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Beyond transport time: A review of time use modeling

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ABSTRACT

Time allocation literature coming from all disciplines is reviewed and organized by means of a conceptual classification. A brief account of the origins and evolution of the modeling perspectives on time use research is presented including activity types and overall time use models. The lack of integration across disciplines is identified as a major limitation.

1. Introduction

Time use studies have been justified primarily by the need to understand how people make decisions about their activities that, by definition, occupy 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, ranging 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, among others. In the case of transport studies, the appraisal of improvements in operations or infrastructure – involving a significant amount of resources – makes it necessary to assign a value to the so-called travel time savings, which has two components: the (dis)pleasure of travel itself and the possibility of substituting travel time for other desired (more rewarding or pleasurable) activities. As transport related decisions at an individual level are unavoidably linked with the overall time allocation problem, travel models are implicitly or explicitly related with time use modeling (Jara-Díaz, 2007), and with the values of leisure and work. As we will show later, this has lead very naturally to extend the focus toward comprehensive frameworks: the activity based analysis (e.g. Kitamura, 1984; Bhat and Koppelman, 1999a,b) and the expanded microeconomic consumer theory, evolving from an emphasis in transport time (Jara-Díaz and Guevara, 2003) toward overall time use models such as Jara-Díaz et al. (2008).

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As we will argue later, research in time-related topics has developed showing little interaction across disciplines, due in part to issues such as the heterogeneous nature of the research approaches and disciplinary backgrounds. We believe that capturing those contributions in a systematic way would facilitate the identification of elements that can help with the construction of a richer basis for time use modeling from different viewpoints such as the formulation, the explanatory power and interpretation of current models.

The purpose of this paper is to understand the contributions to time use modeling from all angles, studying the possible perspectives from which time use research can be viewed and developing what we believe to be an organized and complete way of classifying time use literature, something not accomplished so far with this level of detail. The driving idea is to present what each discipline does and which modeling methods each one uses in order to prompt the individual disciplines to include insights and contributions from other areas into their own work.

In Section 2 we give the reader a brief description of the origins and evolution of time allocation literature through different approaches, offering a comprehensive conceptual classification. In Section 3 we examine the modeling literature through the eyes of the particular activity being studied. In Section 4 we present a description of models focused on studying time as an overall phenomenon, their evolution and limitations. Finally, in Section 5 we summarize some of the principal findings, and we discuss the potential for future research.

2. Describing and organizing time use literature

The allocation of time has been a topic of interest and research since the beginning of the twentieth century, creating an overwhelming amount of literature that contributes to the understanding of people's time allocation from different approaches. Although there are many ways to classify this literature, we have chosen a three dimensional perspective: 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 (Sorokin and Berger, 1939; Minge-Klevana, 1980).

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 toward 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 the 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 2000 s), 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 studies have 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. Zerubavel, 1981; Bergmann, 1992); *psychology*, when dealing with cultural diversity and the understanding of individuals' time allocation (e.g. Block, 1990; Brislin and Kim, 2003); and *economics*, studying the necessity of incorporating time in traditional economic instruments (e.g. Hood, 1948; Becker, 1965; Hamermesh and Pfann, 2005).

Time use has also been analyzed from the perspective of studies on specific groups of the population, such as *gender studies*, detecting differences between men and women in the labor market and in overall activities (e.g. Aliaga and Winqvist, 2003; Bryson, 2007); *gerontology*, studying the relationship between productivity, leisure and personal care activities within elders (e.g. Moss and Lawton, 1982; McKinnon, 1992); and *occupational therapy*, dealing with the impact of well-being perception over adult care activities (e.g. Hasselkus, 1989; Abdul-Rahman, 2008).

Finally, time use analysis has even been covered in disciplines that, a priori, one would suspect are not directly related with time allocation, such as *administration,* studying the impact in work performance of physical activity at the office, and the time allocated to face-to-face interaction among coworkers (e.g. Fonner and Roloff, 2010; von Thiele and Hasson, 2011); and *urban planning* with the inclusion of time in the organization of cities (e.g. Millward and Spinney, 2011; Marsal-Llacuna and López-Ibañez, 2014).

Within the **analytical perspective** – which can be associated with the traditional classification of time use studies[1] – we have identified four distinctive (but not mutually exclusive) types of approaches that can be found in the literature: *conceptual-theoretical discussions*, *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. Block, 1990; Abell, 2003).

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 perform more complete analysis and to assist in the creation of adequate public policies (e.g. Andorka, 1987; UN Economic Commission for Europe, 2010; Bittman and Ironmonger, 2011; Munizaga et al., 2011; Gershuny, 2012; Jara-Díaz and Rosales-Salas, 2015).

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 (e.g. Gershuny and Jones, 1986; Gershuny and Robinson, 1988; Ampt and Richardson, 1994; Gershuny, 2003; Aguiar and Hurst, 2009).

Analytical modeling frameworks encompass an extensive area of research that contains diverse theoretical constructs representing the individual and/or household time allocation decision process using models. Their main purpose is to understand the functioning and dynamics of individuals' choice and the factors, variables and constraints that condition that behavior. (e.g. Becker, 1965; Kitamura, 1984; Apps and Rees, 1997; Jara-Díaz et al., 2004; Bhat, 2008; Bargain, 2009). Regarding its evolution, most of the modeling literature has been built explicitly or implicitly on the classical consumer theory, starting with Becker (1965), who introduced consumption time as one of the inputs of what he called final goods, the basic source of utility, inducing an overall value of time equal to the wage rate as the opportunity cost of leisure. From that point forward, many studies from several disciplines have discussed and expanded his work by incorporating new variables, constraints and theoretical frameworks.

We believe that the best form to organize the modeling literature within time use studies 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 a particular activity and those whose object of study is time use as a whole.

In the first group, we have detected that the literature shows three large families of studies: *paid work*, analyzing time spent in production on the market (e.g. Card, 1991; Blundell et al., 2005b); *unpaid work*, analyzing activities that could be delegated to a paid worker without losing their intrinsic value, such as household production and childcare (e.g. Chiappori, 1997; Bryant and Zick, 2006); and *non-work activities*, that includes a vast array of activity types that can be sub-divided into two categories: *leisure* and *tertiary activities.* These latter activities have several definitions in the literature but, to our opinion, the most adequate definitions are those given by Burda et al. (2007): *Leisure* encompasses those activities that the individual cannot pay other individuals to perform without losing their intrinsic value and that can be suppressed if needed, such as entertainment (e.g. Johnson, 1966; Jara-Díaz and Astroza, 2013); *Tertiary activities* are those that the individual cannot pay other persons to perform without losing their intrinsic value, and that have a minimum ("technical") time requirement. Within this category, the main activity studied from the point of view of time use and time values has been transport (e.g. Train and McFadden, 1978; Small, 1982; Jara-Díaz and Ortúzar, 1989; Jara-Díaz, 1994), although sleep has received some attention as well (e.g. Biddle and Hamermesh, 1990).

In the second modeling group, the focus is the understanding of time allocation as a structural phenomenon; all or a specific combination of the activities the individual performs during a specific period are analyzed (e.g. Becker, 1965; DeSerpa, 1971; Evans, 1972; Pollak and Wachter, 1975; Kitamura, 1984; Gronau, 1986; Bates, 1987; Bhat and Koppelman, 1999a; Jara-Díaz, 2003; Jara-Díaz and Guerra, 2003; Jara-Díaz et al., 2008). An organized view of the Time Use Literature classification can be seen in Fig. 1.

