.50**	**91.23**	**33.55**	**29.66**	**1.00**	**142.50**
Entertainment	99.38	26.99	14.23	4.00	85.00	91.23	33.55	29.66	1.00	142.50
Sleeping and Relaxing	100.00	57.34	10.20	34.00	87.50	-	-	-	-	-
Other Activities	47.89	13.22	13.47	1.00	54.92	-	-	-	-	-
Own childcare	**100.00**	**10.08**	**9.27**	**0.50**	**50.00**	**24.56**	**32.70**	**31.51**	**8.75**	**140.00**
Hired childcare	**6.14**	**5.80**	**7.43**	**0.38**	**21.15**	**6.14**	**38.93**	**47.37**	**5.00**	**137.50**
Fixed expenditures	-	-	-	-	-	86.84	305.63	176.01	2.40	683.00
Non-work income	-	-	-	-	-	42.98	168.62	335.59	2.17	2134.62
Wage	-	-	-	-	-	100.00	16.11	23.01	2.94	244.38
Number of observations	**114**									

4.5. Results and Analysis

To properly estimate the model, some issues have to be considered: first, it is required that workers allocate some positive time to unproductive activities. Then, to estimate the model, a small time (0.3 hours) was appended to those activities for workers who did not allocate time to it; second, given the information available, equation (4.10) cannot be estimated when there is only one good in the set of unproductive unrestricted time with unrestricted expenses (Entertainment).

Consequently, there are four dependent variables in our system: time assigned to work (T_w), time assigned to entertainment ($T_{entertainment}$), time assigned to sleeping and relaxing (T_{sleep}), and time assigned to domestic work, in this case childcare ($T_{childcare}$). There are five utility parameters ($\tilde{\theta}_w$, $\tilde{\theta}_{entertainment}$, $\tilde{\theta}_{sleep}$, $\tilde{\theta}_{childcare}$ and $\tilde{\Phi}$).

Table 4.5 presents the model estimation results for the entire sample and the three separate waves. The upper section of the table presents the model parameters, the lower section displays the average values of time computed using equations (4.11) and (4.12). The table shows that all parameters are statistically significant at the 95% level of confidence. Regarding values of time, both the mean value of leisure and the mean value of work are positive for all samples; consequently, workers considered in the analysis extract pleasure (at the margin) from working and undertaking leisure activities in all waves. Furthermore, to test if the values of time are statistically different among waves, we calculated their confidence interval and conducted an independent t-test, shown in Table 4.6. Results show that for both the value of leisure and work, wave 3 is not statistically different from wave 1 and from the total sample.

Table 4.5. Model estimation results for all individuals in all waves

Model parameters								
Coefficients	Total sample		Wave 1		Wave 2		Wave 3	
	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
θwork	14.181	5.506	17.972	6.726	14.129	6.466	10.861	3.701
θentertainment	6.475	4.355	3.440	3.725	5.263	4.505	7.437	4.853
θsleep	14.882	3.927	12.424	2.403	17.484	3.019	18.423	3.585
θchildcare	3.320	6.412	2.382	5.860	2.890	7.037	2.135	8.462
Φ	8.211	16.172	11.425	20.856	4.519	12.004	10.522	20.606
Mean log-Likelihood	-6.389		-5.678		-5.335		-5.965	
Average values of time [euros/hr]								
	Estimate	Std. Dev	Estimate	Std. Dev	Estimate	Std. Dev	Estimate	Std. Dev
Value of Leisure	28.926	42.494	38.607	39.388	16.386	26.316	32.162	64.738
Value of Work	13.802	46.331	25.387	38.027	0.329	23.365	16.054	66.488
Wage Rate	15.124	15.802	13.219	6.515	16.057	11.664	16.107	23.013
Ratio VoL - wage	1.913		2.920		1.020		1.997	
Ratio VoW - wage	0.913		1.920		0.020		0.997	
Number of observations	301		101		86		114	

Table 4.6. t-test and confidence intervals for all waves

		Total sample		Wave 1		Wave 2		Wave 3	
		t-stat	p-value	t-stat	p-value	t-stat	p-value	t-stat	p-value
VST leisure	Total sample			2.095	0.019	3.345	0.000	0.495	0.310
	Wave 1	2.095	0.019			4.592	0.000	0.893	0.186
	Wave 2	3.345	0.000	4.592	0.000			2.357	0.010
	Wave 3	0.495	0.310	0.893	0.186	2.357	0.010		
VST work	Total sample			2.501	0.006	3.670	0.000	0.332	0.370
	Wave 1	2.501	0.006			5.512	0.000	1.281	0.101
	Wave 2	3.670	0.000	5.512	0.000			2.341	0.010
	Wave 3	0.332	0.370	1.281	0.101	2.341	0.010		
Confidence Interval (95%)									
		Lower B	**Upper B**	**Lower B**	**Upper B**	**Lower B**	**Upper B**	**Lower B**	**Upper B**
VST leisure		24.13	33.73	30.94	46.30	10.83	21.96	20.28	44.06
VST work		8.58	19.05	17.97	32.84	-4.61	5.28	3.86	28.26

The interpretation for these different values of leisure and work is not straightforward, as many variables are involved including not only marginal utilities for work and leisure but also the wage rate and the marginal utility of income. The first important observation is that the value of leisure is positive (as expected) for all waves and significantly different from the wage rate for waves 1 and 3. In addition, the ratio Value of Leisure / Wage varies between one and three, and the value of time assigned to work is practically zero in 2010.

Our results can be analyzed integrating information from three different angles: first, an analysis of the context in which the individuals of our sample are immersed; second, a comparison with a model that does not incorporate the choice of hiring external help; third, studying the evolution of individual behavior, by estimating the proposed model for a group of workers that answered the survey for all waves.

Regarding the context, Tables 4.2, 4.3 and 4.4 present a summary and the evolution of wages and the average time allocated to different activities across waves. Through the years, the average wage rates are constantly rising, although the mean wage in wave 3 is almost the same as in wave 2. Time allocated to work and hired childcare decrease from 2009 to 2010 and increase from 2010 and 2012. On another hand, leisure and committed activities increase from 2009 to 2010 and decrease from 2010 and 2012.

There is one issue that we believe stands out: the decrease of average working hours with an increase in wage rate from wave 1 to wave 2 is followed by an increase of both average working hours and wage rate from wave 2 to wave 3.

The relation between wage rate and working hours can be looked at through the eyes of the backward bending supply curve of labor theory. According to Varian (2010), when the wage rate increases there are two effects: the return to working more increase and the cost of consuming leisure increases. When the wage rate increases, leisure becomes more expensive, which by itself leads people to want less of it (the substitution effect). Since leisure is a normal good, we would then predict that an increase in the wage rate would necessarily lead to a decrease in the demand for leisure—that is, an increase in the supply of labor. But as the labor supply increases, each increase in the wage gives the consumer additional income for all the hours he is working, so that after some point he may well decide to use this extra income to "purchase" additional leisure—that is, to reduce his supply of labor (the income effect). When the wage rate is small, the substitution effect is larger than the income effect, and an increase in the wage will decrease the demand for leisure and hence increase the supply of labor. But for larger wage rates the income effect may outweigh the substitution effect, and an increase in the wage will reduce the supply of labor.

The backward bending supply curve of labor could also be looked at through the eyes of the values of time. In the upper part of the curve, where the income effect dominates, individuals are willing to sacrifice labor time in favor of allocating more hours to non-paid time, suggesting a higher value of leisure than those present in the lower part of the curve, where the substitution effect is more powerful and individuals substitute leisure time in favor of labor with higher wages.

Figure 4.1 presents a graphical description of two possible scenarios of our data regarding wage and working time for the three waves (presented in Table 4.7). Note that the average wages in waves 2 and 3 are almost identical.

In scenario a), wages from waves 2 and 3 are above the breaking point between income and substitution effect, and the average wage from wave 1 is below that point. According to the explanation presented before, one would expect that the values of leisure of individuals from waves 2 and 3, in the upper part of the curve, are higher than the values from individuals in wave 1, in the lower part of the curve. As we can see in Table 4.5, wave 1 presents the highest values of leisure and work among the 3 waves, therefore suggesting that the representation of our data with scenario a) is incorrect.

