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Discrete Choice Decision-Making with Multiple Decision Makers within the Household

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Abstract

There is still a long way to achieve the goal of providing a theoretical and empirical framework to model and apply economics of the family. Decision-making within the family has been neglected too long in transportation. Two special issues by Bhat and Pendyala, 2005 [15] and by Timmermans and Junyi Zhang, 2009 [76] provide the most notable exceptions. The objective of this paper is to set-up a flexible framework to discuss the development of integrated transportation models involving interacting and interdependent actors; updating previous reviews from the point of view of economics of the family . Transportation is very keen to have access to this type of models, since their applications are numerous. Let mention, for example, residential location choice, workplace choice, car ownership, choice of children's school, mode choice, departure time choice activity patterns and the like. The (non unitary) economics of the family models are totally different models, which do not merely extend existing discrete choice models. They introduce new concepts, which are specific to within family interactions: negotiation, altruism, or repeated interaction and Pareto optimality. This review is completed with the study of different types of accessibility measures including recent work on time-geography measures of accessibility.

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1. Introduction

Different research streams concerned with household decision-making have developed independently in different disciplines. The corresponding papers consider topics such as labour supply, transportation decisions, time and task allocation, or residential and employment choices. Literature in these fields has been dominated by models in which the household is treated as a single decision-making unit or unitary models (see Timmermans, 2006 [74] for an extensive review on past research in the transportation literature, and Vermeulen, 2002a [79], 2002b [80] for a literature review on unitary and collective household models). In collective models, the different household members are engaged in a joint decision process involving bargaining. Until recently, interactions within the household were not explicitly modelled and the decision-making process outcome was considered as resulting from a representative individual (as if the household were a black box which needs not to be opened). In such models, household interactions were either introduced through explanatory variables defined at the household level, or simply disregarded in models of activity-travel demand (see Srinivasan and Bhat, 2005 [70]). Examples of household-level explanatory variables like number of household members, of active members, of children, household income, and other household dummy variables (e.g., occupational status, property status, age, etc.) are provided in Townsend, 1987 [77] or in Golob and McNally, 1997 [37], among others.

However, many household decision-making processes involve more than one decision maker who cannot be reduced to a single agent. Note that even when the decision problem under scrutiny does not involve multiple decision makers, most of the individual decisions depend, directly or indirectly, on the choices made by other household members (Timmermans and Zhang, 2009 [76]). A growing body of research in different fields, ranging from transportation demand to labour economics, has recently started to explicitly take into account the interactions between household members, and to model the corresponding strategies. The distinction between discrete and continuous household decisions is at the core of these new theoretical and empirical developments. Van Soest, 1995 [78] proposed a discrete choice model of labour supply disregarding the negotiation process within the household, whereas collective models of time allocation and labour supply focus on this negotiation process in discrete (Vermeulen, 2006 [81]) or in continuous-discrete applications (Blundell et al., 2007 [19]). The

modelling of within-family interactions took off in the transportation literature with the special issues on modelling intra-household interactions edited by Bhat and Pendyala, 2005 [15] and by Timmermans and Zhang, 2009 [76]. In a nutshell, Bhat and Pendyala, 2005 [15] focus on contributions based on utility-maximizing models, whereas Timmermans and Zhang, 2009 [76] present work that "adopt diverse methodologies" as group decision theory, and micro-simulation approaches.

A careful review of the literature reveals two main streams of research using the discrete choice framework to model household decision-making processes in multi-person households (several decision makers), with an explicit modelling of within-family interactions. In these studies, household decision-making models are developed in a discrete choice framework or with discrete choice (econometric/empirical) applications. The first research stream is related to collective models and their discrete labour supply model applications. The second research stream covers the transportation, activity-demand and location literature. These streams will be described in the following sections.

Section 2 explains the difference between individual and family models, and provides a transition from unitary to collective and negotiation models, with a special focus on labour supply models. The transportation and activity-travel demand literature with intra-household interactions is presented in Section 3. Section 4 describes the location and accessibility contributions considering multiple decision makers within the households, while Section 5 concludes.

2.   Individual versus Family Models

There are two cases when it becomes relevant (and often necessary) to switch from individual decision-making models to family decision-making models. The first case is when the choices themselves are relevant to the family (marriage, divorce, number of children). The second case is when individual choices generate externalities to the other members of the household (competition among family members for using a joint car, joint leisure, chores sharing, spatial mobility, retirement plans…).

Current research on family economics aims at providing the best representation of the household decision-making process, when the household is made of several decision-makers. In

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the simplest (unitary) models, the household is considered as the unique decision unit, whereas in the most elaborate models, each household member is characterized by specific preferences, and the household decisions result from the confrontation (or aggregation) of these individual preferences.

2.1. Individual Choices about Consumption and Work

Traditionally, family economics describes household behaviour, focusing on choices concerning consumption and work. In order to examine these questions, the household is described as a small production unit combining domestic time with intermediary goods bought on the market in order to produce some commodities, which are in turn consumed by household members). These developments have allowed economists to answer old but important questions related to major socio-demographic changes over the twentieth century, such as the change in domestic working hours (Gronau, 1977 [39]) and female labour supply, the growing divorce rate (Becker, Landes, and Michael, 1977 [10]), or the diminishing fertility rate (Becker and Lewis, 1973 [11]). The description of household behaviour may rely on contributions from various disciplines such as sociology, demography or ethnology (see Picard, 1999 [62]). The topics under study go far beyond consumption or work choices. However, the way of representing household decisions in family economics until the late 80's is not very far from that of "traditional" models of consumption and labour supply, since these models generally neglect the multiplicity of decision-makers.

