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Nathalie Picard
André Depalma
Sophie Dantan

UNIVERSITÉ de Cergy-Pontoise

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Nathalie Picard
Université de Cergy-Pontoise, THEMA and École Polytechnique
nathalie.picard@u-cergy.fr
André de Palma
École Normale Supérieure de Cachan, Centre d'Economie de la Sorbonne and KULeuven
andre.depalma@ens-cachan.fr
Sophie Dantan
École Normale Supérieure de Cachan and Université de Cergy-Pontoise, THEMA
sophie.dantan@u-cergy.fr

Abstract

We review the literature on household decision-making in economics as well as in transportation and urban economics. This literature starts with Gary Becker in Economics, 30 years ago, and has recently been introduced to study specific questions related to space. We consider two examples: residential location and mode choice for dual earner households. In these two examples, the decision is the outcome of a bargaining process within the household. We show that the results may differ substantially when compared with those of the standard approach.

Keywords: *unitary models, collective models, mode choice, residential location, Pareto optimality.*

1 Introduction

Transportation and urban economics are mainly based on individual decision making processes: residential and job location, mode choice, departure time, or activity patterns. Aggregation of preferences and choices, although crucial, has received very little attention in the profession. The main tool used in transportation and urban economics, discrete choice models, ignores this multi-dimensional facet of decision making. One way to understand this paper is to see it as a first step in the modeling of decision processes within the family, for question raised in the transportation and urban economics context.

One ultimate scope of the research in transport and urban economics is to shed some light to help the public (and occasionally the private) bodies to design better policies. Domains of application are numerous and include infrastructure choices, subsidization, taxes, prices, etc. It is obvious for economists that policies affect individual and therefore aggregate behaviors. Poor policies may have negative consequences, or they may just never become effective due to strong political or grass root opposition. Toll policies provide an obvious example of such opposition, since they are often not accepted by the general public. Different stakeholders are opposed to potential inequalities and lack of fairness potentially induced by such policies. Opposition is often expressed in the media as: "x% of users are opposed", or less often as: "y% of low income people are opposed". All researchers know that tolls may have regressive effects, in the sense that high income individuals may be better-off, while low income individuals may be worse off. However, literature neglects one major point: policies may also generate inequalities within the same family. Household accessibility can be improved in standard models, but it is important to also understand how changes in accessibility affect the different members of the household. A given policy may, for example, improve accessibility for men, and decrease accessibility for women (while the average accessibility is improved). The reason may be schematically explained as follows.

Consider a dual earner household owing a single car used by the woman, who works relatively close by. Assume also that some roads (not used by the woman) are now tolled. One wishes to assess the impact of those tolls. Congestion will presumably be reduced on the tolled roads, but may increase on alternatives roads, especially on the road used by the woman. If the man decides to use the car on the tolled road (now more attractive), he may be better off (since travel time is reduced), while the woman may be worse off for two different reasons: no more access to the car, and less income. How the disposable income is spent and who is using the car are decisions depending on the bargaining process within the family. There is sometimes a "dictator" who decides for everything, but most often, the decisions are the outcome of a bargaining process involving multiple decision makers. The computation of who is winning and who is losing cannot be made without a subtle description of the intra-household decision process. We refer the reader to the previous papers published by the authors and coauthors of this current paper (see [19], [27], [23], [18]).

The objective in this paper is to make a first step to bridge the gap between two strands of literature which developed independently up to now. The first one covers location choice models that consider more than one household member or worker, but consider, implicitly or explicitly, a single decision maker. The second one focuses on the decision process in other contexts, when several decision makers with diverging preferences and constraints have to coordinate for some decisions. These two strands of literature differ not only with respect to their topics, but also with respect to the nature (discrete versus continuous) of the decisions analyzed. As a consequence, these two strands of literature used and developed totally different techniques. This distinction, at the core of new theoretical and empirical developments, is of the scope of this paper. More details on these two literature strands are provided in [19] and in [27]. Our ultimate objective is to make a step forwards in the analysis of joint mode choice and residential location choice in a dual-earner household, and measure the empirical implications of the bargaining process in some specific examples.