In scenario b), all wages are relatively high above the breaking point between income and substitution effect. This would mean that, in average, all individuals are trading working hours for leisure hours, therefore valuing leisure time highly. For this scenario to happen, the level of wages for all waves must be well above a minimum wage, thus enticing people to work less and to consume more leisure or non-paid time. Furthermore, in terms of values of time, individuals from wave 1 should have the lowest values of leisure and work, therefore allocating more working hours at the lowest average wage rate of all the waves. The fact is that (1) wages from all waves are not significantly higher than the Dutch minimum wage, around 8.4 euros/hour in 2012 (Numbeo, 2015), and (2) the highest values of leisure and work are present in individuals from wave 1 (Table 4.5), so that this scenario also seems unlikely. Let us explore this further.

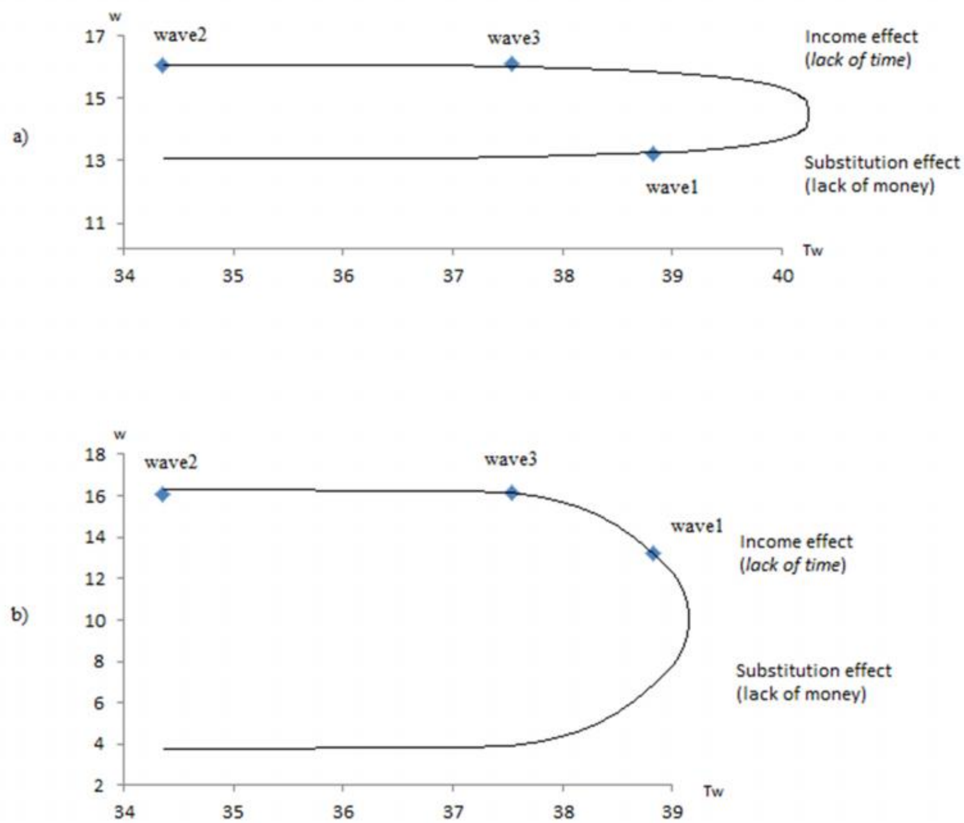

Figure 4.1. Back bending labor supply curve with our data

Table 4.7. Wage rate and working hours for all waves

	Wage rate (euros/hour)	**Working time** (hours/week)
Wave 1 (2009)	13.22	38.82
Wave 2 (2010)	16.06	34.26
Wave 3 (2012)	16.11	37.54

According to Numbeo (2015), in its "Cost of Living in Netherlands" analysis, the adequate average monthly disposable salary (almost constant since 2008) for an individual to adequately live satisfying basic needs should be 2,241.85 euros or 14.74 euros/hour for a 38-hour working week (16.48 euros/hour for a 34-hour working week). In our study, waves 1 and 2 do not present such minimum adequate income, with an average wage rate of 13.22 euros/hour and a mean of 38.82 working hours/week for wave 1, and an average wage rate of 16.06 euros/hour with a mean of 34.26 working hour/week for wave 2. Wave 3 is the only subset with an average income higher than the adequate monthly disposable salary (wage rate of 16.11 euros/hour with a mean of 37.5 working hours/week), a fact that one would expect because, in average, wage rates increase over time. However, when considering that all of the workers in all waves are living with at least one child, the disposable income per person becomes lower than adequate levels.

Within the literature on labor supply, one can find theories that relate the wage rate and the hours of work in the conditions present in our waves. One of the theories that offer an explanation for the behavior detected in our study is Dessing (2002). She states that the canonical labor supply model of textbooks is, in fact, incomplete; it fails to capture the observed behavior of poor people. According to the textbook model poor people would work less. In practice, the opposite is often observed in less industrialized countries, but also in wealthier countries especially during economic downturns. Dessing's model presents a negative labor supply response al low-income levels, describing the behavior of individuals working with wages between the subsistence level and the area where wages are high enough to be explained by the classical backward-bending curve, thereby building on the S-shaped labor supply that can be viewed in Figure 4.2.

Following Fig. 4.2, the model predicts that at low wage rates, workers allocate less labor when wages increase (segment B-C'); and at higher wage rates, individuals offer more work to the labor market when wage rates increase (segment C'-C), thus complementing the classical backward-bending labor supply curve theory (segment C-D-E), first presented by Robbins (1930).

People in impoverished circumstances appear to be working longer hours as wages fall to maintain income constant or even increasing it; therefore displaying negative labor supply elasticity. When dealing with individuals just above the subsistence level, they work just enough to earn a target or subsistence income and therefore reduce their work hours when wages increase (Chelintsev, 1918; Boeke, 1953; Berg, 1961; Mellor, 1963; Myrdal, 1971).

The behavior of our data follows Dessing's model, with average wage rates of all waves above the subsistence level but not relatively high (Fig. 4.3). Within this scenario, from 2009 to 2010, as wages increase, the family decreases its supply of labor to maintain the level of income constant. From 2010 to 2012, individuals increase working hours with higher wage rates. This behavior can be partially explained by the economic crisis that the Netherlands suffered in those years (Hagina, 2013; CPB, 2009). This crisis started in 2008 and has affected the overall economy of the country, ranging from employment to childcare allowances (Statistics Netherlands, 2015).

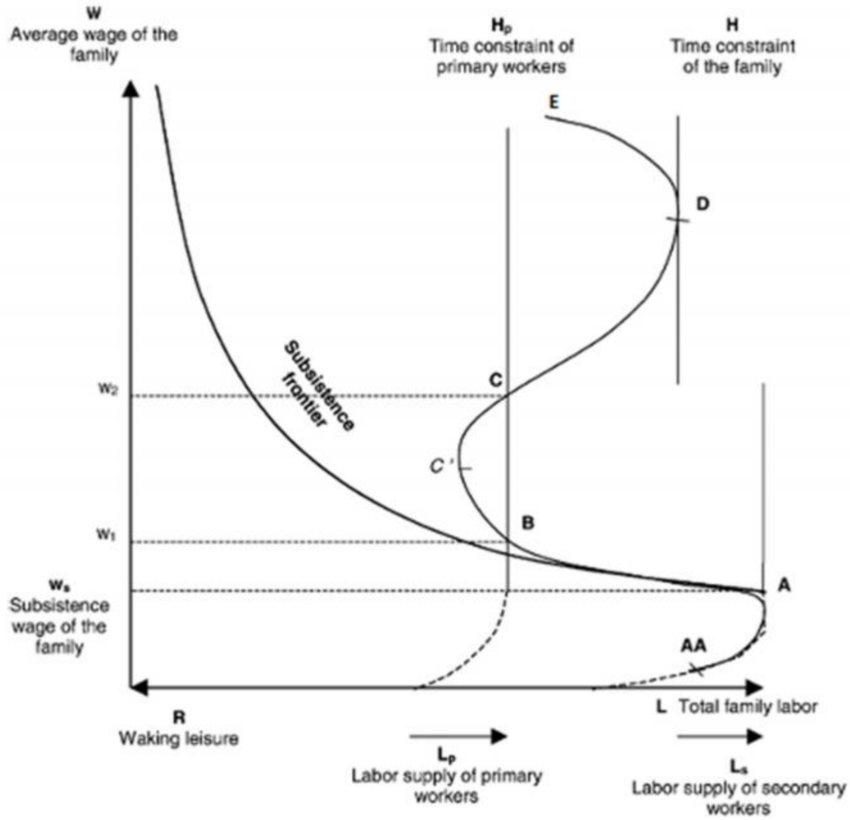

Figure 4.2. Labor supply model according to Dessing (2002)