The methodology traditionally used in family economics is quite straightforward. A (unique) household utility function describes the household preferences, taking as arguments the quantity of goods consumed (including local amenities when location choices are at stake) and/or leisure time. This function is maximized under a unique budget constraint aggregating the resources and expenses of all household members (and possibly a unique aggregated time constraint). The maximization of household utility determines the relevant demand functions. This procedure can be used for assessing the effects of economic policies on individual behaviour and welfare. For example, Hausman, 1981 [43] estimates the effect of a variation in marginal taxation rates on hours worked, and measures the cost of the US taxation system in terms of welfare.

2.2. *Family Economics in Unitary models*

In the "unitary model", the household is considered as a unique decision-maker, and no attention is devoted to the complexity of the decision-making process and of the numerous transactions between family members. As pointed by Nobel Prize laureate Amartya Sen, 1983 [67], in the unitary models literature, the household members are incorporated into a "glued together family". Following the impulsion originated from seminal work by Nobel Prize laureate Gary Becker (1965 [5]; 1973 [6]; 1974 [8]; 1991 [9]), recent developments in family economics broadens the classical research field to new questions such as the marriage decision or choices related to the number of children, their education, and the allocation of tasks and time among household members.

In unitary models, any difference in the demographic structure (e.g. differences between a single person and a couple with or without children) is either totally ignored, or simply reflected in *ad hoc* equivalence scales.

In addition, any conflicting situations that might arise among members (affecting the decision-making process) are disregarded. The unitary model indeed neglects the diverging interests that may arise among household members, and implicitly assumes that these members pursue consensual objectives, leading to a poor understanding (and thus modelling) of decision mechanisms (and therefore, of resources allocation) within the household. This generates three kinds of drawbacks. The first drawback is a wrong interpretation of empirical results. For example, Lise and Seitz, 2011 [53] show that failing to consider changes in the intrafamilial distribution of consumption leads to a major overestimation of inequality growth over the last 40 years in the UK. This bias should be taken into account in any poverty-reducing policy, and its recognition would lead to a fundamental rethinking of the change in intrafamilial distribution of consumption. The second drawback is a wrong assessment of the effects of economic policies on the well-being of each household member, concerning for example a change in the income taxation system. Lundberg, Pollak, and Wales, 1997 [55] illustrate the importance of these questions for family policy, and show that a shift of family benefits from the father to the mother during the 70s in the UK was followed by a rise in the demand for women's and children's clothes. This indisputable empirical result is inconsistent with the "unitary model" of the household in which every member has the same objective function. The third drawback is a

poor predictive power of unitary models and a biased evaluation of behavioural effects of economic policies.

Unitary models implicitly or explicitly assume that the household is the basic decision unit, and acts as a unique decision-maker. In multi-person households, this implies that members are supposed to act as if the household preferences could be represented by a unique utility function, maximized under a unique budget (and time) constraint. The consensus model proposed by Samuelson, 1956 [65] could provide some justification of this unitary description, under very restrictive and unrealistic assumptions. Another attempt to legitimate the unitary approach was made by Becker, 1974 [7], with his famous "rotten kid" theorem. It basically states that, if there is a "benevolent dictator" in the family, then all family members, even if they are selfish, will act to maximize the same utility function as the benevolent dictator. The key assumption is that the benevolent dictator transfers money to each family member. All members then want to please the benevolent dictator in order to receive a larger transfer. However, Bergstrom, 1989 [14] later stressed that this attempt to justify unitary models relies on too arbitrary and unrealistic assumptions (especially the assumption about transfers). Moreover, theoretical predictions derived from unitary models, such as income pooling, are often in contradiction with empirical data. Income pooling means that household decisions depend on household total resources, but not on the distribution of these resources among family members. This prediction comes from the assumption of a unique budget constraint defined at the household level, and a unique household utility function to be maximized. Income pooling has been rejected, for example, by Thomas, 1990 [73], who showed that the relative contributions of men and women to the household income influence household decisions.

2.3. Family Economics in collective and other bargaining models

Collective models and other within-households bargaining models aim at answering the theoretical and empirical criticisms addressed to unitary models of family decision-making. They developed in two major directions.

"Strategic" models rely directly on the theory of non-cooperative games (see, e.g. Ashworth and Ulph, 1981 [4], Leuthold, 1968 [52]), while "collective" models proposed by Chiappori 1988 [22],

1992 [23] rely on the basic assumption that the household decision process leads to Pareto-efficient allocations. The bargaining process may then be either explicit (as in McElroy and Horney, 1981 [56], or in Lundberg and Pollak, 1993 [54]), or non-specified (as in Chiappori, 1988 [22], 1992 [23]). In the latter case, the bargaining process is very general and not restrictive, only assuming Pareto-optimality.

Pareto-optimality hypothesis seems natural for analyzing household decisions since family members, who interact over a long period, are probably able to find mechanisms leading to efficient decisions.

Collective models can be used to study the welfare level of each household member, and therefore to analyze and measure in a consistent way the redistributive effects of any economic policy, not only at the household level but also at the individual level. Indeed, recent theoretical results show that, under some rather plausible conditions, individual utility functions can be recovered from household behaviour (and disentangled from bargaining power effects, whereas bargaining effects induce a bias in the measurement of preference parameters in unitary models).

This evaluation of economic policies offers promising research avenues, especially in the context of urban development or transportation policies.