The emphasis on activities to study, analyze and model time allocation has prompted many reviews that have concentrated on generic activity types such as paid work, unpaid work and non-work activities. Among the reviews within the area of paid work, Heckman (1993) stands out as a concise but comprehensive study, 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 contribution in the study of labor supply between 1970 and 1990 has been the recognition and interpretation of a variety of different labor supply functions that coexist in the empirical literature. Other interesting reviews on paid work have focused on gender segmentation (Pencavel, 1986; Killingsworth and Heckman, 1986), intertemporal dimension (Card, 1991; Heckman, 1993; Bargain, 2009), and the decision agent(s) (Laisney and Beninger, 2002; Blundell et al., 2005b).

[1] For example, Juster and Stafford (1991), organized the time use literature from the perspective of data collection (measurement issues), empirical findings (data analysis) and behavioral modeling.

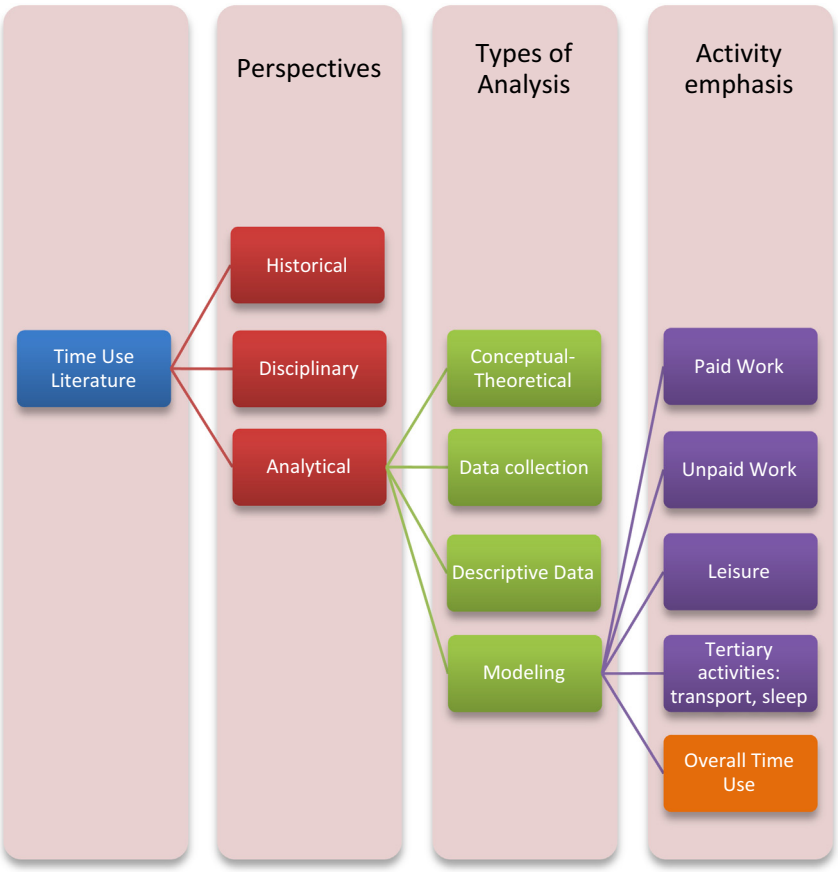

Fig. 1. Time use literature classification.

Unpaid work, more specifically domestic production, has been profoundly analyzed both as a related aspect of labor supply and in its own merit. There are two authors that have produced comprehensive revisions of the evolution of domestic production research: Ironmonger (2000), who 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, and Grossbard (2001, 2010), who studied forty years of New Home Economics and analyzed the evolution from single agents to multi-member household models. Besides these, Pollak (2003) presented a revision of Becker' studies, discussing his contributions to family and household economics, concluding that Becker's ideas have dominated research in the economics of the family, shaping the tools used, the questions asked, and the answers given.

Regarding non-work activities, most of the reviews on leisure have been descriptive (e.g. Ferge, 1972; Shaw, 1982; Harvey, 1990; European Commission, 2003, 2005, 2007, 2008; Aguiar and Hurst, 2007, 2009; Alesina et al., 2006), comparing trends in time allocation between countries, historical periods, specific groups, and contrasting their leisure time allocation with time assigned to other activities, such as work and travel. On tertiary activities, reviews on transport have usually focused on different aspect of travel demand and behavior (e.g. Wardman (1988), on revealed-stated preferences; Axhausen and Garling (1992), on activity-based approaches; Timmermans and Zhang (2009), on household activity travel decisions), travel time values (e.g. Wardman, 1997) and travel and time use (e.g. Bhat and Koppelman, 1999a).

The study of time allocation as a structural phenomenon has provided many insights to time use literature. Jara-Díaz (1994, 1998) covered the role of time and income from a microeconomic viewpoint and Gonzalez (1997) reviewed several models that study the subjective value of time emphasizing behavioral assumptions, the role of constraints, and relevant variables in the utility function. Jara-Díaz (2007) comprehensively reviewed the overall time use models behind travel demand and values.

There is a constant need to incorporate the study of time use modeling within the global context of time use research. Therefore, now we will analyze more profoundly the extent to which single-activity models and overall ones have been presented and described in the literature.[2]

[2] For homogeneity, we will use common notation for the formulation of all models.

3. Single-activity time use models

3.1. Paid work

Work is the only activity that is present in all time use models either in the utility function or in the budget and temporal constraints; it is the only activity that can provide monetary income, which allows individuals to buy market goods – the only source of utility recognized by traditional economics – and undertake activities. 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 labor. This evolved toward the acknowledgment of non-work activities as sources of utility and the fact that resistance to work was not only due to displeasure of working but also due to satisfaction obtained from non-working time, originally considered to be the same as leisure time.

The first labor supply models considered the individual as the decision agent and the only two relevant activities were work and non-work, but only time assigned to the latter was a 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. Its standard form is:

$$max\ U(G,L) \tag{1}$$

$$wT_w - G \geqslant 0 \tag{2}$$

$$T_w + L = \tau \tag{3}$$

The individual chooses to assign his total available time (τ) between paid work (T_w) and leisure activities (L). Given a wage rate (w), the individual spends his total income in goods consumption (G). Note that deciding on working time is based on a trade-off between leisure and consumption: increasing T_w permits higher consumption but at the cost of diminishing leisure. Preferences for leisure (free time) against goods (consumption), combined with the wage rate, will determine the optimal (equilibrium) combination. This equilibrium point is characterized by $\frac{\partial U}{\partial L} = w\frac{\partial U}{\partial G}$.

To our opinion, the most important evolution of labor supply models was the recognition that working time is not only important because of purchasing power but also as a source of (dis)utility and, therefore, belonged into utility (Johnson, 1966; Evans, 1972). Also, what was implicitly hiding behind the L variable began receiving more attention. Therefore, both the utility function and the temporal constraint began incorporating, in latter studies, specific activities drawn from the separation of "non-work" into explicit categories, such as transport, unpaid work, leisure and others.

This activity-oriented evolution came in parallel with other advances. The consideration of all activities performed by individuals induced the examination of the decision agent: the individual or the household and its members. The time assigned to work by one individual is now dependent on the income needed both by the individual and the household, and this household now faces the opportunity of having a complementary source of income. This change in modeling induced a new way of looking at the trade-off between work and non-work and a new look at the way individuals interact within the household: cooperation, bargain, and unilateral decisions.