The paper is organized as follows. Section 2 reviews the first strand of literature, on household models not interested in the bargaining process itself, starting with the definition and limits of "unitary models", followed by specific applications in transport and residential location contexts. Section 3 reviews the second strand of literature, which focuses on the within-family interactions and bargaining process, usually in domains hardly related to transport or location. Section 4 then proposes a few applications of household decisions related to transport or location involving several decision-makers, highlighting the importance of the bargaining process. Section 5 discusses insights for future work and concludes.

2 Household models neglecting the bargaining process

2.1 Unitary models

In the economic literature, models considering a single decision maker are usually referred to as *unitary models*. This literature has been developed in economics, since the early work of Gary Becker ([5], [6], [7], [8], [9]), who was awarded the Nobel Prize for such seminal contribution.

Many researchers, especially in family economics, tend to criticize this assumption, questioning the hypothesis that the behavior of multi-person households can be described by a single decision-maker model satisfying the basic preference axioms (such as transitivity or continuity, for example), or the *income pooling* property (no matter who earns income in the family, it is spent the same way). Incidentally, we know, since the Arrow impossibility theorem, the difficulty to aggregate preference within small groups.

Different research streams concerned with household decisions have developed independently in different disciplines such as in labor supply, transportation, time and task allocation, or residential location and job choices. In these *unitary models*, the household is treated as a single decision-making unit; the interactions within the household are not explicitly modeled and the decision-making process outcome is, implicitly or explicitly, considered as resulting from a representative individual (as if the household were a black box which needs not be opened).

More recently, in the urban and transport literature, researchers have started to study the family determinants of choices affecting the family, even though they did not yet study the within-family bargaining process. In the current models, household interactions are either introduced through explanatory variables defined at the household level, or simply disregarded (in models of activity-travel demand, for example, see [30]). Examples of household-level explanatory variables are number of household members, of active members, of children as well as household income, and other household dummy variables (e.g., household head occupational status, tenure status, age, etc. See [34] or [22], inter alia).

2.2 Transport models

There is still a long way to achieve the goal of providing a theoretical and empirical framework to model and apply the framework of the economics of the family. Family decisions have been neglected too long in transportation. Two special issues ([11], [33]) provide the most notable exceptions, although they are not interested in analyzing or modeling the bargaining process itself. Transportation should be very keen to have access to this type of models, since their applications are numerous. Let mention, for example, choices related to residential location, workplace, car ownership, children's school, mode, departure time, activity patterns and the like. This review is completed with the study of different types of accessibility measures including recent work on time-geography measures of accessibility. We also refer the reader to another extensive review on past research on household (unitary) models in the transportation literature ([32]).

2.3 Residential location

The residential and job location choice literature is dominated by models considering a single decision-maker in each household. In such early models, the analysis of joint decisions (such as residential location choices, involving monetary cost, but also emotional and time dimensions) is usually simplified by assuming away the within-household bargaining process. De facto, it is assumed that there is a single decision maker, who can be seen as a more or less benevolent dictator, to use the terminology introduced more than 30 years ago, by Gary Becker, the father of Economics of the Family.

In the context of residential location, it is highly probable that some intra-household bargaining process plays an important role in dual-earner households. Intra-household bargaining process refers to the negotiation process within the household with respect to joint decisions, such as residential location, use of the car (when there is a single car), or choice of a holiday location. In particular, in the context of residential location, each worker in the household has his own preferences and constraints depending on his own workplace, generally different from the workplaces of the other workers in the same household.