2.4. Labour supply models within the family

Examples of applications of the two-adult model are provided by Hausman and Ruud, 1984 [42]; Ransom, 1987 [64]; Bloemen, 1989 [17]; Kapteyn, Kooreman, and van Soest, 1990 [45]. In these models, hours worked by the two spouses are treated as mixed discrete and continuous random variables, whereas in van Soest, 1995 [78] they are treated as discrete, which allows easily incorporating nonlinear taxes, joint filing, fixed costs of working, unemployment benefits, hours restrictions, unobserved wage rates of non-workers, and random preferences, etc., without challenging model tractability. The models are estimated using smooth simulated maximum likelihood relying on Gourieroux and Monfort, 1993 [38].

The method is illustrated by several policy simulations. Unfortunately, it assumes a unitary model, which neglects the effect of the policy on respective bargaining powers, and may therefore lead to severe bias in labour supply reactions.

In the collective models (Chiappori, 1988 [22]; Chiappori, 1992 [23]), the only assumption made about the decision-making process is the Pareto efficiency (optimality of decisions). That is, the decision-making process involving more than on household member leads to allocations such that it would not be possible to make one household decision-maker better-off, without making at least another household decision-maker worse off. The collective models are very general in the sense that they do not rely on a restrictive specific bargaining process, and they do not assume any restrictive functional form for each member preferences. Collective models have proved at many occasions to perform better than the usual unitary models to explain observed behaviour (Vermeulen, 2002a [79]).

Collective models of labour supply have been developed for two-earner households (e.g., Fortin and Lacroix, 1997 [34]; Moreau and Donni, 2002 [59]; Chiappori, Fortin, and Lacroix, 2002 [25]) in a continuous framework. However, the interest here is limited to the models in which utility functions are directly estimated and household labour supply is considered as a discrete choice problem. The contributions of Van Soest, 1995 [78], Bingley and Walker, 1997 [16] and Keane and Moffitt, 1998 [46] are the first ones to use a discrete choice framework to study labour supply, but this was done in the context of a unitary model.

Van Soest, 1995 [78] developed a joint labour supply model for two spouses, in which the budget set is discrete. The discretization of the budget set allowed for incorporation of nonlinear taxation and non-convexities, which gave rise to a series of discrete collective labour supply models, starting with Laisney, 2002 [50] and subsequently with Vermeulen et al., 2006 [82], Vermeulen, 2006 [81], and Blundell et al., 2007 [19]. Laisney, 2002 [50] considers household labour supply as a discrete choice problem, and integrates non-participation and nonlinear taxation. Vermeulen et al., 2006 [82], develop a discrete choice collective model and solve it using a procedure mixing calibration and estimations. Blundell et al., 2007 [19], consider a model in which the male labour supply is discrete, whereas the female labour supply is continuous. Vermeulen, 2006 [81], models female labour supply in a discrete choice framework considering male labour supply as given, and including non-participation and nonlinear taxation.

Other discrete collective models of labour supply include Callan, Van Soest, and Walsh, 2009 [21]; Bloemen, 2010 [18]; Haan, 2010 [40]; Michaud and Vermeulen, 2011 [57]; Pacifico, 2012 [61].

3. Intra-household interaction and group decision-making models

The main research stream applying discrete choice models to household decisions involving multiple decision-makers has been developed in the transportation literature. It includes the so-called intra-household interaction and group decision-making models of transportation, activity-demand, and location choices. Intra-household interaction models study how the household decides in the long run and in the short run. More precisely, these models take into account the interdependencies between residential location and workplace of household members (long term), or between activities and travel patterns (short term). Intra-household interaction models are interested in studying, for example, which activities are conducted in a day or over several days by the household members (sharing maintenance responsibilities, household cars, and pick-up and drop-off); when, where, by whom and with whom the activities are performed (joint or independent engagement on activities); and how job types and job locations of the different household members affect professional and residential mobility and location decisions of the household.

The general research stream concerned with intra-household interaction and group decision-making models of transportation, activity-demand, and location choices research stream can be subdivided into two interconnected subfields of study. The first subfield is concerned with choices in a long-term decision context (i.e. residential location and mobility; job location and mobility, car ownership). Abraham and Hunt, 1997 [1]; Freedman and Kern, 1997 [35]; Sermons and Koppelman, 2001 [68] and Waddell, 1996 [87] have analyzed residential and professional location choices as resulting from a multiple-worker household decision-making process.

The second subfield is made of studies concerned with choices in a short-term decision context: the activity-travel demand literature (i.e. mode choice, travel behaviour, car sharing, and task allocation and activity based models). This literature develops models of task allocation, decisions related to joint travel and activity participation, mode choice, car sharing and so on.

Discrete choice modelling on these topics has been studied by Wen and Koppelman, 1999 [89], 2000 [90]; Gliebe and Koppelman, 2002 [36]; Scott and Kanaroglou, 2002 [66]; Vovsha, Petersen, and Donnelly, 2003 [84]; 2004a [86]; 2004b [85]; Bradley and Vovsha, 2005 [20]; Srinivasan and Athuru, 2005 [69]; Srinivasan and Bhat, 2006 [71], among others.

The work of Gliebe and Koppelman, 2002 [36]; Scott and Kanaroglou, 2002 [66]; Vovsha, Petersen, and Donnelly, 2003 [84]; Srinivasan and Bhat, 2006 [71] concerns the decision to participate in an activity jointly or independently from other household members. Gliebe and Koppelman, 2002 [36] model independent activity participation, allocation of time to joint activities, and the interplay between individual and joint activities using a proportional share model. Scott and Kanaroglou, 2002 [66] develop a trivariate (by household type) ordered probit to model the number of non-work, out-of-home activity episodes for household heads.