There have been many attempts to expand the traditional single-agent approach over the years. The origins of this expansion can be traced back to research by Becker (1965, 1973, 1974a, 1974b, 1976, 1981a, 1981b), who introduced several modeling innovations within the topic of marriage dynamics. Becker's (1965) paper was the basis for several developments or interpretations on labor supply.[3] Becker himself (1981a, 1981b) developed a two-member household model, where each individual is characterized by his/her own preferences, introducing the idea of "caring" by assuming that the preferences of one individual are influenced by the other member's utility function; also, individual specific wage rates are introduced. This approach generated a family of labor supply models such as Chiappori's (1992), who 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. This was expanded by Blundell et al. (2005a) who introduced public goods within the household, specifically expenditure on children; and then by Cherchye et al. (2012) by incorporating children not only as expenses but also as household members – with no bargaining power of their own.

These studies have not been exempt of criticisms. Duguet and Simonnet (2003) considered that research such as Chiappori (1992) and most collective labor supply models are limited because they are restricted to the case where both household spouses work. From the studies that consider the possibility of one working member, the focus is on the participation decision of women, but they all treat the decision of the other household member as exogenous. The incorporation of the husband's working time in a married woman's labor supply is often used to test for the presence of an added worker effect, per which the spouse of an unemployed man would offer more labor than a woman with an employed spouse to compensate the income loss of the household (Lundberg, 1985). The model presented by Duguet and Simonnet (2003) was constructed to calculate the incentives to work for each household member. Note that there is research that considers one (or

[3] Wetzell (2002) re-interpreted Becker's (1965) model by noting 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.

none) working spouse (Donni, 2000; Blundell et al., 2005b), but these exclude public goods, e.g. married couples without children.

The modeling framework also evolved in terms of the period analyzed. A dynamic, lifetime or multi-period model presents alternatives to consumption: investing or saving money to use it in another period. The interest in lifecycle labor supply arose from two issues. First, Lucas and Rapping (1970) presented a lifecycle framework 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 the evolution of individuals' labor supply schemes as a response to the evolution of individual wages. 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 work 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. Recently, López-Ospina et al. (2015) explicitly included a temporal dimension within a microeconomic approach, recognizing 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. By specifying two time scales (micro and macro), they conclude that preference observations at the micro level, such as transport mode choice, are strongly conditioned by the prevailing choices at the macro scale.

Further research within labor theory could benefit from the formulation of specific technical relations with different types of activities. For example, to analyze the incorporation of working trips into the total working hours; or to explore the relationship between the quality of the work performed and sleep; and finally, to continue the study of the relationship between paid and unpaid work.

3.2. Unpaid work

In general, unpaid work activities can be separated into three main activities: household production – or domestic labor, care for others (mostly childcare) and volunteering, with most research focused on the first. In the mid-1960s a major theoretical development from the neoclassical consumer theory took place, known as "new home economics" (Mincer, 1962; Becker, 1960, 1965). In this theory, the household is regarded as a productive sector with household activities modeled as a series of industries (Ironmonger, 2000). Households produce commodities that are designed to satisfy separate wants such as thirst, hunger, warmth and shelter. The characteristic 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 adopted almost the same framework but with a clear emphasis on how to value work conducted inside the household. Additionally, the presence of children appears as an important issue when allocating individual and/or household time. Furthermore, there is a clear distinction between the consumption of market goods and household produced goods, difference not acknowledged in the labor supply literature, e.g. restaurant dinner versus home cooking.

As with the labor supply literature, domestic work research recognizes that a realistic way to model household behavior is to consider a multi-member approach, which is why most models in this category represent a 2-member household as the unit of analysis. The generic domestic labor model structure can be formulated as:

$$max \sum_n U^n(X_{jn}, Y_{hn}, L_n) \tag{4}$$

$$\sum_n (w_n T_{wn} + I_n) - \sum_n \sum_j X_{jn} \geqslant 0 \tag{5}$$

$$T_{wn} + T_{hn} + L_n = \tau \quad n = 1, 2 \tag{6}$$

$$h(T_{h1}, T_{h2}) - Y \geqslant 0 \tag{7}$$

U^n is the individual utility of member n; X_{jn}, Y_{hn}, L_n are the consumption of market purchased good j, household produced good h and time assigned to leisure by individual n respectively; T_{wn}, w_n, I_n, T_{hn} are time assigned to market work, wage rate, non-work income, and time assigned to household production for individual n, respectively; 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 by both members.

Unlike standard labor supply models, the unpaid work framework includes market consumption and household produced goods (home and/or childcare), from which the time assigned to leisure and domestic labor (or childcare) appears explicitly. Some studies incorporate households and individuals' socio-demographic characteristics and sometimes individual decisions are influenced not only by the own income but also by the spouse's. 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). It is worth noting that some self-labeled labor supply models contain explicit links with unpaid work models, with a focus on domestic labor (e.g. Cherchye et al., 2012).

There have been attempts to estimate a monetary value to domestic labor or household production (Clark, 1958; Morgan et al., 1962; Nordhaus and Tobin, 1972; Sirageldin, 1973; Weinrobe, 1974; Murphy, 1978). However, this has not yet been

included in official national accounts such as the Gross National Product (GNP) or even considered as a formal measure of household income and expenses. The fact that GNP estimations ignore the value of goods and services produced within the household might seriously underestimate its magnitude and produces a bias in national and international comparisons between domestic and market indexes.

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 second method, "*specialist replacement cost*", 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. Finally, a "*generalist replacement cost*" method of valuation uses the wage rate for a generalist worker or housekeeper. This is regarded as more appropriate than the former since the working conditions and ranges of activities are similar to those of household members.

Because time use surveys usually provide limited information about household activities (i.e. time allocated to domestic labor), they tend to omit the contribution from non-human capital such as land, housing and equipment (technology) owned by households, therefore leaving behind the value added by such elements toward domestic production.

There is still work to be done within unpaid work research. As pointed out by Ironmonger (1996), the role of households in building human capital resources needs much greater research. Education, nurturing and training are still classified as 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. Furthermore, the effects of changing household technology on unpaid household work need a more detailed examination to understand changes in, for example, gender division of labor. Some of these issues have emerged recently; for example, the introduction of domestic activities where external providers could be hired, an issue closely related with the distinction between homemade goods and market goods (Rosales-Salas and Jara-Díaz, 2017).

3.3. Non-work activities: Leisure

So far, we have treated non-work activities as a single category but, as justified in Section 2, it includes leisure and tertiary activities. As we will now discuss, the concept of leisure is a rather complex and highly relevant issue that has received great attention.

Beginning with the seminal works of Mincer (1962) and Becker (1965), and further influenced by labor supply models, there was an overall acceptance that time can be conceptually divided into two activities: work and non-work (or leisure).

According to Feldman and Hornik (1981), despite the apparent simplicity and benefit of leisure defined in terms of freely chosen, intrinsically satisfactory activities, theorists do not agree about how much non-work should be defined as leisure, because the freedom of choice of many non-work activities is subjectively determined (Kaplan, 1960, 1975; Voss, 1967; Ennis, 1968; Bull, 1971; Gronau, 1977). Activities defined as leisure are the consequence of subjective perception on the part of each consumer. For example, cleaning the pool on summer could be unpaid work to one individual and leisure to another.

Within the past decades, the need to disaggregate non-working time into specific types of activities grew, beginning with Johnson (1966) who directly incorporated time allocated to an activity (leisure and work) into the utility function. Later, all activity times where introduced by DeSerpa (1971) and Evans (1972), Gronau (1977) divided available time into consumption time, market work and work at home; Stafford and Cohen (1974) and Biddle and Hamermesh (1990) presented nonmarket activities that contribute to market productivity and job performance, e.g. work breaks and sleep; Jara-Díaz and Guerra (2003) gave each activity a role both within the utility function and in the constraints.