Recently, economists and transport researchers have worked on explaining the effect of intra-household variables on the choice of residential location and workplace ([42], [1], [29]). Their analysis addressed the multiple-member household decisions, but not the multiple decision-maker problem, which involves a within-household bargaining process. Overall, intra-household considerations remain limited in this literature; the theoretical and empirical contributions on the effect of intra-household variables on the residential location and workplace choices are scarce. In particular, there are no published contributions on within-household bargaining process in location decisions (with the exception of the ongoing research [16] sum-up in the Section 4.4.

3 Household models recognizing the bargaining process

3.1 Past and current research in family economics

By contrast to the models reviewed in Section 2, *collective models* recognize that household decisions result from a bargaining process involving several decision-makers with individual specific bargaining power. These non-unitary models developed in the economics of the family literature do not merely extend existing unitary model, and discrete choice models. They introduce new concepts, which are specific to within family interactions: negotiation, altruism, repeated interaction and Pareto optimality. See [36] and [37]) for reviews of economic literature on unitary and collective household models.

More precisely, when there is more than one decision-maker in the household, a complex bargaining process usually takes place, and the resulting decisions would appear irrational if they were analyzed using a single decision-maker model. Since the 80's, economic literature has developed models analyzing the within-family bargaining process in other contexts such as labor supply or consumption. For example, [25] developed a specific bargaining process in the presence of multiple interrelated decisions made by multiple decision-makers, whereas [14] developed the so-called *collective model*. Collective models take account of the fact that multi-person households face joint decisions involving more or less altruistic members with specific preferences and constraints. In collective models, decisions are assumed Pareto-optimal in the sense that the solution of the bargaining process is on the Pareto frontier. By definition, when a decision is Pareto optimal, it is not possible to increase the well-being of one household member without decreasing the well-being of at least another member. In other words, spouses jointly make decisions leading to a Pareto-optimal outcome, if it is not possible to make one spouse better-off without making the other spouse worse-off. Pareto-optimality can be bested empirically, and is usually not rejected. By contrast, the assumptions and/or conclusions of unitary models are usually rejected in multi-person households.

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 were developed in two major directions. “Strategic” models rely directly on the theory of non-cooperative games (see, e.g. [3] or [24]), while “collective” models ([14], [15]) rely on the basic assumption that the household decision process leads to Pareto-efficient allocations. The bargaining process may be either explicit (as in [26], or in [25]), or non-specified (as in ([14], [15]). 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.

As shown in [15], 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. More specifically, he showed that, under some rather plausible conditions, individual utility functions can be recovered from household behavior (and disentangled from bargaining power effects, whereas bargaining effects induce a bias in the measurement of preference parameters in unitary models.

In addition, a few contributions use experimental economics methodology to compare the decisions taken by the husband alone, the wife alone, and then by the spouses together (see [4], [10] or [18]). However, these papers do not explicitly analyze and model the decision mechanism within the couple.

3.2 Application to residential location

Beyond the simple differentiation of location choice by socio-demographic characteristics, recent models dealing with family location decisions allow for the identification of differences between females and males, and between multiple-worker households and single-worker households. In the context of Paris Area, we analyze in this paper differences between spouses' commuting times and we show that spouses' disparities in commuting is a key element in the intra-household decision process. The single-worker household approach might leave aside important intra-household considerations that influence commuting time and accessibility to jobs. As a consequence, the one-worker oriented location choice models may lead to misleading conclusions for dual-earner households. More precisely, we argue that the framework introduced in [23], could also be adapted to analyze residential and job location choices in a two-worker household. By accounting for two accessibility variables (one for each spouse), their three-level nested Logit model could be used to study the interdependency of residential location and workplace, while accounting for variation of preferences for job types across individuals. This could be performed both in single- and in two-worker households.

4 Modeling intra-household decisions in specific examples

An important issue in modeling residential and job location is the interdependence of these two decisions, both at the individual level and at the household level. It can be argued that the choice of residential location is made conditional on the workplace, or vice versa ([42]). We can also argue that the choice of residential location is made in different time frames according to the life cycle of individuals. What households then consider in their joint location decisions, with a varying degree of importance along their life cycle, are the chances of each active member in the household to access a good job in each alternative location, which determines the accessibility to jobs of each household member, from any given residential location.