The work concerned with task allocation (of maintenance activities) is better represented by discrete choice model systems that are embedded in tour-based travel demand modelling systems. On the one hand there is the discrete choice system of Vovsha, Petersen, and Donnelly, 2003 [84]; 2004a [86]; 2004b [85] that is the joint travel model component that makes part of the Mid-Ohio Regional Planning Commission. On the other hand there is the discrete choice system of Bradley and Vovsha, 2005 [20] that is part of the activity-based model of the Atlanta region.

Bradley and Vovsha, 2005 [20] survey the contributions on activity-travel demand literature, in which either intra-household decision-making *is not* considered explicitly, or discrete choice model techniques are not used.

The attention is restricted here to theoretical or empirical developments that consider a discrete choice modelling strategy in activity-travel demand models accounting for interpersonal dependencies in multiple decision-makers households. However, the activity-travel demand literature has also used seemingly unrelated regressions (SUR) and structural equation modelling (SEM) to account for household interactions (see Srinivasan and Bhat, 2005 [70]). These approaches usually develop a SUR or SEM system of two or more equations corresponding to the time invested in activities by the household head and the other members in consideration (household head spouse and/or children or other active household members).

Other classifications of activity-travel demand models that account for interpersonal dependencies in households with multiple decision makers have been proposed. For instance, Timmermans, 2006 [74] classifies activity-based travel demand models that explicitly consider interactions within households with multiple decision makers into three categories: micro-simulation, rule-based and utility-maximizing models. Micro-simulation models simulate a household member daily activity-travel pattern using algorithms that replicate the observed patterns from data (including time constraints and actual decision-making outcome) giving timing and sequence of activities schedules that account for household's and personal's characteristics (see, e.g., Pribyl and Goulias, 2005 [63]). The second category of models is referred to as the rule-based models. They build multi-agent computational processes in which the individual activity-travel decisions reflect "if-then" decision tree structures, regarding which activities, with whom, and for how long the activities are conducted (see, e.g., Arentze and Timmermans, 2004 [3]).

Timmermans' last category of models corresponds to the utility-maximizing models. He further subdivides utility-maximizing models into those using the discrete choice approach (based on the random utility models) and in those using the time allocation approach. Time allocation models are based on a group utility function. This function is a linear function of individual-specific terms and of interaction terms that reflect the interactions between different individuals in a multiplicative form. The household then allocates its time to activities such that its utility would be maximized given individual time constraints (see, e.g. Zhang and Fujiwara, 2006 [93]).

4.   Location and Accessibility

Lee et al., 2009 [51] categorized accessibility measurement approaches into four groups: the proximity based (measured in term of travel time, distance, etc.), the gravity-based (derived from the denominator in the gravity model), the cumulative opportunities approach (as a special case of the gravity-based measure), and the utility-based approach (denominator of the MNL model). See Lee et al, 2010 [51] for more details on this classification and for further references.

The utility-based approach allows for the development of disaggregated or individual-specific accessibility measures captured in the log-sum variable when the nested logit formulation is used. See Ben-Akiva and Lerman, 1979 [12]; Srour et al., 2002 [72]; Waddell and Nourzad, 2002 [88]; and Zondag and Pieters, 2005 [94] among others.

A major determinant of household location is accessibility. Accessibility to jobs measures the spatial proximity of the residential location to the job location. In the absence of income effects, and with a Logit demand function, the accessibility is measured by a log-sum term, which is a measure of consumer surplus. In the Logit case, accessibility corresponds to the expected maximum utility, which is equal to the Logarithm of the denominator of the Logit demand function. It is easy to see that when the utility is additive in income, the derivative of the accessibility is the demand function. This is a direct application of Roy's identity. The same property in true for the GEV, provided that the utility is additive in income (and, as a consequence, there are no income effects). The reader is referred to Anderson, de Palma, and Thisse, 1992 [2]; and de Palma and Kilani, 2007 [28] for details.

In the homogenous case, all agents have the same preferences (this means in particular, the same values of time and the same preferences for jobs), and therefore have the same measure of accessibility. In the heterogeneous case, the accessibility depends on household characteristics and in particular on the value of time.

Research on residential location has commonly used accessibility as an aggregated measure of ease of access to jobs or people in choice models where the household is considered as a single decision-making unit (individual or unitary approach). By contrast, Chiappori, de Palma and Picard, 2012 [24] have studied residential location of households including two active spouses. In the context of a collective model assuming Pareto-optimality, they measure simultaneously spouses' respective values of time and bargaining powers. They show that neglecting bargaining powers can lead to a bias in the estimated values of time which may reach 20%. The order of magnitude of this bias is comparable to the male-female difference in values of time.

In the individual or unitary approach, accessibility has been (1) studied in single and multiple-worker location choice models, (2) measured using different approaches, and (3) used as an

indicator of non-work activities. We develop in the following subsections these three issues on the use and measurement of accessibility measures.

4.1. Accessibility Measures From Multiple Worker Location Choice Models

The study of the interactions between household members within a household in residential location choice models has allowed the differentiation of accessibility measures by socio-demographic characteristics, identifying differences between females and males, and between multiple-worker households and one-worker households. The reference studies of multiple-worker residential location choice models are the works of Timmermans et al., 1992 [75], Abraham and Hunt, 1997 [1], Freedman and Kern, 1997 [35], and Sermons and Koppelman, 2001 [68]. Note that Timmermans et al., 1992 [75] studied the residential location choice of two-worker households but using a nine-steps (decompositional) joint choice model.