Classifying activities is not a trivial matter and leisure, as a category, presents an extra difficulty: subjectivity (Clark et al., 1990; Neulinger, 1981; Kelly, 1974, 1980). The literature acknowledges 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 characterized in many ways. According to Feldman and Hornik (1981), economic analysis defines leisure as a normal good with a positive income effect (Hall, 1970; Gronau, 1977). Additionally, leisure implies consumption time, in contrast with work and domestic labor that can be categorized as production (Pollak and Wachter, 1975; Becker, 1976). 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 (Neulinger and Crandall, 1976; Williams, 1977). Leisure can also be linked with the definition of "discretionary time" as the time beyond that necessary to attend to required functions (Goodin et al., 2008). There is, however, no consensus on what "necessary time" means and could depend on the individual or the situation (Goodin et al., 2005). On the same grounds, leisure could be seen as the time left after household production time, paid work and commuting time have been deducted (Gronau, 1973; Barnet-Verzat and Ekert-Jaffé, 2003). These views point to leisure as a residual category of activities (Lundberg et al., 1934; Kaplan, 1960; Szalai, 1972; Kirsh et al., 1974; Schliewen, 1977).

Although one could view this variety of approaches as an advantage and as something to be encouraged, its major limitation has been the lack of theoretical development within the field of study and the non-cumulative nature of much of the research. Clark et al. (1990) stated that leisure research that has been undertaken has not had the impact it might have had, because the lack of agreement over definitions has made it difficult to create a comprehensive understanding of leisure patterns. The process of categorizing activities as leisure or as non-leisure is problematic. One problem is that this approach

does not take the individual into account. Instead, it imposes a universal definition: that is, if an activity is categorized as leisure it is defined as leisure for everybody in all circumstances. As Clark et al. (1990) stated, it is difficult to think of any specific activity which could not be considered as either work or as leisure by different individuals. Accordingly, this would suggest that no categorization of activities could be "correct" because of individual differences in attitudes toward specific activities. Additionally, there is another problem present with leisure definitions: situational specificity. The same individual participating in the same activity may consider it to be leisure at one particular time or location, whereas at another time or location he or she may consider it to be work, or at least non-leisure (Shaw, 1982). Other situational factors which may affect the definition of the activity include the day of the week, the duration of the activity and the presence or absence of other people.

This vast array of definitions shows a significant contrast with what researchers have used when formulating their time use models. Because the modeling aspects of time use research must represent reality as best as possible within certain limitations (e.g. to analyze 70 activities is a more complex task than to analyze 3 groups of activities such as work, leisure and tertiary activities), several simplifications have come to existence.

To present a clear classification of activities, a decision must be made in terms of separating non-work activities into clear and mutually exclusive categories. Let us present the conceptions that we believe to be the most adequate operational definitions of leisure. The first one is derived from the third-party rule proposed by Reid (1934, p.11). She presented a test 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,* $(X_1^*, \ldots, X_n^*)$*, a minimum amount of time, specified by the parameters,* $a_1, \ldots, a_n$*, 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*." Although these definitions are born from different angles – non-delegable activities or activities one is willing to extend beyond necessity, they have a similar intention that distinguishes leisure activities from those that must be performed but the individual is never willing to extend, i.e. tertiary activities (to be covered in point 3.4).

Broadly speaking, these converging definitions can be understood in two ways: first, if an activity does not have to be performed, the individual has a choice, e.g. playing soccer with friends, or not; second, if an activity must be performed, the individual can choose to allocate more time than the required if he or she wishes to, e.g. eating lunch in 10 min or the same lunch in 30 (the individual chooses to assign the extra 20 min). Both scenarios coincide with the definition presented by DeSerpa (1971), accepting that the minimum could be zero.

The leisure modeling literature can be classified into three somehow overlapping groups of articles: those that deal with recreation demand modeling, which is an established field by itself; those that focus on obtaining a value of leisure from different viewpoints; and those articles that – independently of each other – deal with a specific activity of interest, which we will call general leisure modeling. Let us begin with the latter.

The main purpose of general leisure models is to analyze how the time assigned to a particular activity has affected the ability of the individual or the household to supply labor into the market. Therefore, there are as many studies as leisure activities of interest and every model emphasizes two main activities: the specific leisure activity conducted, and paid work. 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.

$$max\ U(G, T_p) \tag{8}$$

$$wT_w + I - G \geqslant 0 \tag{9}$$

$$T_w + \sum_{i \neq p} T_i + T_p = \tau \tag{10}$$

Under this generic approach many activities classified as leisure have been studied. This the case of watching TV (Corneo, 2005), picking fruit (Carpio et al., 2008), physical activity (Mullahy and Robert, 2010), whale watching (Shaikh, 1998), hobbies (Browning and Gørt, 2012), "active" leisure (Kimmel and Connelly, 2007), social activities (Solberg and Wong, 1992), in-home and/or out-of-home discretionary activities (Yamamoto and Kitamura, 1999; Chen and Mokhtarian, 2006; Spissu et al., 2009), resting (Bhargava, 1997), leisure travel (Collings, 1974; Palmquist et al., 2010; Fezzi et al., 2014), searching for information (Hauser et al., 1993), market recreation (Owen, 1971), church attendance (Azzi and Ehrenberg, 1975), among others. In general, the intention within these studies is, among other purposes, to analyze, model and interpret individual behavior, toward the understanding of the determinants of activity engagement and the relationship and/or tradeoff in time allocation between different activities, mostly focusing on their relation with labor supply. Using diverse time-use datasets, these studies perform empirical tests to estimate their models and to conduct comparative and segmentation analysis using components such as wage, goods consumption, marital status, number of people in the household, and gender differences.

Although recreational activities could be understood as a synonym of leisure, recreation demand models are an established area of research by itself, used to forecast frequency, duration and goods consumption associated with visiting recreational sites, as well as to determine the value that individuals – who allocate time to recreation – place on the diverse

factors that affect their decisions. Models in this area form a self-contained category and usually combine information on the individuals' characteristics, site visits and travel costs, which includes both direct costs (e.g. fuel and vehicle maintenance), and the opportunity cost of travel time. We have found that, in accordance with Train (1998), the recreational activity that has received most attention from modelers is fishing (Bockstael et al., 1989; Morey et al., 1991, 1993, 1995; Wegge et al., 1991; Parsons and Needleman, 1992; Parsons and Kealy, 1992; Hausman et al., 1995; Desvousges et al., 1996). These models are used to describe the choices of whether to take a fishing trip during a given period, the duration of the trip, which species of fish to target, and/or where to go fishing (e.g. trip to a lake or river), providing estimates of the individuals' willingness to pay for changes in site attributes, as well as the values of individual sites themselves (Bockstael et al., 1991).

Most of the recreation demand models have been developed following two formulations of the consumer choice process. On one hand, a composite market good and recreation trips provide utility (e.g. McConnell, 1975; McConnell and Strand, 1981). On the other hand, income and the amount of work and leisure time directly enter the utility function (e.g. Cesario, 1976). Within the first type of formulation, recreation trips consider a given period, and time allocated to recreation must be diverted from other uses if the recreation trip is to be taken. The second type of recreation demand modeling considers the general problem of allocating time between work and leisure activities. It assumes that the decision to visit a recreation site is the same as any other leisure activity choice.