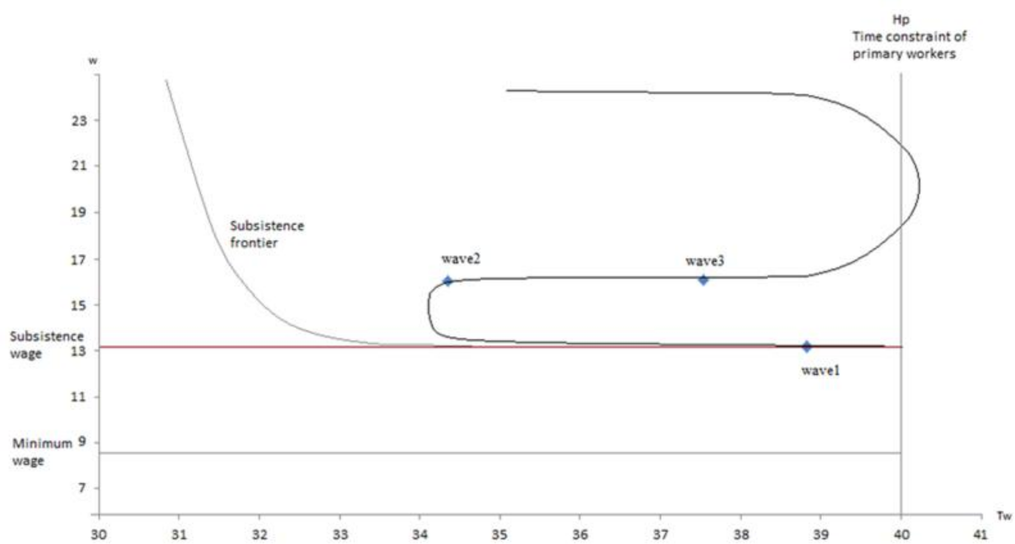

Figure 4.3. Labor supply model according to Dessing (2002) matched with our data

Next in the analysis of our results is the comparison of our results with a model that does not incorporate the choice of hiring external help, as developed by Jara-Díaz et al. (2008). We computed the corresponding values of time following the activity classification previously presented when describing the data.

The novelty of the new model presents the advantage of not needing to determine *a priori* if productive activities (e.g. childcare), are committed or unrestricted activities. Furthermore, when estimating the base model, we had two different scenarios: first, childcare is a committed activity with committed expenses (Table 4.8); second, childcare is regarded as an unrestricted activity with unrestricted expenses (Table 4.9). In both scenarios, the cost of hiring external childcare is classified as committed expenses.

Table 4.8. Model estimation results with no external agent, childcare as committed expenses and committed time

Model parameters								
Coefficients	Total sample		Wave 1		Wave 2		Wave 3	
	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
α	0.464	35.387	0.453	34.414	0.471	36.029	0.468	35.764
β	0.114	15.308	0.124	16.368	0.107	13.327	0.112	15.863
ϴentertainment	0.455	34.580	0.470	35.129	0.442	34.269	0.451	34.328
ϴsleep	0.441	32.548	0.453	32.451	0.425	31.027	0.442	33.782
Mean log-likelihood	-8.249		-8.452		-7.905		-8.329	
Average values of time [euros/hr]								
	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
Value of Leisure	70.233	2.766	81.456	3.170	55.141	2.941	74.834	2.813
Value of Work	55.109	2.298	68.237	2.782	29.894	2.253	58.727	2.125
Wage Rate	15.124		13.219		16.057		16.107	
Ratio VoL - wage	4.64		6.16		3.43		4.65	
Ratio VoW - wage	3.64		5.16		1.86		3.65	
Sample size	301		101		86		114	

Table 4.9. Model estimation results with no external agent, childcare as an unrestricted activity

Model parameters								
Coefficients	Total sample		Wave 1		Wave 2		Wave 3	
	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
α	0.433	35.575	0.401	35.832	0.428	34.001	0.465	36.534
β	0.111	17.466	0.116	17.377	0.129	18.052	0.093	17.102
ϴentertainment	0.724	31.183	0.752	29.033	0.703	34.381	0.715	30.676
ϴsleep	0.337	29.051	0.265	27.162	0.338	28.139	0.399	31.412
ϴchildcare	0.210	24.927	0.212	23.746	0.180	24.083	0.230	26.610
ηentertainment	0.107	14.718	0.118	13.752	0.098	15.041	0.104	15.329
Mean log-likelihood	-9.019		-8.684		-8.540		-8.111	
Average values of time [euros/hr]								
	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
Value of Leisure	39.117	2.875	46.722	3.155	27.801	2.924	38.276	2.780
Value of Work	23.994	2.535	33.503	2.758	11.744	2.088	22.169	2.436
Wage Rate	15.124		13.219		16.057		16.107	
Ratio VoL - wage	2.59		3.53		1.73		2.38	
Ratio VoW - wage	1.59		2.53		0.73		1.38	
Sample size	301		101		86		114	

Results show that, for the model based on Jara-Díaz et al. (2008), the values of leisure and work for the first scenario (i.e. childcare as a component of committed time and committed expenses), are almost 80% higher, on average, than the values of time for the second scenario (i.e. childcare is considered an unrestricted activity). In terms of the temporal evolution of the results, we can see the same trend occurs in every model estimated (new model and both scenarios of the base model). The values of leisure and work are lower on the second wave.

If we compare the values of leisure and work between the new model and both scenarios analyzed from the base model, we can identify a clear difference: the model without the externalization of domestic activity (*base model*) overestimates the values of time. In other words, when omitting the possibility of hiring another person, the model cannot correctly capture the individual valuation of time. Furthermore, the first scenario has a higher overestimation of time values than the second scenario.

A possible explanation of a lower overestimation of the second scenario could be the fact that, as with the new model, childcare is an unrestricted activity with unrestricted expenses. The difference, however, could be due to childcare being part of a new set of activities: productive ones.

These results show the importance of acknowledging time allocated to productive activities such as domestic production and childcare independently from leisure or committed activities, and the consideration of individuals other than household members, such as external agents for domestic work, therefore, generating more precise estimations that do not overestimate the individual values of leisure an time. This consideration is corroborated by research that investigate the influences of formal child care on behavioral problems (e.g. Middeldorp et al., 2014), the causal effect of maternal childcare time allocation on children's cognitive outcomes (Villena-Roldán and Ríos-Aguilar, 2012), and studies that show an encouragement for the private for profit childcare sector to take the lead in providing care for children (Lloyd and Penn 2010).

Finally, in order to see the evolution regarding the behavior of individuals, we selected the same workers that answered the survey for all waves and run the model. The sample size was 21 individuals and the results are shown in Table 4.10. Furthermore, to test if the values of time are statistically different among waves, we calculated their confidence interval and conducted a dependent t-test, shown in Table 4.11.

Results show that, in average, the values of leisure and work do not differ significantly from the ones obtained when considering the entire sample (Table 4.5) but the confidence interval is wider, especially for the values in wave 3; moreover, they follow the same trend, having the lowest values of leisure and work in 2010. Furthermore, results in Table 4.11 show that for both the value of leisure and work, wave 3 is not statistically different from wave 2.