Abraham and Hunt, 1997 [1] used a logit model structure with a system for weighting the contributions of different workers to the household utility in a three-level nested logit (residential location, workplace, and mode choice). Freedman and Kern, 1997 [35], analyzes residential location and workplace with a joint logit model where a two-worker household jointly chooses residential location and both spouses workplace to maximize utility, subject to budget and time constraints. Sermons and Koppelman, 2001 [68] develop a multinomial logit model of residential location choice to study differences between males and females in sensitivity to commuting time for two-worker households.

In general, these studies showed that females are more sensitive to commuting time and accessibility measures than males. Demographic characteristics such as presence of children, workplace status, and spouses occupation and workplace location, are determinants for commuting time and accessibility measures, and therefore residential location choices in a multiple worker household.

4.2. Individual-specific Accessibility Measures

Despite the variety of contributions to the study of residential location, little has been said regarding the influence of job type on the individual-specific accessibility to jobs, and therefore

on the residential location and workplace choices when individuals are considered forward-looking. Household members choose a workplace conditional on their current residential location, while also considering the future changes on workplaces when choosing their residential location.

Inoa, Picard, and de Palma, 2012 [44] have elaborated a three-level nested logit model that allows to study the interdependency of residential location and workplace, while accounting for variation of preferences for job types across individuals. Residential location is the upper level choice, and workplace and job type are the middle and lower level choices, respectively. With this nested structure, an individual-specific accessibility measure is constructed, which corresponds to the expected maximum utility across all potential workplaces and job types. When considering accessibility to jobs, the choice of a particular workplace depends on the distribution of jobs by type, which are valued differently by different workers. Their modelling of the job type choice allows them to compute an individual-specific measure of attractiveness to job types (log-sum variable) and to use it in the workplace location choice model.

Using data from the Paris Region Census, Inoa, Picard, and de Palma, 2012 [44] find that the individual-specific job type attractiveness measure is a more significant predictor of workplace location than the standard total number of jobs measure. Most importantly, the individual-specific accessibility measure is an important determinant of the residential location choice, and its impact on the residential location choice strongly depends on gender, fertility, age, and education. Some resulting individual-specific accessibility maps are displayed in Annex. They show that accessibility is more equally distributed over the region for the lowest education level, whereas it is more concentrated in the CBD for the most educated workers.

4.3. Time Geographic Measures of Accessibility

4.3.1. Activity Pattern Models

The literature on residential location has not restricted accessibility to the concept of proximity to jobs. It has also studied the accessibility to different (non-work) activity opportunities and measured their respective influence on residential location. Activity–travel demand and task allocation models are concerned with the activity patterns of households and individuals all over a day (and even all over a week, in the new activity-based time use data sets). Capturing non-

work accessibility is therefore essential when modelling in-home and out-of-home activity patterns and trip chaining (Neutens et al., 2012 [60]). Accessibility measures adapted for these models can be found in the framework of time geographic measures of accessibility.

Hägerstrand, 1970 [41] introduced the concept of time-space prism (TSP) in order to describe the temporal and spatial constraints in which individuals travel to and participate in activities. Time-space prisms define the locations that an individual can reach given a time budget. The area shaped by the potential locations that the individual can reach in a given time gap is referred to as the potential path area (PPA). A thorough study of the time-geographic measures can be found in the work of Miller, 1991 [58] and Kwan, 1998 [49]. Kim and Kwan, 2003 [47] provide a review on accessibility measures used in empirical settings derived from the time-space prism.

There exist only a few applications where time-geographic measures of accessibility have been used in the literature under consideration here, that is, discrete choice location models and activity-travel demand and time allocation models that consider intra-household interactions. Among these applications are the work of Lee et al., 2010 [51]; Yoon and Goulias, 2009 [91], 2010 [92]; Kitamura et al., 2001 [48]; Ettema, 2006 [33].

Lee et al., 2010 [51] developed a discrete choice residential location model that includes a disaggregated accessibility measure to non-work activities (derived from the TPS framework), while also accounting for the accessibility to jobs. Yoon and Goulias, 2009 [91], 2010 [92] developed a structural equations model of activity and time allocation that consider intra-household interactions in households without child only and then in households with and without child where the accessibility measure used is based on time geography. Using time-geographic accessibility measure, Kitamura et al., 2001 [48] studied the influence of travel patterns and residential location on car ownership; and Ettema, 2006 [33] developed a discrete continuous Tobit model of activity participation and duration.

4.3.2. Dynamic Transport Models

The time geographic models described above neglect the interactions between households. However, such interactions are important in the case of congested cities and they evolve across time and geography. Such externalities are analyzed in dynamic transport models.

METROPOLIS is a dynamic model which describes mode choice, route choice and departure time choice (see de Palma and Marchal, 2002 [32]; de Palma, Kilani, and Lindsey, 2005 [29]; and de Palma and Lindsey, 2006 [30]). It is *dynamic* in the sense that congestion depends on the time of the day. It uses a nested logit model, where the mode choice is made at step one, while departure time choice is made at step two.