We present here an innovative perspective on the interdependence between residential location and workplace of spouses, taking into account the process of negotiation within the household, the travel time of each spouse, and the job accessibility for each spouse. For this we models of residential location to try to give clear answers to various theoretical and empirical issues concerning: the residential location conditional on workplaces and the joint choice of residential location and workplace of each spouse.

The work has allowed expanding and developing models that correct the bias in the individual value of time of spouses, separately measuring the influence of explanatory variables on the decision-making process within the household and the value of time of spouses by taking into account the bargaining power to analyze the effect of the commuting time of spouses to the household residential location choice. For more details on the modeling framework of the results developed below see [16].

4.1 Mode choice and spouses travel times

The differences between male and female observed travel times depend (1) on spouses endogenous joint mode choices, (2) on the distribution of male and female jobs over the region (marginal distribution of the destination of morning commuting trips), (3) on the distribution of dwellings over the region (marginal distribution of the origin of morning commuting trips), as well as (4) on the household joint residential and job location choices. The link between the marginal distributions of origins (home) and destinations (work place) and their joint distribution is partially explained by the spouses bargaining powers for location choice in the household. If the women's bargaining power is larger than the men's one, then the joint distribution of household residential location and spouses' job locations results in a reduction in woman's travel time compared to man's travel time.

In this section, we make a first step at disentangling the effects of these different sources, focusing on the relative reduction in actual women's and men's travel times (compared to all potential travel times) resulting from their respective bargaining powers.

Using data form the 1999 Census in Paris Region, we analyze the distributions of spouses' potential and actual travel times, and interpret their differences in the light of respective bargaining powers. Paris Region is composed by 8 "*départements*": Paris, 3 *départements* around Paris ("inner ring"), and *départements* farther away ("outer ring"). The region contains 10,724,748 inhabitants for a total of 4,510,369 households. Household location and workplace are observed only in a 5% sample. About half of the individuals in this 5% sample work, which represents 242,516 workers, among which 239,499 work in Paris area. We finally restrict our sample to couples in which both spouses live and work in the Paris Region, which leads to 60,798 dual earners households (the difference corresponds to singles and one worker families).

Commuting network distances and travel times in chosen alternatives are computed using individual information on actual residential location and workplace, and reported in Table 1, in our sample of 60,798 dual-earner households. These distances and travel times correspond to the actual, or observed commuting trips. The upper (resp. medium) part of the table reports distance and travel time information for women (resp. men), and the lower part of the table reports the average differences and tests the significance of these differences.

Table 1. Actual commuting distances and travel times

Women				
Variable	Mean	Std Err	Min	Max
Network distance (public, km)	13.151	13.973	0.25	134.73
Network distance (private, km)	10.710	11.716	0.25	107.32
Travel time (public, minute)	42.574	34.936	1.00	384.56
Travel Time (private, minute)	15.200	14.248	0.76	151.51
Men				
	Mean	Std Err	Min	Max
Network distance (public, km)	15.417	15.047	0.25	134.73
Network distance (private, km)	12.557	12.620	0.25	109.12
Travel time (public, minute)	48.242	36.732	1.00	384.56
Travel Time (private, minute)	17.431	15.199	0.76	149.36
Difference (Women-Men)				
	Mean	Std Err	t-Stat	p-value
Network distance (public, km)	-2.266	0.083	-27.21	<0.01%
Network distance (private, km)	-1.847	0.070	-26.45	<0.01%
Travel time (public, minute)	-5.668	0.206	-27.57	<0.01%
Travel time (private, minute)	-2.231	0.084	-26.41	<0.01%

In the chosen alternatives, women's commuting distances and travel times are shorter than men's. The average difference is 2.27 km and 5.67 minutes through the public transportation network, and 1.85 km and 2.23 minutes through the private car network. The standard errors are those of the average difference between female and male actual commuting distances and travel times. The t-Stats are the ratios of the Mean to Std Err columns. Under the null hypothesis that the male and female average distances and travel times are equal, this statistic follows a Student distribution. For the 4 variables considered, the absolute values of the t-Stats are very large, and the null hypothesis is clearly rejected: actual commuting distances and travel times are significantly lower for women than for men.