Table 4.10. Model estimation results for the same individuals in all waves

Model parameters						
Coefficients	**Wave 1**		**Wave 2**		**Wave 3**	
	Estimate	**t-stat**	**Estimate**	**t-stat**	**Estimate**	**t-stat**
θwork	44.274	5.001	35.483	4.357	29.115	2.430
θentertainment	9.645	3.006	6.265	2.955	5.170	2.078
θsleep	34.517	2.848	31.794	2.739	15.357	1.151
θchildcare	3.773	4.175	4.121	2.893	1.393	2.522
Φ	10.472	3.017	4.096	2.091	5.369	2.169
Mean log-Likelihood	-6.030		-6.022		-5.971	
Average values of time [euros/hr]						
	Estimate	**Std. Dev**	**Estimate**	**Std. Dev**	**Estimate**	**Std. Dev**
Value of Leisure	44.658	35.060	20.043	18.930	31.413	72.707
Value of Work	30.279	30.699	2.864	20.697	5.626	87.172
Wage Rate	14.379	9.440	17.179	12.729	25.787	50.791
Ratio VoL - wage	3.106		1.167		1.218	
Ratio VoW - wage	2.106		0.167		0.218	
Number of observations	21		21		21	

Table 4.11. Model estimation results for the same individuals in all waves

		Wave 1		**Wave 2**		**Wave 3**	
		t-stat	p-value	t-stat	p-value	t-stat	p-value
VST leisure	Wave 1			3.217	0.002	1.731	0.049
	Wave 2	3.217	0.002			0.717	0.241
	Wave 3	1.731	0.049	0.717	0.241		
VST work	Wave 1			4.092	0.000	3.680	0.001
	Wave 2	4.092	0.000			0.145	0.443
	Wave 3	3.680	0.001	0.145	0.443		
Confidence Interval (95%)							
		Lower B	**Upper B**	**Lower B**	**Upper B**	**Lower B**	**Upper B**
VST leisure		29.66	59.66	11.96	28.14	0.33	62.51
VST work		17.16	43.41	-6.00	11.73	-31.67	42.92

4.6. Synthesis and Conclusions

We have developed a model explicitly introducing a piece that was missing in previous models of time use: information about hiring an external agent to perform an activity for the individual without losing its intrinsic value, namely, productive activities.

This indeed improves over the previous most advanced microeconomic formulations, although a closed solution for activities and work time could not be found. However, we have generated a system of equations where the decision variables are work, domestic activities and those activities that are assigned more than the minimum time required. From this system, the parameters of the implicit equations can be estimated using maximum likelihood techniques without assuming independence of the error terms.

Our microeconomic framework is applied to three Dutch weekly time use and consumption databases. To our knowledge, these are one of the few surveys in the world that includes both time allocation and good consumption information. Using the estimated model parameters, we computed the values of time (value of leisure and value of work).

Results are aligned with labor supply theory proposed by Dessing (2002), when considering that the combination of average wages and weekly working hours in our data are just above a subsistence level for the average Dutch population.

A comparison of these estimates with those from two different models that do not include the novelty of hiring external domestic help shows substantial differences: the values of time for the models without an external agent performing domestic activities are higher than the values of time of our proposed model, and that overestimation is lower when considering the base model with childcare as an unrestricted activity with uncommitted expenses, showing the importance of correctly introducing relations between personal and hired time allocation in the modeling framework. Furthermore, a comparison of the new model's estimates with those from a sub-sample considering the same individuals was performed. No significant differences in the valuation of time were observed, providing interesting insights regarding Dutch workers preferences and lifestyle.

These empirical results are particularly relevant from a policy standpoint, as a miscalculation of the value of time can lead to erroneous decisions in public investment projects. One important policy implication that emerges from the present model is that negative labor supply presents the need for enforcing minimum wage legislation to face the lack of quality of life resulting towards this behavior.

We believe that further research can be pursued in two main directions: data and modelling issues.

In terms of data issues, first, one should explore the dynamics of multi-workers households. This study was conducted with workers who live in one-worker households (with its income being the same as the household's income). This last criterion allows assigning all personal and household expenditures to the only worker in the household, without making assumptions regarding how the household expenditures are shared among income producers. Further research could focus on a two-breadwinner scenario and study the interaction between working spouses. Second, data size has a significant impact on the analyzed performed. It is important to acknowledge that this study is being performed in an aggregate level and not for specific segments of the sample. It could be possible that the values of time can vary, for example, by gender and/or by age; however, given the small sample available, these potential differences across segments could not be studied.

In terms of modeling issues, one should explore other forms of integration and data treatment. Most of the time-use model estimation procedures are based on the overall allocation of time into specific activities and not on an episode-based framework, therefore overlooking the explicit value of performing activities in a precise sequence within the period analyzed. We believe a path of advancement could be episode-based analysis. Since minute-by-minute observations are almost never achievable and people are not always willing to participate in the exhaustive recollection of their every move, having appropriate modeling tools is critical for supporting public policy analysis. However, limitations in computational and methodological tools have interfered with the development of appropriate models, having to depend on aggregations, simplifications, and on the omission of important interactions. To properly conduct episode-based analysis would improve the understanding of individual time allocation.

5. SYNTHESIS, CONCLUSIONS AND FURTHER RESEARCH

5.1. Synthesis and conclusions

The goal of this thesis was to contribute to build and establish a new, more ample basis to advance in the study of individual time allocation decisions from a modeling approach. To accomplish that, first we systematized, organized and classified the time use modeling literature. Then, we analyzed the role of the period of analysis in time use valuation. Finally, we explored the role of new variables in the analysis of individual time use, formulating and estimating an extended model that considered information about hiring external agents to perform certain activities.

In terms of the review conducted, we summarized, addressed and examined different forms of looking at time use literature: by discipline, historical context and type of analysis. And within the latter one, we extended our exploration towards modeling.

Although the time use modeling literature has a central point where all studies converge (the expansion of consumer theory), there were many ways to systematize it. We believe that the best form to organize the modeling literature within time use studies was by paying attention to the type of activity or activities being modeled. We postulate that the strongest manifestation of the importance individuals attach to their time use is its allocation to activities, resulting from the superposition of individual preferences, institutionalized rhythms and collectively imposed conditions. Within this focus, it was useful to establish the coexistence of two study groups: those in which there is an attempt to study and understand a particular activity and those whose object of study is time use as a whole.

We concluded that, even though contributions to conceptual frameworks and theoretical bases in time use modeling are present in different areas (e.g. leisure, transport, household production, work-life balance), there is hardly any interaction among disciplines. This limits the formulation, the explanatory power and interpretation of current models. The almost non-existent contribution induces a research line based upon potential complementarities among approaches to solve existing modeling disadvantages.

Furthermore, we detected that there was a need for an appropriate data analysis to estimate time use models. The information on how individuals allocate their time is both rich and varied, however the means of generating and collect these data is a subject that has generated much controversy in the specialized literature, particularly regarding the duration of the period of observation. One, two, three or seven days (weekly) surveys have been supported as optimal from different viewpoints.

We studied different dimensions of data quality, duration and variability of activities, and modeling capabilities, using nine detailed European surveys based on seven-days diaries. Our results showed that two and three-days weighted surveys seemed to be an adequate surrogate for the information obtained in weekly surveys that capture a basic work–leisure cycle.

Given the analysis on the period of data and systematic review of time use models, we presented an extended time allocation and valuation model. We believe that the formulation of a more complete time use modeling framework needed the collaboration among different conceptual backgrounds and the incorporation of various disciplinary contributions. This would improve the understanding of individual time allocation and possibly lead to a better evaluation of the decision-making process involving economic activities that so far have not been explicitly incorporated into official accounts, such as household production.

Studies covering collaboration among individuals within a household have presented an improvement from current individual modeling frameworks. However, we believe multi-individual interaction lacks an important aspect of time use decisions: time allocated by hired market agents to perform the individual' activities. Current multi-individual models have as an underlying assumption the fact that there is no external help for household maintenance tasks. Household members are supposed to take all these responsibilities. In reality, however, households may hire domestic helpers to take some or most of the household maintenance activities, including childcare.