A general formulation of recreation demand models is presented by Lew and Larson (2005), where the consumer faces the following problem:

$$max\ U_j(\mathbf{x}) \tag{11}$$

$$wT_w + I - \mathbf{p} * \mathbf{x} - p_j \geqslant 0 \tag{12}$$

$$T_w + \mathbf{t} * \mathbf{x} + t_j = \tau \tag{13}$$

This is an utility maximization problem conditional on the *j*th recreational site being chosen, with the individual allocating time freely to work and other activities (**x**) given their money cost (contained in **p**) and their time (contained in **t**). This type of framework can be traced back to McConnell (1975) and provides the basis for a discrete choice approach, where the individual is seen as choosing the site that yields the maximum conditional utility, similar to what has been done in the area of travel demand as shown in 3.4 below.

Recreational demand models have emphasized the issue of time valuation. According to Larson and Shaikh (2004), several studies have followed the basic logic of Becker (1965), assuming that the opportunity cost of recreation time (i.e. the value of other time forgone in favor of recreation) is an exogenous parameter, such as the average wage rate or, some fraction thereof. This fraction is either chosen arbitrarily or estimated as part of the recreation demand model, as in Cesario (1976), McConnell and Strand (1981) and Smith et al. (1983). Recently, however, there have been attempts to formulate some form of the value of leisure that goes beyond the average wage rate. For example, Fezzi et al. (2014) formulated the value of travel time to recreation sites using a framework based on DeSerpa (1971) and Lew and Larson (2012) estimated the value of recreation time in sport fishing by asking individuals to select among different trip choices based on a series of attributes.

There is, however, a limitation that we have detected across the leisure literature focused on specific activities, including recreation: in general, it has not accounted for the studies conducted within the overall time use modeling literature (covered in Section 4) that has significantly evolved from works such as Becker (1965) and DeSerpa (1971). One of such studies, Jara-Díaz et al. (2008), formulated a time use model built from DeSerpa's framework which leads to both a labor supply equations and equations for freely chosen activities, labeled as leisure under that framework, i.e. equations that represent leisure models in themselves. One of the main outcomes from such models is the estimation of a *value of leisure* – analytically deduced – that happens to be a function not only of the wage rate, but also of what they called *committed expenses* E_c (the sum over expenses in constrained goods minus fixed income I), of *committed time* T_c (the sum of constrained activities) and of parameters related with the perception of freely chosen activities (Θ) and freely chosen goods (Φ), as shown in Eq. (14).

$$Value\ of\ Leisure = \frac{\mu}{\lambda} = \frac{\Theta}{\Phi} * \frac{(wT_w^* - E_c)}{(\tau - T_w^* - T_c)} \tag{14}$$

Leisure equation models leading to values of time have also been estimated using the structural equations framework, adding variables representing expenses on leisure activities (Konduri et al., 2011). The combination of both approaches has led to a new concept called the *revealed willingness to pay for leisure* (RWPL), identified and estimated by Jara-Díaz and Astroza (2013), that contributes to form a *total value of leisure* (Eq. (15)) which is the sum of the shadow price of time – the original value of leisure within the microeconomic theory (Eq. (14)) – and the RWPL, equal to the total effect of time allocated to a leisure activity and expenses associated with them.

$$Total\ value\ of\ leisure = \frac{\mu}{\lambda} + RWPL \tag{15}$$

By understanding how the formulation of the values of time (e.g. value of leisure) evolved within different theoretical backgrounds, one can detect why there is a significant disconnection between the value of leisure presented in overall time use models and in the recreational demand area (and a few other fields): in general, recreation demand models do not incorporate all activities conducted by the individual into the utility function (particularly work), leading toward the same problem found in both paid work (Section 3.1) and unpaid work models (Section 3.2) – the assumption that some activities do not

contribute (dis)utility to the individual, therefore ultimately yielding a biased value of time. This is yet another evidence of the lack of interaction among disciplines dealing with time use, and points toward the need to elaborate a unified and operational taxonomy for leisure, tertiary and unproductive activities (Reid, 1934; DeSerpa, 1971; Burda et al., 2007).

3.4. Non-work activities: Tertiary activities

Considering that in the previous section we concluded that the concepts of leisure provided by DeSerpa (1971) and Burda et al. (2007) converge, let us recall the latter: "*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*" (p.5). With this definition, we clearly are left with activities that are neither work nor leisure, which have been 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*". According to this definition, this sub-category includes activities such as 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 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, there are two activities that have been covered in the literature to our knowledge: transport and sleep. However, the literature on transport, time assigned and its value is overwhelmingly large, constituting an area of research by itself, as we will now see.

3.4.1. Transport

The object of study in transport analysis is multifaceted and covers the issues of the generation (to travel or not) and distribution (where to go) of travel, mode choice (how to travel) and the (re)location of activities. The models within this area of research have been formulated, in general, based on the classical theory of the consumer and its extension to encompass time use.

Models of discrete transport mode choice were first 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 like travel time, 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" were developed from the pioneering work of Kitamura (1984) to the most recent of Bhat et al. (2013). The 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 the 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 Jara-Díaz (2003, 2007), Munizaga et al. (2008) and Jara-Díaz 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, as explained below (Section 4).

Within travel decision-making at an individual level, mode choice is an area that has been covered extensively by the literature. As stated above, the first approach aimed at understanding mode choice is the goods/leisure trade-off framework for daily travel to work 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:

$$max\ U(G, L) \tag{16}$$

$$wT_w + I - G - c_m \geqslant 0 \tag{17}$$

$$T_w + \sum_{i \neq t} T_i + T_{t_m} = \tau \tag{18}$$

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. The use of endogenous income by Train and McFadden's (1978) was challenged by Jara-Díaz and Farah (1987). They presented a version of the goods/leisure model in which the hours of work and the total income 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, which in this model can be adjusted only within the possibilities open by the travel modes available to the individual, who must choose between cheap-slow modes and expensive-fast ones. Evidently, cost and time are not the only determinants in this type of choice (Jara-Díaz, 2007).

Besides the microeconomic approach presented so far, research regarding individuals travel choice behavior has been also performed under the heading of activity-based travel analysis (extensively covered in Section 4). According to Clarke et al. (1981) the focus in this type of studies is the individuals' activity schedule, the importance of spatial and temporal constraints, and the interaction between household members, aiming at the prediction of changes in households' activity schedule where travel is one such activities. An important part of this approach is the various constraints that limit an individual choice set. Another is that travel behavior is dependent upon household structure, for example different stages in a family life cycle (e.g. without children, with children or retired).

Within transport modeling, there are still some issues that need to be addressed, such as data requirements (new and/or more detailed kinds of data) and modeling challenges, like the inclusion of new variables (e.g. comfort, attributes and/or preferences).

It is next to impossible to provide a definitive answer regarding the information required to estimate every transport model, as models differ widely in terms of their theoretical background and can be always further developed to include new elements. However, Arentze et al. (1997) presented an analysis of the dimensions that need to be addressed when studying data needs and the requirements when analyzing data quality. On one hand, the consensus regarding data needs, is that the researcher wants information on activities, location, timing, "with whom", and transport mode. On another hand, in terms of data quality, the authors state that, even though it is a multidimensional concept that has received different meanings in different disciplines, there are overall requirements needed to conduct proper research, such as reliability, i.e. the consistency with which an instrument measures whatever it does measure; validity i.e. whether the selected variables measure the concept they intend to measure; level of detail, understood as the compatibility between the operational definitions of the choice dimensions, the explanatory variables and the aim of the model-building process; consistency, whether the same definitions and classifications have been used across the data sources; completeness, the notion that one should always be able to classify every unit of observation; and an efficient use of the data.