This difference may come from two different phenomena: (1) the marginal distributions of dwellings (irrespectively of the male and female workplaces) is such that dwellings are on average closer to female jobs than to men jobs; (2) the distribution of dwellings conditional on female and male workplaces is such that, for a specific household, the dwelling is closer to the woman's workplace than to the man's workplace.

In order to quantify the first phenomenon, we randomly select 9 hypothetical residential locations for each household, independently from the husband and wife workplaces. To do so, we consider a uniform distribution over the 5 million dwellings of the region. Equivalently, we perform importance sampling of communes, which weights proportional to the number of dwelling in this commune (see [2] for more details on importance sampling). Following this strategy, we build a sample of dwelling locations independent from both spouses' workplaces, and the distribution of these hypothetical dwellings is statistically identical to the marginal distribution of dwellings in the region.

The resulting distances and travel times are reported in Table 2, which is built on a sample of 60,798*9=547,182 hypothetical (unchosen) alternatives for residential location. The structure of Table 2 is the same as the one of Table 1, except that the figures are now those of hypothetical commuting trips.

Table 2. Hypothetical commuting distances and travel times using the marginal distributions of dwellings

Women				
Variable	Mean	Std Err	Min	Max
Network distance (public, km)	31.712	21.177	0.33	182.33
Network distance (private, km)	26.995	19.399	0.33	155.90
Travel time (public, minute)	86.200	50.193	1.32	564.52
Travel Time (private, minute)	35.020	20.778	1.00	233.01
Men				
	Mean	Std Err	Min	Max
Network distance (public, km)	31.154	20.813	0.35	182.33
Network distance (private, km)	26.464	19.020	0.35	155.90
Travel time (public, minute)	84.844	48.704	1.40	564.52
Travel Time (private, minute)	34.469	20.355	1.05	233.01
Difference (Women-Men)				
	Mean	Std Err	t-Stat	p-value
Network distance (public, km)	0,558	0,0401	13,90	<0.01%
Network distance (private, km)	0,531	0,0367	14,46	<0.01%
Travel time (public, minute)	1,356	0,0945	14,34	<0.01%
Travel time (private, minute)	0,551	0,0393	14,01	<0.01%

In the hypothetical case in which households would randomly choose a residential location independent from husband's and wife's workplaces, the average commuting distances and travel times would be approximately multiplied by 2. Stated differently, the fact that households (partially) adjust their residential location choice to the spouses' workplaces divides by 2 the spouses commuting distances and travel times, compared to the hypothetical case in which they would randomly pick one of the existing dwellings.

More interestingly, in this hypothetical situation, women's commuting distances and travel times would be slightly larger than men's travel times. This means that, on average, dwellings are marginally closer to male jobs than to female jobs.

The fact that actual commuting distances and travel times are shorter for wives than for men according to Table 1 cannot come from the marginal distributions of dwellings and jobs because the relationship is reversed in Table 2, but it comes from the conditional distribution of dwellings given spouses workplaces. Stated differently, the endogenous household residential location favors wives rather than husbands, which suggests a larger bargaining power for women than men in the residential location choice.

This result is also consistent with [1], who explained that the probability of moving is more strongly related to commuting distance for women than for men, which results in shorter commuting distance for women after a relocation.

Note also that the endogenous residential location reduces more actual travel time of women compared to men by public transit than by private car. Given that women have a stronger tendency than men to commute by public transit, this result suggests that households locate so as to favor woman's commuting by transit.