Therefore, we formulated and estimated a model with the explicit introduction of other individuals' time, namely an external agent to perform certain activities, i.e. productive activities, in this case, childcare. Values of time were computed using three Dutch weekly time use and consumption datasets. Furthermore, we compare our results with those from two previous formulations that did not include the novelty. Present models yield values of leisure and work that are larger than the values of time taking into account the possibility of hiring external agents for childcare. This overestimation of time values is lower for the model where childcare was considered as an unrestricted activity with uncommitted expenses. Finally, we compared the results of our new model with those drawn from a sub-sample with the same individuals in all waves. Results showed no significant differences in values of leisure or work.

These empirical results are particularly relevant from a policy standpoint, as a miscalculation of the value of time can lead to erroneous decisions in public investment projects. One important policy implication that emerges from the present model is that negative labor supply presents the need for enforcing minimum wage legislation to face the lack of quality of life resulting towards this behavior.

5.2. Further Research

Time use modeling is an ever-expanding research subject for people who try to understand individual and collective behavior. The goal of this thesis was to propose an extended model, but in no way to establish that this is the only appropriate expanded structure required for a multidisciplinary integration of contributions.

Because the analysis performed in this dissertation was threefold, further research can be focused in these three areas: time use literature, data analysis, time use models.

To systematize the time use literature is a never-ending process given that new studies are conducted constantly and their analysis can somehow overlap with past and current research. Future studies can focus on an expansion of the activity-driven perspective presented in this thesis. This could lead to answer questions such as: Are the categories presented here adequate? Should we consider other activities to be as important as work or leisure? Is the category 'tertiary activities' really necessary? Should we emphasize more the distinction between productive and unproductive activities? Can leisure be separated into more specific activities?

To classify time use models into specific categories, even though beneficial, can lead to the loss of information due to the oversimplification of such groups. Is a leisure model not useful to understand labor supply? Are sleep models not overlapped with overall time use models given that sleep takes one third of the day and one can acknowledge that work and leisure take almost the rest of it? Are transport models, specifically regarding commute, part of a labor supply category or should they be treated just as transport, or even as a separate classification?

Furthermore, the classification of models by activity can somehow be complemented by other topics somehow covered in this thesis, such as unit of analysis or intertemporal dimension. However, due to an extensive number of aspects to classify models by, one could finish with a categorization as large as the number of existing models. Should a collective household, dynamic lifetime leisure model be just classified as leisure? Or as a multi-individual model? Or as a intertemporal one?

Second, the data analysis presented in this thesis dealt with what we thought to be the most important topic of information availability: duration of the period of observation. Further research can concentrate in other data aspects such as (i) *detail*, with an emphasis in episode-based or overall daily data; (ii) *richness of the information*, with the consideration of capturing complementary data such as income and expenses; (iii) *data size*, with the purpose of comparing different sociodemographic groups to better understand our results.

In terms of detail, we detected that within the time use modeling literature there are different purposes to accomplish and those objectives need different levels of detail. If one wishes to estimate models aimed at understanding patterns and their value, researchers should focus on acquiring episode-based data. On another hand, if the purpose is to estimate models aimed at understanding the evolution of individual and/or group behavior, overall daily data should suffice. Further research should focus on questions such as: Are daily datasets acceptable to estimate pattern-based models? Is the burden of asking more detailed information too big for the individuals? Is the information gathered from more complete data worth the higher collection costs?

Regarding richness of information, we detected that most of the current available data is generally separated between time use information (on time use surveys) and expenses/income information (on household surveys). We believe that there is a need collect more complete information and, if that cannot occur, to use data mining techniques to create a matching procedure which will allow the generation of adequate and complete time use data and to perform complete sensitivity analysis to better understand our results. Future studies should aim at answering questions such as: Is a matching procedure adequate enough to cover for the lack of complete datasets? Is the burden of asking time and monetary information too large? Is the monetary data too sensitive to be asked?

In terms of data size, we believe that in order to conduct proper segmentation analyzes, surveys should have sufficient individuals to have a representative sample and answer questions such as: Is gender a significant variable to understand time allocation? Are the values of time different according to age? Is the urban/rural dynamic valuable to understand time use? Is the additional analysis worth the extra cost of a bigger sample?

Third, the search for other ways to formulate more complete time use models is an interesting topic for further research. We believe such a path to have many directions: (i) unit of analysis, (ii) temporal dimension, and (iii) episode-based analysis.

In terms of the unit of analysis, the incorporation of a domestic production function and the possibility of hiring an external agent can have an entirely different impact when the model analyzed is a multi-individual model, rather than a unitary one, and even within collective/bargaining models, the impact could be different if there is a cooperative bargain structure, or if we are dealing with a non-cooperative model.

Furthermore, the dynamics of a multi-member household is completely different when there are two bread-winners in the family, in terms of monetary decisions. Should the household hire an external agent or allow one of the members to stop working and perform that activity? Should the other member work more or just forego that potential income? Could we acknowledge older children as potential participants in childcare instead of the parents and external agents?

Moreover, the study conducted in this thesis was limited in terms of available data of external agents, having only childcare as a possibility for hire. Could the results significantly change if other productive activities were to be included in the model? Given that the interaction parent-child is not limited to care, were we right to consider childcare as a productive activity? Can it be considered leisure?

The temporal dimension can also play an important role on time use modeling, given that choices made in one period can have a significant impact in future choices, not only regarding activities performed but also monetary budgets. Should we integrate the possibility of hiring an external agent in a multi-period framework?

Regarding episode-based analysis, we detected that current time-use models are overwhelmed by limitations. Most of the time-use model estimation procedures are based in the overall allocation of time into specific activities and not on an episode-based framework, therefore overlooking the explicit value of performing activities in a precise sequence within the period analyzed.

Episode-based or activity pattern modeling can be a fruitful direction of future studies, providing insight on the behavior of certain groups of individual, on how specific activities and/or group of activities are being performed, and on the valuation of routines, patterns and repetitions. This type of modeling should require a detailed representation of numerous and quasi-unique alternatives (episode sequences). This level of detail would be impossible to implement in present modeling structures and results in the omission of certain attributes that needs to be overcome with the collection of more complete data.