Regarding modeling challenges, changes in policy, theory development and modeling in general have led to the development of new classes of transport demand models that are of increased complexity, such that the explanatory variables traditionally confined to attributes of the transportation system, have become inadequate. This has led to the analysis of issues such as the influence of comfort and convenience on travel mode choice, in addition to travel time and travel cost (e.g. DeSerpa, 1973; Hensher et al., 1975; Koppelman and Pas, 1980; Koppelman and Lyon, 1981; Nerhagen, 2000); and the impact of information and communication technologies (ICTs) on the valuation of travel time, transit services and teleactivity (e.g. Frei et al., 2015; Pawlak et al., 2015).

Data needs, modeling challenges, and the requirements for data quality have been emphasized in a series of recent articles. In terms of activities, level of detail and the use of ICT, Gerike et al. (2015) analyzed the recollection procedures behind Travel Surveys and Time Use Surveys, considering both travel and non-travel activities. They recommended using continuous time intervals for activity diaries, besides other improvement recommendations for the design of both type of surveys, such as proxy reporting, survey coding instructions, multiple activities recording, and incorporation of data regarding the usage of information and communication technology (ICT). In terms of timing, completeness and travel time, Minnen et al. (2015) showed that multi-day time-diary data might help identifying temporal regularities, such as repetition and timing of transportation activities. They demonstrated that a breakdown of continuous time-use data in 10-min 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. In terms of an efficient use of the data, Jara-Díaz and Rosales-Salas (2015) analyzed the appropriate duration of time diaries as a source of time use data. They studied the advantages and limitations of different lengths of data collection on time-use analysis. They found that a two-day weighted survey seems to be an adequate surrogate for weekly time-use information in the context of a work-leisure cycle. However, the authors note 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*" (Jara-Díaz and Rosales-Salas, 2015, p. 54).

3.4.2. Sleep

The other activity that stands out within this group is sleep, a necessary activity that has vast implications for multiple aspects of everyday life, consuming a large amount of non-working time. Although research on this area has been growing since the 1990's, the amount of studies conducted is still relatively small in absolute terms. This might explain why the availability of time for activities with active participation (awake) is usually considered a fixed quantity (Hegarty, 2012).

The first authors that addressed this topic from a microeconomic perspective were Biddle and Hamermesh (1990), who built on Becker's (1965) idea that sleep and other activities are required for efficiency to increase monetary income. In their model, utility is assumed to depend on time allocated to sleep (T_s) and commodities consumption (G), which in turn is related to time assigned to their consumption (T_G) and market goods (X); sleep increases productivity, which is represented by a positive effect on wages (w_2). The model is:

$$max\ U(G, T_s) \tag{19}$$
$$wT_w + I - G \geqslant 0 \tag{20}$$
$$T_w + T_G + T_s = \tau \tag{21}$$
$$w = w_1 + w_2 T_s \tag{22}$$
$$T_G = bG \tag{23}$$
$$X = aG \tag{24}$$

From this model, the cost of a unit of sleep time happens to be equal to the opportunity cost of the time used during the period the individual slept: "*the wage rate minus any addition to labor income that occurs as a result of the effect of extra sleep on productivity*" (Biddle and Hamermesh, 1990, pp. 934). Their empirical results show that people with higher wages sleep less, especially men. In their words "*Individuals whose time is more valuable substitute away from the relatively time-intensive commodity sleep, a commodity that yields utility but no direct income*" (pp. 938).

The impact of sleep on workers' performance was empirically supported by Akerstedt (1991). In this century, Szalontai (2006) found strong and significant negative effects of wages and education on sleep using South African data. Also, Stolzar (2006) studied time allocation among college students, finding a negative association between grade point averages (GPA scores) and sleep hours. Recently, Asgeirsdottir and Zoega (2011) extended the formulation of Biddle and Hamermesh (1990) by modeling the decision on sleep quality as endogenous and as an investment in the level of alertness that the individuals enjoy during the day.

Several studies on sleep habits and sleep time have been performed in many countries and with different purposes. Tune (1968) reviewed habitual sleep patterns in adults using time diaries, finding variations in mean sleep time of over 30 min across age groups, results that were confirmed by Morgan (1987) and Hume et al. (1998), who showed that sleep time decreases with age. The relationship between sleep and cognitive performance, alertness, memory, decision making, reasoning, problem solving and accidents has been analyzed by Van Dongen et al. (2003) and Turner et al. (2007), among others. Similarly, there are studies regarding deprivation of sleep (e.g. Carskadon and Dement, 1981), which have found that sleep serves a purpose of physical and mental restitution. The timing of sleep has also been studied in relation to an individual's circadian rhythm and the effects on the quality of sleep (Wyatt et al., 1999; Aeschbach et al., 2003; Van Dongen et al., 2005). According to Asgeirsdottir and Zoega (2011), sleep and its effects vary a great deal with factors such as the presence of children, diet, appetite, income, and both the nature and amount of work, which relates with the markets for sleep medications, pillows, mattresses, time-saving gadgets, alcohol, caffeine and other drugs, etc. (Walsh and Engelhardt, 1999; Wyatt et al., 1999).

In terms of time use modeling, sleep research has a long way to go and we believe that the elements required to advance are available but not yet properly integrated. As described, there is a rich body of literature dealing with the links between socio-economic characteristics of individuals and the quality and quantity of sleep. It would be beneficial to enrich present modeling frameworks with those findings, as has been done by including elements such as alertness and its links with sleep, productivity and enjoyment.

4. Overall time use modeling

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

4.1. The utility framework

Time use models can be derived from a utility maximizing framework in order to obtain time allocated to an activity as a function of independent variables. There are two groups of models that use the concept of utility in their formulation: microeconomic models – those that expand the neoclassical consumer theory to include time related constraints besides the money budget -, and activity-based models – a framework that was born recognizing mainly the time constraints, emphasizing the context in which the individual decides to allocate his or her time to any particular activity (Astroza, 2012).

4.1.1. Microeconomic models

The first general theory of time allocation was formulated by Becker (1965). Although this approach has been disputed and extended over the decades by many authors, there is a consensus in the idea that individual time use is derived from the maximization of a household utility function subject to a time and a budget constraint. After Becker's economic theory, other studies contributed to the understanding of the value of time. Johnson (1966) was the first to directly incorporate time allocated to an activity (i.e. leisure and work) into the utility function, departing from Becker's idea that the individual draws utility from "final goods". By doing so, he established that the value of time was equal to the wage rate plus another component: the subjective value of work. Furthermore, he stated that the total value of work was equal to the value of leisure, which in turn was also equal to the value of travel time. However, Oort (1969), building on Johnson's analysis, proposed that

not only work and leisure had to be including into the utility function, but also travel time, thus differentiating the value of leisure from the value of travel time, now referred to as the *subjective value of travel time savings* (SVTTS). After that, an important contribution came both in terms of the constraints present in the model and the utility function. DeSerpa (1971) was the first to acknowledge that all activities had an impact over the individual's utility, together with all goods consumed. He also explicitly introduced a set of technical constraints relating time and goods, establishing that consumption of a given good required a minimum allocation of time. Furthermore, Evans (1972) was the first to present a utility function dependent only on time allocated to activities, establishing that those activities need consumption of goods as inputs. Many reviews (e.g. Pas and Harvey, 1997; Gonzalez, 1997; Jara-Díaz, 2007) have discussed the economic formulations of time allocation and we refer the interested reader to these studies.