The fact that both dwellings and jobs are rather located in the center of the region divides by about 2 the distances and by about 2.5 the travel times in comparison with the hypothetical situation in which dwellings and jobs would be uniformly and independently distributed among the communes. In this even more hypothetical case, the average distance between dwellings and jobs would be 66 km both through public and private networks, and it would represent an average travel time of 215 min by public transportation and 80 minutes by car.

The geographical distribution of actual commuting time for women and men by public transportation and private care are depicted in Figure 1 and Figure 2, respectively, by gender. Actual commuting times in public transportation and private car are increasing functions of the distance to the center of the region, in which most of the jobs are concentrated. The difference in travel times between the outer ring and the central part of the region (Paris and inner ring) is more pronounced for public transportation than for private car, which reflects the fact that the public transportation network is concentrated in the center of the region and is poorly adapted to trips from the outer ring to the outer ring.

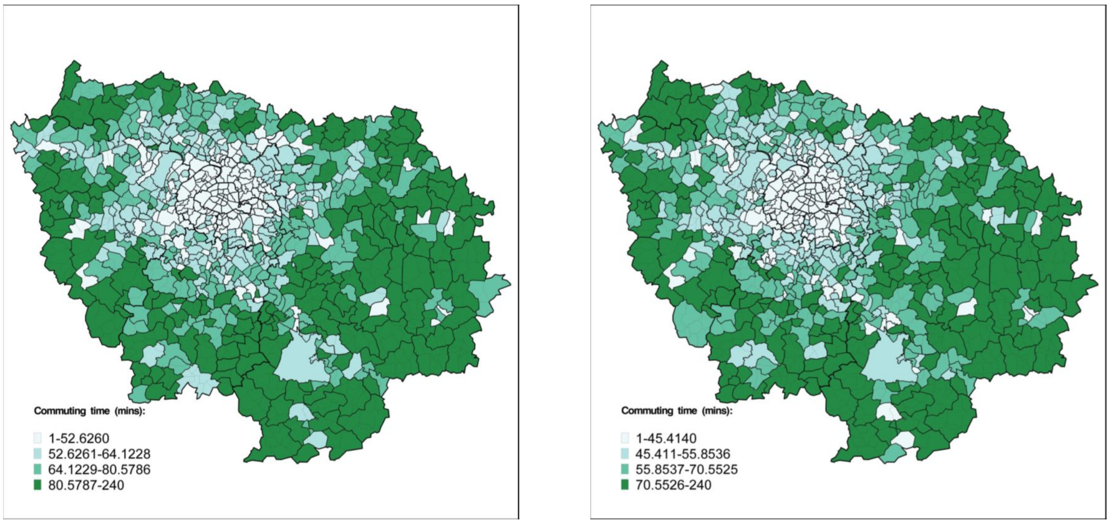

Figure 1. Actual commuting times by public transportation for women (left-hand side) and for men (right-hand side)

The geographical distribution of relative (woman-to-man) travel times depicted in Figure 3 shows that women work closer to their dwelling than men in the outer ring, whereas, for households living in Paris or in the inner ring, the husband's workplace is closer to the dwelling than the wife's workplace. This is consistent with the fact that men's jobs are concentrated in the core of the region, whereas female jobs are more uniformly spread over the region.