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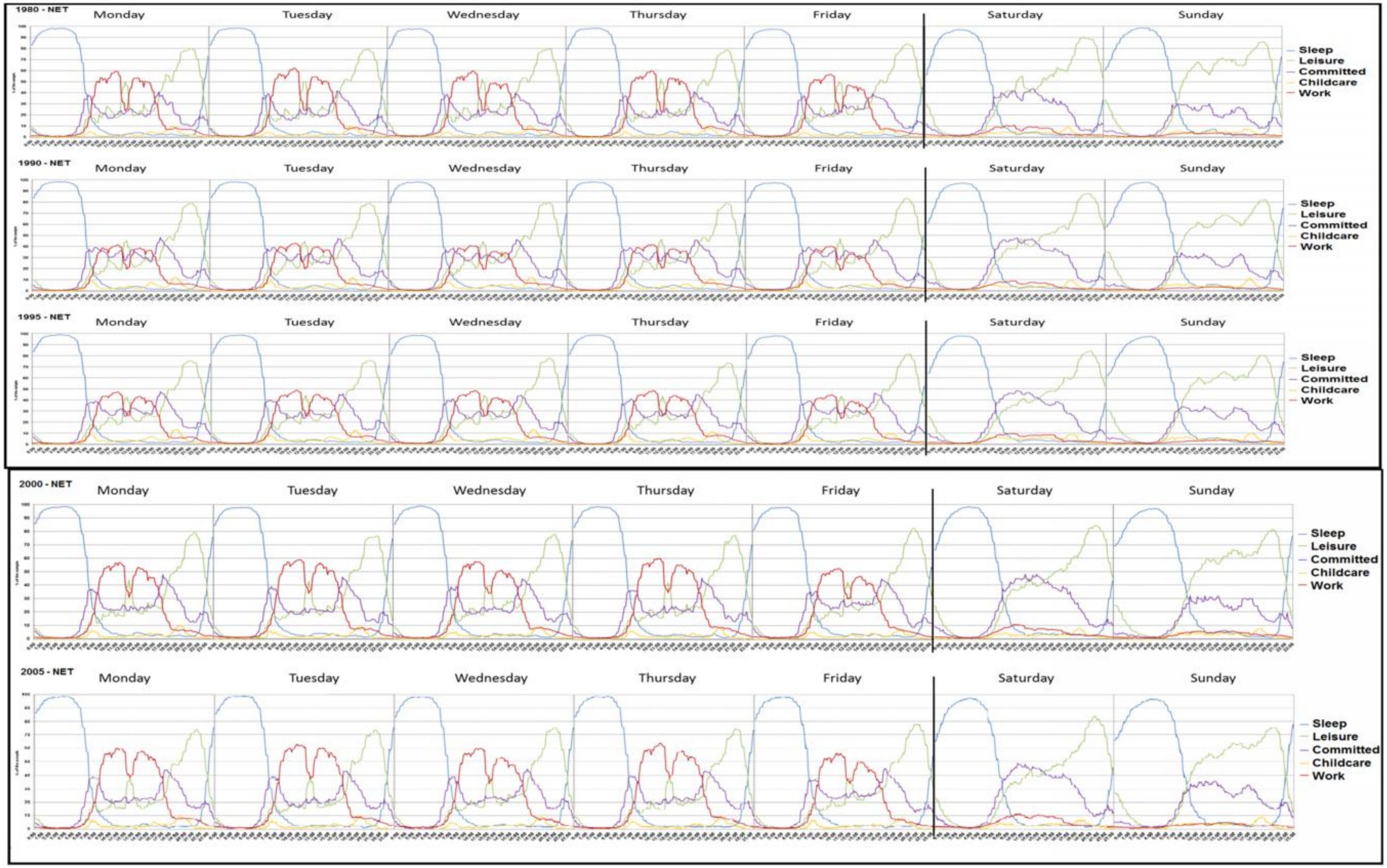
APPENDIX

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, theatre, 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/hhld 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



Appendix C. Model formulation, model estimation, and Value of Time derivation

- *Model formulation*

The proposed model has the following initial formulation:

$$MaxU = \Omega T_w^{\theta_w} \prod_i T_i^{\theta_i} \prod_d \left(T_d + T_{d_0}\right)^{\theta_d} \prod_j X_j^{\varphi_j} \prod_d Z_d^{\varphi_d} \qquad (A.1)$$

$$I + wT_w - \sum_d P_d Y_d - \sum_j P_j X_j - \sum_d s_d H_d - c_f \geq 0 \qquad (A.2)$$

$$\tau - T_w - \sum_d T_d - \sum_d T_{d_0} - \sum_i T_i = 0 \qquad (A.3)$$

$$T_i - T_i^{min} \geq 0 \quad \forall i \qquad (A.4)$$

$$X_j - X_j^{min} \geq 0 \quad \forall j \qquad (A.5)$$

$$\left(\varsigma_d Y_d + \varpi_d\left[T_d + T_{d_0}\right] + \zeta_d H_d\right) - Z_d = 0 \quad \forall d \qquad (A.6)$$

We have defined the consumption of intermediate goods as a function depending on time allocated by the individual and/or the hired agent to the production of the domestic good *d:*

$$Y_d = g_d\left(\left[T_d + T_{d_o}\right] + H_d\right) \qquad (A.7)$$

Now both domestic goods and intermediate goods are dependent on just domestic time (individual and hired), so we incorporate equation (A.7) into equations (A.2) and (A.6), obtaining the model as presented in Chapter 4:

$$MaxU = \Omega T_w^{\theta_w} \prod_i T_i^{\theta_i} \prod_d \left(T_d + T_{d_0}\right)^{\theta_d} \prod_j X_j^{\varphi_j} \prod_d Z_d^{\varphi_d} \qquad (A.8)$$

$$I + wT_w - \sum_d P_d\left(\sigma_d\left[T_d + T_{d_0}\right] + o_d H_d\right) - \sum_j P_j X_j - \sum_d s_d H_d - c_f \geq 0 \leftarrow \lambda \qquad (A.9)$$

$$\tau - T_w - \sum_d T_d - \sum_d T_{d_0} - \sum_i T_i = 0 \leftarrow \mu \qquad (A.10)$$

$$T_i - T_i^{min} \geq 0 \leftarrow \kappa_i \quad \forall i \qquad (A.11)$$

$$X_j - X_j^{min} \geq 0 \leftarrow \eta_j \quad \forall j \qquad (A.12)$$

$$\left(\epsilon_d\left[T_d + T_{d_0}\right] + \psi_d H_d\right) - Z_d = 0 \leftarrow \gamma_d \quad \forall d \qquad (A.13)$$

- *Model estimation and Value of Time derivation*

The first order conditions for the proposed model are:

For remunerated work:

$$\frac{\theta_w U}{T_w} + \lambda w - \mu = 0 \qquad (A.14)$$

For each domestic work activity engaged by the individual:

$$\frac{\theta_d U}{\left(T_d + T_{d_0}\right)} - \mu - \lambda P_d \sigma_d + \gamma_d \epsilon_d = 0 \quad \forall d \in D \tag{A.15}$$

For each activity different tan remunerated work and domestic work:

$$\frac{\theta_i U}{T_i} - \mu = 0 \quad \forall i \in A^f \tag{A.16}$$

$$\frac{\theta_i U}{T_i} - \mu + \kappa_i = 0 \quad \forall i \in A^r \tag{A.17}$$

For market goods:

$$\frac{\varphi_j U}{X_j} - \lambda P_j = 0 \quad \forall j \in G^f \tag{A.18}$$

$$\frac{\varphi_j U}{X_j} - \lambda P_j + \eta_j = 0 \quad \forall j \in G^r \tag{A.19}$$

For domestic goods:

$$\frac{\varphi_d U}{Z_d} - \gamma_d = 0 \quad \forall d \in D \tag{A.20}$$

For each domestic work activity engaged by the hired agent:

$$-\lambda s_d - \lambda P_d o_d + \gamma_d \psi_d = 0 \quad \forall d \in D \tag{A.21}$$

First order conditions (A.16) plus constraints (A.10) and (A.11) from the model, for all activities in A^f yield:

$$\frac{\mu}{U} = \frac{\Theta}{\left(\tau - T_w - \sum_d T_d - \sum_d T_{d_0} - \sum_{i \in A^r} T_i^{min}\right)} \tag{A.22}$$

First order conditions (A.18) plus constraints (A.9) and (A.12) from the model, for all goods in G^f yield:

$$\frac{\lambda}{U} = \frac{\Phi}{\left(I + wT_w - \sum_{j \in G^r} P_j X_j^{min} - \sum_d P_d\left(\sigma_d\left[T_d + T_{d_0}\right] + o_d H_d\right) - \sum_d s_d H_d - c_f\right)} \tag{A.23}$$

If committed time and committed expenses are defined as $T_c = \left(\sum_{i \in A^r} T_i^{min} + \sum_d T_{d_0}\right)$ and $E_c = \left(\sum_{j \in G^r} P_j X_j^{min} + c_f - I\right)$, then by diving equation (A.14) by U and replacing (A.22) and (A.23) we have:

$$\frac{\theta_w}{T_w} + \frac{w * \Phi}{\left(wT_w - E_c - \sum_d P_d\left(\sigma_d\left[T_d + T_{d_0}\right] + o_d H_d\right) - \sum_d s_d H_d\right)} - \frac{\Theta}{\left(\tau - T_w - \sum_d T_d - T_c\right)} = 0 \tag{A.24}$$

Combining equations (A.16) and (A.22):

$$\frac{\theta_i}{T_i} - \frac{\Theta}{(\tau - T_w - \sum_d T_d - T_c)} = 0 \quad \forall i \in A^f \tag{A.25}$$