In the last decade, contributions toward the empirical estimation of time use models and calculation of time values from a microeconomic perspective have been proposed and applied. The model by Jara-Díaz (2003) formulated a conceptual structure that expanded on DeSerpa (1971) and included technological relations between goods consumption and time assignment to activities.

$$\max U = \Omega T_w^{\theta_w} \prod_i T_i^{\theta_i} \prod_j X_j^{\eta_j} \tag{25}$$

$$I + wT_w - \sum_j P_j X_j \geqslant 0 \rightarrow \lambda \tag{26}$$

$$\tau - T_w - \sum_i T_i = 0 \rightarrow \mu \tag{27}$$

$$T_i \geqslant f_i(X) \quad \forall i \rightarrow \kappa_i \tag{28}$$

$$X_j \geqslant g_j(T) \quad \forall j \rightarrow \varphi_j \tag{29}$$

where U is the utility function, θ_i and η_j are parameters corresponding to activities and goods respectively, Ω is an 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, τ is the length of the period considered, $f_i(X)$ is the minimum time that has to be assigned to activity i (which depends on goods consumed), $g_j(T)$ is the minimum amount of good j that has to be consumed in order to perform activities T. The parameters λ, μ, κ and φ are the Lagrange multipliers that represent the change in utility when the corresponding constraint is relaxed by 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.

Jara-Díaz and Guevara (2003) presented a simplified version of this model and linked it to discrete travel choice, calculating the components behind the value of travel time (leisure and (dis)utility). This was extended by Jara-Díaz and Guerra (2003) by including all activities, goods consumption and any discrete choice. By replacing the general transformation functions in equations (28) and (29) with exogenous minima, i.e., T_i^{min} and X_j^{min} they obtained closed form solutions for the decision variables (time at work and freely chosen goods and activities) as functions of total committed expenses E_c (sum over expenses in constrained goods minus fixed income I), total committed time T_c (the sum of constrained activities) and the wage rate. From these, the authors obtain the values of leisure and work for each individual as:

$$\textit{Value of Leisure} = \frac{\mu}{\lambda} = \frac{\Theta}{\Phi} * \frac{(wT_w^* - E_c)}{(\tau - T_w^* - T_c)} \tag{30}$$

$$\textit{Value of Work} = \frac{\partial U/\partial T_w}{\lambda} = \frac{\theta_w}{\Phi} * \frac{(wT_w^* - E_c)}{T_w^*} \tag{31}$$

where $\Theta > 0$ and $\Phi > 0$ are the summations of the positive exponents θ_i and η_k over all unrestricted leisure activities and unrestricted goods, respectively. These equations fulfill the condition that:

$$\textit{Value of leisure} = \frac{\mu}{\lambda} = w + \frac{\partial U/\partial T_w}{\lambda} = \textit{total value of work} \tag{32}$$

Microeconomic models also have limitations that open space for improvements. A first type of problem must do with the functional form. The studies performed by Jara-Díaz and associates chose a Cobb-Douglas functional form for utility, which permits the estimation of time allocation models and the different values of time, properties that do not follow from functional forms such as the CES, Stone-Geary, quadratic or Translog, among others (Contreras, 2010). However, there are two main limitations associated with the Cobb-Douglas formulation. First, it imposes marginal utilities with a constant sign for each argument, something that should be open to empirical verification. For example, Prasch (2000) states that it is reasonable to think that the marginal utility of leisure activities could present different signs depending on income, as for individuals with medium or high salaries the marginal utility of leisure activities would be, in general, positive; however, marginal utility could also be negative for unemployed individuals with very low income and consumption below a level to permit leisure enjoyment. Also, the marginal utility of work could change sign from positive to negative as time at work increases. A second problem is related with the multiplicative form of the Cobb-Douglas, such that no arguments can have a

zero value. Of course, there are ways to overcome these problems, like proper segmentation per socio-economic characteristics to have correct point estimates for different segments but variability across segments; or imposing minima on the time assigned to discretionary activities.

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. This situation does not occur for a large segment of the population in many developing countries. As previously examined, Jara-Díaz and Farah (1987) proposed a model where the hours of work (T_w) and the total income (I) were fixed within the period. Expanding the analysis of this study, Jara-Díaz (2002) concludes that if the individual works more than strictly required by contract, then the value of leisure is equal to the subjective value of work, which must be positive. This is equivalent to the case when the individual chooses the working hours but with a zero wage rate.

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 lifetime 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 must 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, with friends, family or a group. 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.

Besides the specific limitations shown above, microeconomic models share characteristics that have been criticized by some authors. According to certain social sciences, the assumption of stability in individual preferences is troublesome (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. Pérez (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).

4.1.2. Activity-based models

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:

$$max\ U(T_1,\ldots,T_n,q_1,\ldots,q_n)=\sum_{i=1}^{n}U_i(T_i,q_i) \tag{33}$$

$$\sum_{i=1}^{n}T_i=\tau \tag{34}$$

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:

$$U_i=\epsilon_i\gamma_i f_i(q_i)\ln(T_i) \tag{35}$$

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 discretionary activities, they do not generate utility from them. From this, the utility function U_i is generated as follows:

$$U_i=\begin{cases}\epsilon_i\gamma_i f_i(q_i)\ln(T_i) & if\ T_i>0\\ 0, & if\ T_i=0\end{cases} \tag{36}$$

In the last decades, the activity-based approach to travel demand analysis has received much attention and has experienced significant progress (see Pinjari and Bhat (2011) and Ronald et al. (2008) for recent reviews). For example, there have been several advancements in the utility function formulation of these models, such as Munshi (1993), Kitamura et al. (1996a, 1996b), Kim et al. (2002) and Bhat (2005, 2008), among others. Note that this particular type of activity-based models does not allow obtaining time values because it only uses a temporal constraint.

Although not founded within an utility framework, there is an activity-based family of models that has helped the formulation of time use models; this are the structural equations models (SEM), that try to capture the influence that certain exogenous variables have over endogenous variables (activities in this case), and the influence of endogenous variables among themselves (see Golob, 2003, for an extended review). SEM is essentially a system of linear equations with as many endogenous variables as equations, synthesized as:

$$T = AT + BS + \epsilon \Rightarrow T = (I - A)^{-1}(BS + \epsilon) \tag{37}$$

Here, 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. This has been used in various forms by Golob and McNally (1995), Koppelman and Townsend (1987), van Wissen (1989), Stopher and Vadarevu (1995) and Lu and Pas (1997).

Konduri et al. (2011) extended system (35) by including expenditure equations on leisure activities to induce the calculation of a value for leisure. This prompted the formulation by Jara-Díaz and Astroza (2013) who improved the incorporation of expenses, activities and socioeconomic variables into the SEM and calculated the *revealed willingness to pay for leisure* (RWPL), a concept theoretically different from the value of leisure formulated within a microeconomic framework. As explained in Section 3.3, RWPL can be considered a component of a larger construct: the *total value of leisure*. The authors conclude that the SEM by itself does not allow the calculation of the value of leisure and that the microeconomic approach needs to expand to consider explicit constraints relating goods consumption and time use.

Finally, the models based on a multiple discrete-continuous extreme value (MDCEV) approach (Bhat, 2005, 2008), considers that many consumer choice situations are characterized by the simultaneous demand for multiple alternatives that are imperfect substitutes for one another. He introduced a simple and parsimonious econometric approach to handle multiple discreteness, which is also based on the generalized variant of the translated CES utility function but with a multiplicative log-extreme value error term. Bhat's 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.