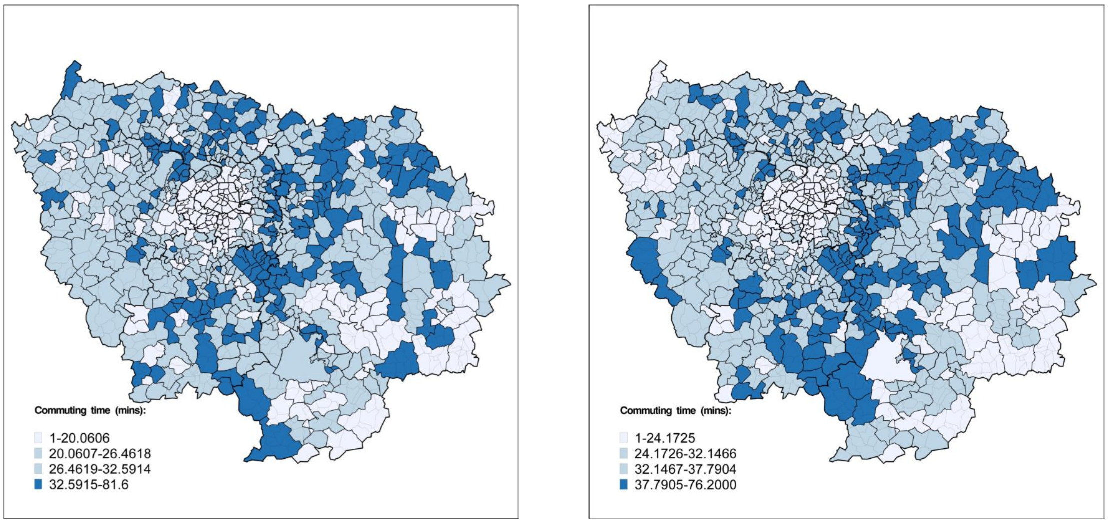

Figure 2. Actual commuting times by private car for women (left-hand side) and for men (right-hand side)

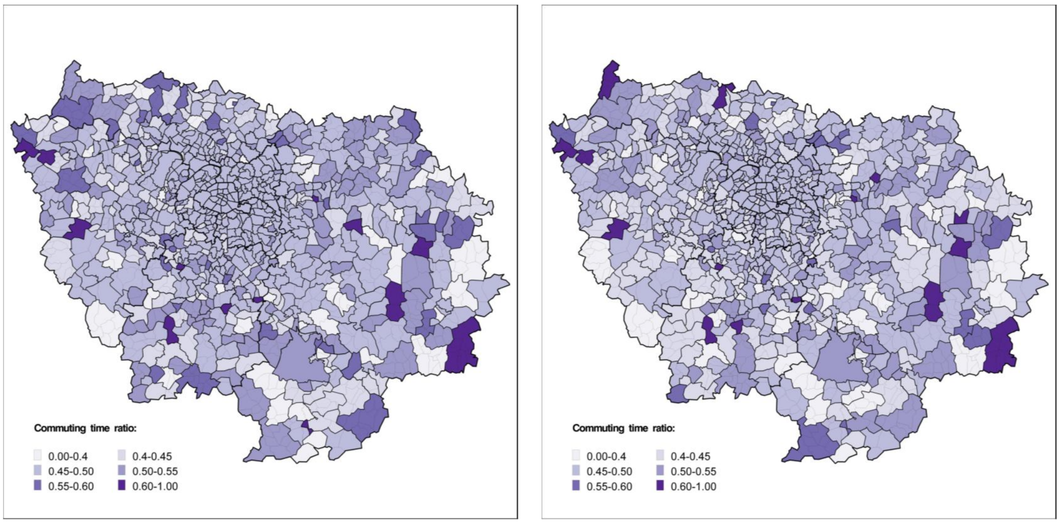

Figure 3. Geographical distribution of relative (man-to-woman) travel times by public transport (left-hand side) and by private car (right-hand side)

4.2 Car ownership and mode choice

Using the same sample as in subsection 4.1, we estimate a multinomial Logit model of residential location conditional on husband and wife workplaces, as a function of local dwelling price (per square meter, in log) and spouses' actual travel time, by mode and gender.