From equations (A.15), (A.22), (A.23) and replacing equation (A.20):

$$\frac{\theta_d}{(T_d + T_{d_0})} - \frac{\Theta}{(\tau - T_w - \sum_d T_d - T_c)} - \frac{P_d \sigma_d * \Phi}{(wT_w - E_c - \sum_d P_d(\sigma_d[T_d + T_{d_0}] + o_d H_d) - \sum_d s_d H_d)} + \frac{\varphi_d \epsilon_d}{Z_d} = 0 \quad \forall d \in D \tag{A.26}$$

From equations (A.21), (A.22) and replacing equation (A.20):

$$\frac{\varphi_d \psi_d}{Z_d} - (s_d + P_d o_d)\frac{\Phi}{(wT_w - E_c - \sum_d P_d(\sigma_d[T_d + T_{d_0}] + o_d H_d) - \sum_d s_d H_d)} = 0 \; \forall d \in D \tag{A.27}$$

It can be seen that equations (A.26) and (A.27) share the term $\frac{\varphi_d}{Z_d}$. Therefore, both equations can be reduced to the following:

$$\frac{\theta_d}{(T_d + T_{d_0})} + \left(\frac{\epsilon_d}{\psi_d}(s_d + P_d o_d) - P_d \sigma_d\right)\frac{\Phi}{(wT_w - E_c - \sum_d P_d(\sigma_d[T_d + T_{d_0}] + o_d H_d) - \sum_d s_d H_d)} - \frac{\Theta}{(\tau - T_w - \sum_d T_d - T_c)} = 0 \; \forall d \in D \tag{A.28}$$

From equations (A.18) and (A.23):

$$\frac{\varphi_j}{P_j X_j} - \frac{\Phi}{(wT_w - E_c - \sum_d P_d(\sigma_d[T_d + T_{d_0}] + o_d H_d) - \sum_d s_d H_d)} = 0 \; \forall j \in G^f \tag{A.29}$$

Equations (A.24), (A.25), (A.28) and (A.29) form a system of $|A^f| + |D| + |G^f| + 1$ equations. Once the system is solved, the value of time as a resource, or value of leisure can be obtained as:

$$\frac{\mu}{\lambda} = \frac{\Theta}{\Phi}\frac{(wT_w - E_c - \sum_d P_d(\sigma_d[T_d + T_{d_0}] + o_d H_d) - \sum_d s_d H_d)}{(\tau - T_w - \sum_d T_d - T_c)} \tag{A.30}$$

Similarly, the value of work can be formulated as:

$$\frac{\partial U / \partial T_w}{\lambda} = \frac{\mu}{\lambda} - w \tag{A.31}$$

For the estimation of the model, first presented by Jara-Díaz et al. (2015), we divide equations (A.24), (A.25), (A.28) and (A.29) by Θ and add stochastic error terms on each equation (u_w, u_i, v_d, v_j), obtaining:

$$\frac{\tilde{\theta}_w}{T_w} + \frac{w * \tilde{\Phi}}{(wT_w - E_c - \sum_d P_d(\sigma_d[T_d + T_{d_0}] + o_d H_d) - \sum_d s_d H_d)} - \frac{1}{(\tau - T_w - \sum_d T_d - T_c)} = u_w \tag{A.32}$$

$$\frac{\tilde{\theta}_i}{T_i} - \frac{1}{(\tau - T_w - \sum_d T_d - T_c)} = u_i \quad \forall i \in A^f \qquad (A.33)$$

$$\frac{\tilde{\theta}_d}{(T_d + T_{d_0})} + \left(\frac{\epsilon_d}{\psi_d}(s_d + P_d o_d) - P_d \sigma_d\right)\frac{\tilde{\Phi}}{(wT_w - E_c - \sum_d P_d(\sigma_d[T_d + T_{d_0}] + o_d H_d) - \sum_d s_d H_d)} - \frac{1}{(\tau - T_w - \sum_d T_d - T_c)} = v_d \quad \forall d \in D \qquad (A.34)$$

$$\frac{\tilde{\varphi}_j}{P_j X_j} - \frac{\tilde{\Phi}}{(wT_w - E_c - \sum_d P_d(\sigma_d[T_d + T_{d_0}] + o_d H_d) - \sum_d s_d H_d)} = v_j \; \forall j \in G^f \qquad (A.35)$$

where $\tilde{\theta}_w = \frac{\theta_w}{\Theta}, \tilde{\theta}_i = \frac{\theta_i}{\Theta}, \tilde{\theta}_d = \frac{\theta_d}{\Theta}, \tilde{\Phi} = \frac{\Phi}{\Theta}, \tilde{\varphi}_j = \frac{\varphi_j}{\Theta}$

The terms $P_d\sigma_d$ and $P_d o_d$ were directly computed from the data by dividing time by expenditure for the domestic activity. Note that only the terms $P_d\sigma_d$ and $P_d o_d$ are needed to estimate equations (A.32), (A.34) and (A.35), and we do not require the value of P_d, σ_d and o_d independently.

Due to the existence of the time and income budget constraints, only $n-1$ time assignment and goods consumption equations can be estimated, where *n* is the number of unconstrained activities and goods.

For convenience we define 3 new indexes *l*, *b* y *m* with:

$l = 1$ (remunerated work)

$l = 2,3, \dots, L+1$ (freely chosen activities corresponding to set A^f; L its cardinality)

$m = 1,2, \dots, M$ (freely chosen goods corresponding to set G^f; M its cardinality)

$b = 1,2, \dots, B$ (domestic goods corresponding to set *D*; B its cardinality)

The left hand of equations (A.32)-(A.33) is a function of time assigned to activities $f_w(T_w, T_l, T_b, X_m, H_b), f_l(T_w, T_l, T_b, X_m, H_b)$, and to consumed goods $g_m(T_w, T_l, T_b, X_m, H_b), h_b(T_w, T_l, T_b, X_m, H_b)$. Therefore, those equations can be summarized in:

$$f_l(T_1, \dots, T_{L+1}, T_{L+2}, \dots, T_{L+B+1}, X_1, \dots, X_M, H_1, \dots, H_B) = u_l \quad l = 1,2, \dots, L+1 \qquad (A.36)$$

$$g_m(T_1, \dots, T_{L+1}, T_{L+2}, \dots, T_{L+B+1}, X_1, \dots, X_M, H_1, \dots, H_B) = u_m \quad m = 1,2, \dots, M \qquad (A.37)$$

$$h_b(T_1, \dots, T_{L+1}, T_{L+2}, \dots, T_{L+B+1}, X_1, \dots, X_M, H_1, \dots, H_B) = u_b \quad b = 1,2, \dots, B \qquad (A.38)$$

Vector $\boldsymbol{u} = (u_1, u_2, \dots, u_{L+1}, v_1, v_2, \dots, v_{M+B})'$ is then assumed to be a realization from a multivariate normal distribution, so that $u \sim MVN_{L+M+B+1}(\boldsymbol{0}, \boldsymbol{\Omega})$ indicates an (L+M+B+1)-variate normal distribution with mean vector of $\boldsymbol{0}$ and covariance matrix $\boldsymbol{\Omega}$. As with the estimation procedure for the microeconomic model explained in Chapter 3, the errors can be assumed to to be in a multivariate normal distribution because they arise from different independent sources and because the normal distribution often describes the actual distribution of errors in real-world processes reasonably well.