The departure time choice is given by a continuous logit model, with the log-sum formula as the welfare measure. In this case, the mode choice model, at the upper level, depends on the accessibility at the lower stage. Consider a user going from origin *i* to destination *j.* The attractiveness of this car user (the formula is similar for the public transportation users) is:

$$A_{ij}(t) = \int_0^T \exp\left[-C_{ij}(u)/\mu\right] du,$$

where $C_{ij}(u)$ represents the generalized cost of an individual using private transportation, and *u* (and *t*) denote the departure time. Following Vickrey, 1969 [83], this generalized cost is given by:

$$C_{ij}(u) = \alpha tt_{ij}(u) + \beta\left(t^* - u - tt_{ij}(u)\right)^+ + \gamma\left(u + tt_{ij}(u) - t^*\right)^+,$$

where α is the value of time, β is the unit schedule delay early parameter, γ is the unit schedule delay late parameter, t^* is the desired arrival time at destination and $tt_{ij}(u)$ is the travel time given the departure time *u*. Such measure is potentially useful for other applications, such as activity choice, or residential location. In the latter case: the log-sum aggregation over the destinations *j* provides a potential user benefit of residential location at *i.*

In the case of couples, the value of time of the man may not be the same in the case his spouse is at home at the time he leaves and in the case she leaves before him, and vice versa. In that case, the generalized cost function of the man depends on the departure time of the woman, and the generalized cost function of the woman depends on the departure time of the man. The resulting within-family externalities have been studied by de Palma, Picard, and Lindsey, 2012 [31]. They showed that, although cooperation is clearly beneficial for couples themselves, it may exacerbate congestion and thus worsen negative externalities between families.

4.4.   *Interactions within families outside the household*

Compton and Pollak, 2009 [26] have analyzed interactions within larger families, living in different households. They describe and analyze the patterns of proximity and co-residence

involving adult children and their mothers using data from the National Survey of Families and Households (NSFH) and the U.S. Census. Their idea is that the ability of family members to engage in intergenerational transfers of hands-on care requires close proximity or co-residence. They find that, in spite of the decline in intergenerational co-residence in the United States, most Americans still live within 25 miles of their mothers, and even closer for the lowest educational levels. Individual characteristics such as age, race and ethnicity affect both the probability of co-residence and close proximity, and their effect depends on gender and marital status, indicating the need to model the corresponding categories separately.

Compton and Pollak, 2011 [27] further show that close geographical proximity to mothers or mothers-in-law has in turn a substantial positive effect on the labour supply of married women with young children. They argue that proximity increases labour supply through the availability of childcare. Their interpretation of availability is there broad enough to include not only regular scheduled childcare during work hours but also an insurance aspect of proximity (e.g., a mother or mother-in-law can provide irregular or unanticipated childcare). Using large American datasets, they find that the predicted probability of employment and labour force participation is 4-10 percentage points higher for married women with young children living in close proximity to their mother or their mother-in-law compared to those living further away.

5.   Conclusion and extensions

There is still a long way to achieve the goal of providing a theoretical and empirical framework to model and apply economics of the family models. Decision-making within the family has been neglected too long in transportation. Two special issues by Bhat and Pendyala [12] and by Timmermans and Junyi Zhang [55] provide the most notable exceptions. We also refer the reader to the discussion on group behavior, held at the 11th IATBR conference (Kyoto), and organized by J. Zhang and A. Daly.

The objective of this paper was to set-up a flexible framework to discuss the development of integrated transportation models involving interacting and interdependent actors. Transportation is very keen to have access to this type of models, since their applications are numerous. Let mention, for example, residential location choice, workplace choice, car ownership, choice of children's school, mode choice, departure time choice activity patterns and the like. The (non unitary) economics of the family models are totally different models,

which do not merely extend existing discrete choice models. They introduce new concepts, which are specific to within family interactions: negotiation, altruism, or repeated interaction and Pareto optimality.

It is our belief that that activity pattern, mode choice, allocation of time, residential and job location choices, as well as departure time choice, cannot be analyzed in the family, without the idea that there are almost always conflicting interests, given the budget and the time constraints of the different family members. Therefore, some coordination and cooperation is needed to achieve common goals, even if the cost borne by spouses is often not identical. The transportation field has made large advances in this area, but the connection with the theoretical and the econometric model are still open.

The IATBR session mentioned above has also shown that cross-fertilization between the economics of the family and the transportation field is needed. We hope that this chapter will provide a first step to fulfil this gap. Some preliminary discussion on how to integrate bargaining and collective models in transportation and urban economics can be found in Ben-Akiva et al., 2012 [13].