It is worth emphasizing that the MDCEV formulation has been extended such that the activity based approach has met the microeconomic approach by incorporating a money budget constraint (Eq. (38)) that generates a general model represented by (Castro et al., 2012):

$$max\ U = \sum_{i=1} \frac{\gamma_i}{\alpha_i} \psi_i(q_i) \left(\left(\frac{x_i}{\gamma_i} + 1 \right)^{\alpha_i} - 1 \right) \tag{38}$$

$$\sum_{i=1} g_i x_i = \tau, (\mu) \tag{39}$$

$$\sum_{i=1} p_i x_i = G, (\lambda) \tag{40}$$

where $\psi_i > 0$ is the marginal utility when consumption of x_i is zero, ψ_i is a function of the attributes vector q_i of activity i. γ_i is a positive parameter for each good i. G is the total expense in consumption. Given that τ is total time available for goods consumption, g_i is the time rate for which each unit of good i is consumed. In addition, $0 < \alpha_i \leqslant 1$ captures satiation effects, where if $\alpha_i = 1$ for every i, there is no satiation, or equivalently, a constant marginal utility. When α_i decreases, the satiation effect on good i 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 (μ/λ).

Even though traditional activity-based models have made conceptual, theoretical and methodological contributions in the understanding of travel behavior, there are challenges that can still be addressed. Regarding 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 cannot be achieved.

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. Bhat and Koppelman (1999b) stated that 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. Of course, the use of an entire week as the unit of analysis could be quite expensive, which offers research opportunities for the development of data collection methods and coverage that

can generate weekly information without being prohibitively expensive or being excessively intrusive (e.g. Jara-Díaz and Rosales-Salas, 2015).

4.2. The unit of analysis

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

Models on household activity start with the contribution of Becker (1965) who, as stated before, 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, individuals' preferences interact as part of the decision-making process of the household. 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 consider 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-Díaz (2007). According to Laisney and Beninger (2002), this type of model presents several difficulties, but the main ones are aggregation of preferences (Arrow, 1951; Hildenbrand, 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.

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 behaves as if it were maximizing the household welfare function. This would lead to an optimal redistribution of income among the household members per their individual expenditures. On the contrary, Becker (1974b, 1981a, 1981b) proposed a model where the family utility function is the same as an "altruistic" head of the family. His decisions determine the intra-family distribution of resources and the redistribution of utility among household members according to his 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, 1990a, 1990b).

Within a multi-individual modeling framework, bargain models are, to our opinion, the most relevant decision-making processes studied. 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. Contrary to unitary models, individuals within a household are considered to be autonomous decision-making units with their distinct, but interdependent, optimization - utility maximization - 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 assume that individuals form a multi-member household when the benefit of doing so is higher than remaining alone. These benefits can be obtained due to 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 what differentiates bargain models from unitary ones (Alderman et al., 1997). Cooperative models assume 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. Per this assumption, the bargaining process guarantees intra-family time allocation and distribution of resources where the position of each family member cannot 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).

The assumption of free communication, symmetry of information and voice between family members led to the formulation of a specific cooperative approach: the collective model (Chiappori, 1988, 1992; Apps and Rees, 1988), where household members have their own utility function and the household equilibrium is Pareto-efficient: they behave as if the household optimizes a collective utility function, with the individual utilities of the members as arguments. As stated in Laisney and Beninger (2002), the basic model has been extended in several directions, including household production, children and resource sharing rules within the household (e.g. Apps and Rees, 1996, 1997, 1999; Chiappori, 1997; Chiuri, 1999;

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).

On another hand, 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 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; Cheng and Woolley, 2001). Although one member cannot coordinate his 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 must be produced by one member but can then be consumed by all of them.

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; Wells and Maher, 1996; Konrad and Lommerud, 2000), accounting 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 to explain 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.

5. Synthesis, conclusions and further research

Time use research is a multidisciplinary field with contributions originated from diverse areas, focuses and approaches. This diversity can be an excellent basis to build a solid theoretical and methodological structure toward the study of time allocation. We have summarized, addressed and examined different forms of looking at time use literature: by discipline, historical context and type of analysis. We gave the reader a brief description of the origins and evolution of time allocation literature through different approaches, focusing later on the modeling part of time use research through the eyes of the particular activity being studied and as an overall phenomenon. This exhaustive exercise has taught us some lessons.

To our opinion, the main resulting insight from this review is that the literature on time use research is overwhelmingly diverse and disconnected, showing little interaction across disciplines, due in part to issues such as the heterogeneous nature of the research approaches and disciplinary styles and backgrounds. This compartmental evolution has not allowed overcoming limitations that could be solved by integrating the advantages of multiple frameworks, such as the formulation, the explanatory power and interpretation of current models. We believe there are clear opportunities of knowledge transfer between the individual disciplines.

Regarding paid work, labor theory would benefit from the formulation of specific technical relations with different types of activities, e.g. the incorporation of working trips into the total working hours or the relationship between the quality of the work performed and sleep time.

In terms of unpaid labor, the exploration of the role of households in building human capital resources should de further addressed. So far, items as education, nurturing and training are still classified as consumption rather than investment, leading – for example - to the debate about the extent to which childcare is a community concern rather than just a private, parental responsibility. Also, there is a need to further study the effects of changing household technology on unpaid household work and its links with, for example, gender division of labor.

Leisure literature could benefit greatly from agreeing on a unified and operational taxonomy for productive and unproductive activities (leisure, tertiary). Additionally, recreational demand modeling would benefit from the interaction with the theoretical background already developed in overall time use literature.

In terms of tertiary activities, further research in transport analysis should focus on data requirements (new and/or more detailed kinds of data) and data quality; and on modeling challenges, like the inclusion of new variables and the treatment of the increasing complexity of transport models. Regarding sleep, given its relevance both in magnitude within a work-leisure cycle and the impact on the quality of other activities, integration with other disciplines and the enrichment of present modeling frameworks with past and current findings, is nearly mandatory. Further research could be built upon the development of alertness and of the relationship between sleep and productivity.

Finally, the study of the use of time as a whole could evolve toward an exploration of the utility framework (e.g. different utility functions and diverse budgetary and technical constraints) and the study of the interaction between different units of analysis.

The interdisciplinary research needs and opportunities identified above are examples of what we consider the main issue in time use modeling, which is the general disconnection among studies on time use across different disciplines. To estimate models mainly focused on paid work, unpaid work, or non-work activities (leisure or tertiary) might lead to biased results given that individual time allocation decisions are not properly represented. Thus, it is our recommendation that, even if researchers are trying to understand a particular activity, they need to assess the importance and influence of all activities that the individual performs in a given period – even at an aggregate level - so that the decision process is fully characterized.

Looking at different activities simultaneously within the context of overall activities is far from trivial. Future studies should consider the type of categories identified here as they imply different analytical treatments, e.g., classifying commute

as transport or paid work, or categorizing childcare as a tertiary activity or leisure. Further research could yield another type of classification (e.g. productive and unproductive activities) or a further disaggregation of categories. Furthermore, the classification of models by activity can somehow be complemented with the treatment of other dimensions covered here, such as the unit of analysis or the intertemporal framework.

Another important lesson for the immediate research agenda on time use is the detection of interesting formulations and methodologies in some areas that could feed other areas and facilitate integration. For example, some activities have been looked, modeled and analyzed as discrete choices, as is the case of travel and recreation. Discreteness has received attention from the modeling viewpoint by itself, which has generated sophisticated treatments that have led to the emergence of models like the multiple discrete-continuous extreme value approach, whose generality and flexibility makes it a good candidate to accommodate an integrating view of time use as an all-embracing phenomenon that can have a magnifying lens on specific activities.

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 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-Díaz, 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 is close to mandatory in the present stage of world development, where technical advancements have changed domestic and work life dramatically.

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