The probability distribution function of $\boldsymbol{u}$ is denoted by $\phi^*_{L+M+B+1}(.;\mathbf{0},\boldsymbol{\Omega})$. Then, the probability that the individual assigns T_1 to work, $T_2,\dots,T_{L+1}$ to activities in A^f, $T_{L+2},\dots,T_{L+B+1}$ to domestic work activities, $X_1,\dots,X_M$ goods in G^f, and hires $H_1,\dots,H_B$ external domestic help, corresponds to:

$$P(T_1,\dots,T_{L+1},T_{L+2},\dots,T_{L+B+1},X_1,\dots,X_M,H_1,\dots,H_B) \\ = |\det(\mathbf{J})|\phi^*_{L+M+B+1}(f_1,\dots,f_{L+1},g_1,\dots,g_M,h_1,\dots,h_B) \quad (A.39)$$

where $\mathbf{J}$ is the Jacobian of the vector function $\boldsymbol{F}(T_1,\dots,T_{L+1},T_{L+2},\dots,T_{L+B+1},X_1,\dots,X_M,H_1,\dots,H_B)=(f_1,\dots,f_{L+1},g_1,\dots,g_M,h_1,\dots,h_B)'$. Let $\boldsymbol{\omega}$ be the diagonal matrix of standard deviations ω_r of $\boldsymbol{\Omega}$, and let $\phi_{L+M+B+1}(.;\boldsymbol{\Delta})$ be the multivariate standard normal probability distribution function of dimension L+M+B+1 and correlation matrix $\boldsymbol{\Delta}$. Then,

$$P(T_1,\dots,T_{L+1},T_{L+2},\dots,T_{L+B+1},X_1,\dots,X_M,H_1,\dots,H_B) \\ = |\det(\mathbf{J})|\left(\prod_{r=1}^{L+M+B+1}\omega_r\right)^{-1}\phi_{L+M+B+1}(\boldsymbol{\omega}^{-1}\boldsymbol{F};\boldsymbol{\omega}^{-1}\boldsymbol{\Omega}\boldsymbol{\omega}^{-1}) \quad (A.40)$$

Yields the likelihood function:

$$L\left(\tilde{\theta}_1,\dots,\tilde{\theta}_{L+1},\tilde{\theta}_{L+2},\dots,\tilde{\theta}_{L+B+1},\tilde{\varphi}_1,\dots,\tilde{\varphi}_M,\tilde{\varphi}_{M+1},\dots,\tilde{\varphi}_{M+B},\overline{\boldsymbol{\Omega}}\right) \\ = P(T_1,\dots,T_{L+1},T_{L+2},\dots,T_{L+B+1},X_1,\dots,X_M,H_1,\dots,H_B) \quad (A.41)$$

where $\tilde{\theta}_1=\tilde{\theta}_w$, and $\overline{\boldsymbol{\Omega}}$ is a row vectorization of the upper diagonal elements of $\boldsymbol{\Omega}$. Due to identification issues, one of the standards deviations of $\boldsymbol{\Omega}$ has to be fixed to 1. To ensure that the normalized utility parameters $\tilde{\theta}_2,\dots,\tilde{\theta}_{L+1},\tilde{\theta}_{L+2},\dots,\tilde{\theta}_{L+B+1},\tilde{\varphi}_1,\dots,\tilde{\varphi}_M,\tilde{\varphi}_{M+1},\dots,\tilde{\varphi}_{M+B}$ are positive, we parameterize them as using an exponential function.

- *Computation of the elements of the Jacobian*

The elements of the Jacobian are given by:

$$J_{lh} = \frac{\partial f_l(T_1, \dots, T_{L+B+1})}{\partial T_h} \qquad (A.42)$$

where function f_l is defined in equation (A.32) for $l = 1$ (work), in equation (A.33) for $l = 2,3, \dots, L + 1$ (activities in A^f), and (A.34) for $l = L + 2, \dots, L + B + 1$ (activities in D). Let

$$C = \left[\frac{1}{wT_w - E_{ec} - \sum_d P_d(\sigma_d[T_d + T_{d_0}] + o_d H_d) - \sum_d s_d H_d}\right]^2 \widetilde{\Phi} \qquad (A.43)$$

$$D = \left[\frac{1}{\tau - T_w - \sum_d T_d - T_{ec}}\right]^2 \qquad (A.44)$$

Then, the lh^{th} element of the Jacobian is:

$$J_{11} = -\theta_w T_w^{-2} - w^2 C - D \qquad (A.45)$$

$$J_{1h} = \begin{cases} 0 & for\ 2 \leq h \leq L + 1 \\ wP_d\sigma_d C - D & for\ l + 2 \leq h \leq L + B + 1 \end{cases} \qquad (A.46)$$

$$J_{l1} = \begin{cases} -w\left(\frac{\epsilon_d}{\psi_d}(s_d + P_d o_d) - P_d\sigma_d\right)C - D & for\ 2 \leq l \leq L + 1 \\ wC & for\ l + 2 \leq l \leq L + B + 1 \end{cases} \qquad (A.47)$$

$$J_{1h} = \begin{cases} -\frac{\theta_i}{T_i^2} q_{lh} & for\ 2 \leq l \leq L + 1, and\ 2 \leq h \leq L + 1 \\ -D & for\ 2 \leq l \leq L + 1, and\ L + 2 \leq h \leq L + B + 1 \\ 0 & for\ L + 2 \leq l \leq L + B + 1, and\ 2 \leq h \leq L + 1 \\ -\frac{\theta_d}{(T_d + T_{d_0})^2} * q_{lh} + \left(\frac{\epsilon_d}{\psi_d}(s_d + P_d o_d) - P_d\sigma_d\right)P_d\sigma_d C - D & for\ L + 2 \leq l \leq L + B + 1, and\ L + 2 \leq h \leq L + B + 1 \end{cases} \qquad (A.48)$$

Where $q_{lh} = 1$ if $l = h$ and $q_{lh} = 0$ if $l \neq h$. There is no closed-form structure for the determinant of the Jacobian.

Appendix D. Association of expenditures to activities

Activity	Expenditure category considered
Commute	• Average weekly household expenditure transportation, multiplied by 0.36. *Assumption*: According to a recent study in the Netherlands, about 18% of all trips are trips to work (Bohte and K. Maat, 2009). Then, trips to and from work account for about 36% of all trips.
Household chores	• Average weekly household expenditure in cleaning the house or maintaining the garden, divided by the number of adults in the household. (*Assumption*: all adults in the household equally participate in household chores).
Personal care	• Average weekly personal expenditure in eating at home. *Assumption*: Some respondents did not declare their expenditure in this category, but they reported the household expenditure in eating at home (for all household members). Then, for those respondents with missing data, this expenditure was computed as the household expenditure divided by the household size. The assumption is that all household members consume the same amount of food. This was validated by computing the proportion of personal expenditure in eating at home, compared to the total household expenditure which, in average, was consistent with this assumption. • Average weekly personal expenditure in food and drinks outside the house. • Average weekly personal expenditure in personal care products and services. • Average weekly personal expenditure in medical care and health costs not covered by insurance.
Education	• Average weekly personal expenditure in (further) schooling.
Activities with children	• Expenditure per week for children living at home in: food and drinks outside the house, cigarettes and other tobacco products, clothing, personal care products and services, medical care and health costs not covered by insurance, leisure time expenditure, (further) schooling, donations and gifts, other expenditures. *Assumption*: all children-related expenditure is associated with the time spent with them. This is not necessarily true: a parent can buy food and drinks outside the house for the children, but not spend time while the children eat. Or he/she can purchase a movie ticket and do not go with the children to the cinema. However, the survey does not provide information that allows us to identify the relationship between expenditures and activities with children, and we decided to consider all expenditures related with children.
Entertainment	• Average weekly personal expenditure in leisure time expenditure. • Average weekly household expenditure in daytrips and holidays with the whole family or part of the family.
Assisting friends and family	No expenditure.
Administrative	No expenditure.

chores and family finances	
Sleeping and relaxing	No expenditure.
Other activities	No associated expenditure.

Additionally, the hired childcare expenses category considered:

- Average weekly household expenditure in children's daycare.

Finally, we constructed the fixed expenses c_f considering the following expenditure categories:

- Average weekly household expenditure in mortgage and rent.
- Average weekly household expenditure in general utilities and insurances.
- Average weekly household expenditure in alimony and financial support for children not (or no longer) living at home.
- Average weekly household expenditure in debts and loans.
- Average weekly household expenditure in other household expenditure.
- Average weekly household expenditure transportation, multiplied by 0.64 (corresponds to the expenditure on transportation for other household members and non-work travel).
- Average weekly household expenditure in eating at home, minus average weekly household expenditure in eating at home (corresponds to the expenditure in eating at-home for other household members).