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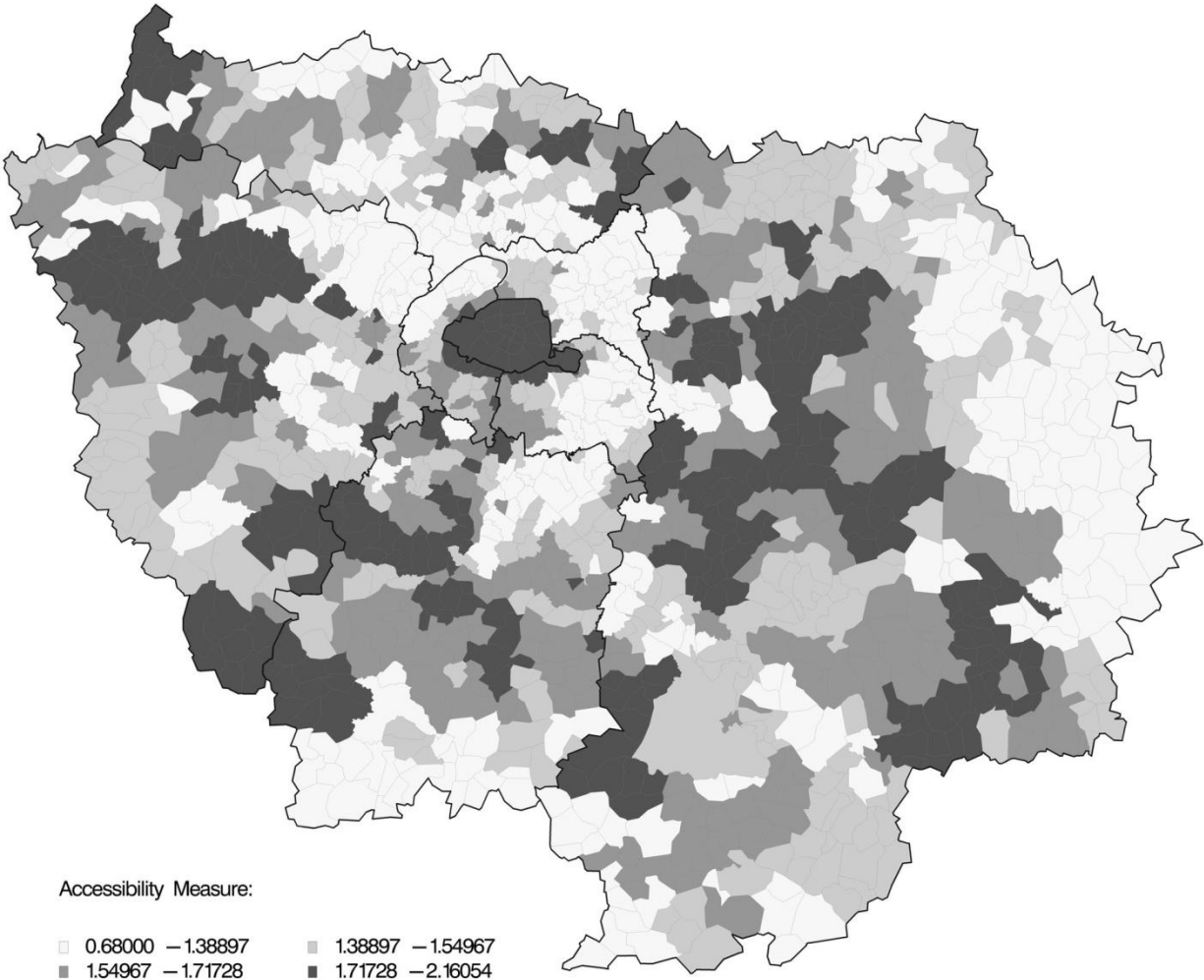
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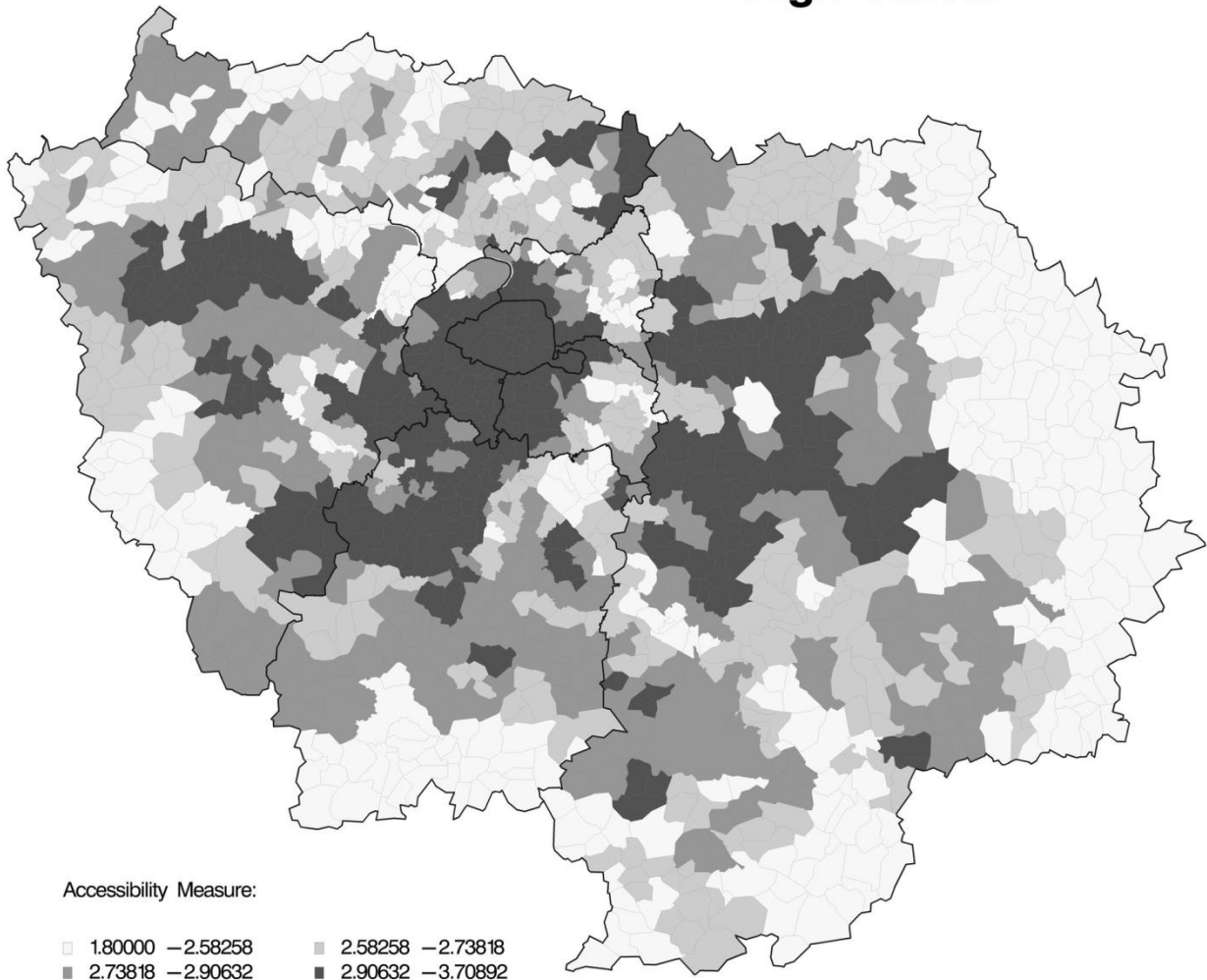
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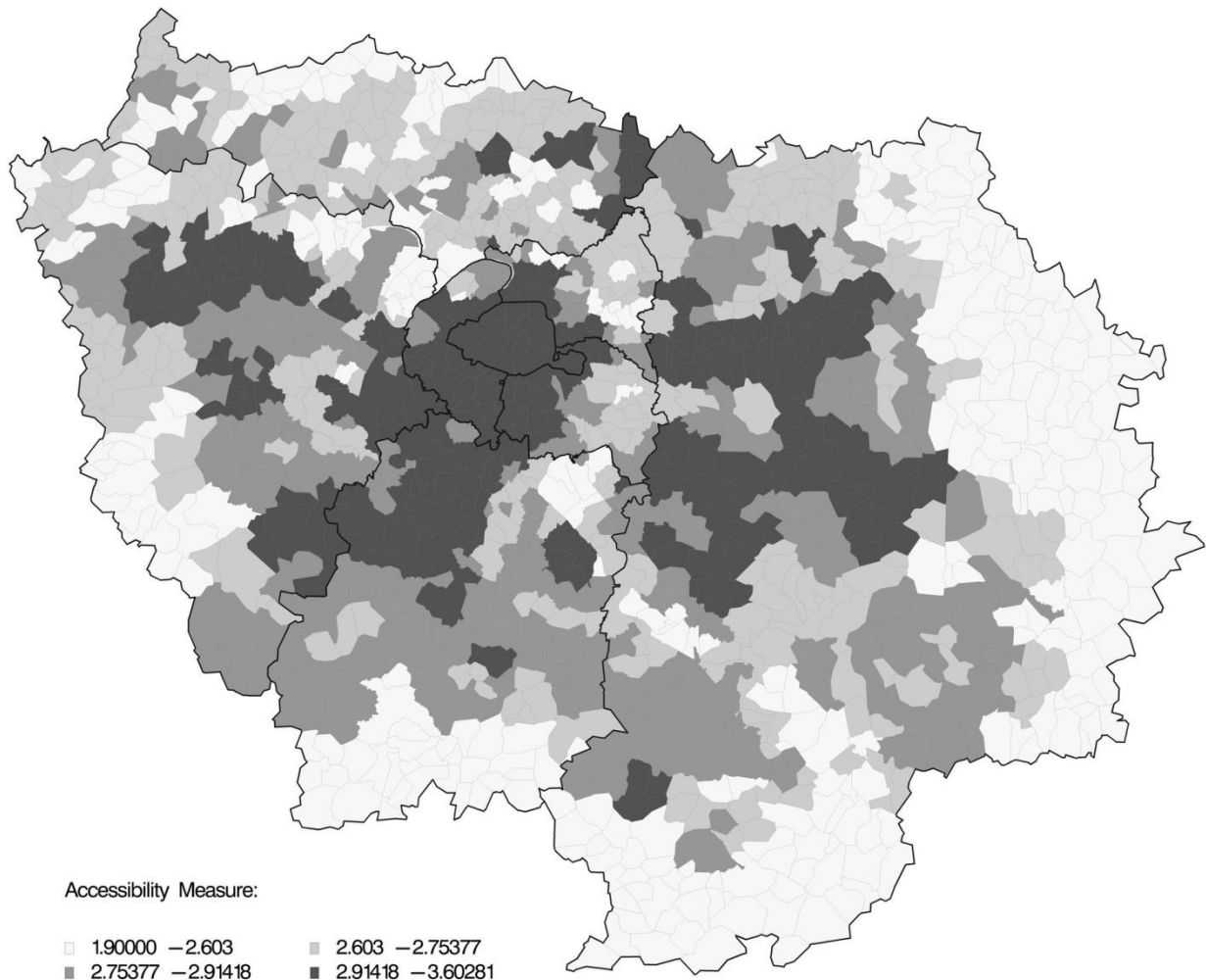
Appendix: Accessibility measures, by education level

Elementary and Middle School

Accessibility Measure:

☐ 0.68000 − 1.38897   ▦ 1.38897 − 1.54967
▨ 1.54967 − 1.71728   ■ 1.71728 − 2.16054

High School

Accessibility Measure:

☐	1.80000 − 2.58258	☐	2.58258 − 2.73818
■	2.73818 − 2.90632	■	2.90632 − 3.70892

Undergraduate

Accessibility Measure:

- 1.90000 − 2.603
- 2.603 − 2.75377
- 2.75377 − 2.91418
- 2.91418 − 3.60281

Graduate

Accessibility Measure:

- 2.32000 − 3.07778
- 3.21715 − 3.36903
- 3.07778 − 3.21715
- 3.36903 − 4.00525