Table 3. Effect of spouses' commuting times on household location

Parameter	Coeff.	Std Err	t Stat	Pr>|t|
Model 1: Travel time by mode and gender				
Log(Price)	-3.7977	0.0314	-120.9	<.0001
Travel time (public transportation) Wife	-0.0325	0.000467	-69.59	<.0001
Travel time (public transportation) Husband	-0.0172	0.00047	-36.58	<.0001
Travel time (private car) Wife	-0.0212	0.000979	-21.68	<.0001
Travel time (private car) Husband	-0.0183	0.000968	-18.87	<.0001
Model 2: Travel times by sex, mode, and number of cars				
Log(Price)	-4.0008	0.0323	-123.87	<.0001
Travel time (public transportation) Wife, 0 car	-0.0578	0.00226	-25.57	<.0001
Travel time (public transportation) Wife, 1 car	-0.0394	0.000693	-56.9	<.0001
Travel time (public transportation) Wife, 2 cars	-0.0233	0.000645	-36.07	<.0001
Travel time (public transportation) Husband, 0 car	-0.0414	0.00232	-17.84	<.0001
Travel time (public transportation) Husband, 1 car	-0.0232	0.000697	-33.31	<.0001
Travel time (public transportation) Husband, 2 cars	-0.0094	0.000651	-14.46	<.0001
Travel time (private car), Wife, 0 car	-0.0059	0.004761	-1.23	0.2191
Travel time (private car), Wife, 1 car	-0.0114	0.001442	-7.89	<.0001
Travel time (private car), Wife, 2 cars	-0.0319	0.01391	-22.97	<.0001
Travel time (private car), Husband, 0 car	-0.0075	0.00474	-1.58	<.0001
Travel time (private car), Husband, 1 car	-0.0169	0.001425	-11.89	<.0001
Travel time (private car), Husband, 2 cars	-0.0191	0.00137	-13.95	<.0001

Table 3 shows results of two different models. In the first model, the Value of Time (coefficient of the travel time variable) only depends on mode and gender. In the second model, the travel time variable is crossed not only with mode and gender, as in the first model, but also with the number of cars owned by the household.

The Price has the usual negative sign and is highly significant in both models. According to the first model, household location is slightly more sensitive to woman's than man's travel time by private car (|-0.0212| is significantly larger than |-0.0183|), but it is twice more sensitive to woman's than man's travel time by transit. The second model helps understanding such differences.

Travel time by private car (both for husband and wife) has no influence on household location for households without any car, which is totally consistent. Households do not care how much time husband or wife would spend commuting by car, when they have no access to any car.

For each household, 9 unchosen alternatives are generated using importance sampling. The weights are proportional to the number of dwellings in the commune and travel times are computed using the dynamic transport network model METROPOLIS ([17]). Alternatives correspond to the 1300 communes of the Paris

Region. The city of Paris accounts for 20 *arrondissements* that correspond to 20 communes. The associated coefficients are the only ones which are not significant.

The difference between the coefficients of travel time by private car for the wife in households with 0 or 1 car is not statistically significant. For the husband, it is the difference between 1 and 2 cars which is not significant. This means that the husband's commuting time by private car becomes relevant in residential location choice as soon as there is at least one car in the household. By contrast, the wife's commuting time by car becomes really relevant only when there are at least 2 cars in the household. This gives a strong indication that the husband has the priority to use the car to commute when there is competition between spouses for the use of the unique car.

The influence of travel time by public transportation on residential location is decreasing with the number of cars in the household, both for the wife and for the husband. This influence nearly disappears for men when there are two cars in the household, suggesting that the husband usually commutes by car and does not care about transit travel times when there are 2 cars in the household. These results are consistent with the fact that, on the one hand, public transportation is a substitute for private car when household members can easily reach a station, which is usually the case in Paris and inner ring, whereas it is a complement when individuals have to drive to the station in order to use public transportation. The fact that husband's transit commuting time plays virtually no role in residential location of two-car households, whereas the wife's transit commuting time still matters suggests that, when there are two cars in the household, men will anyway entirely commute by car, whereas wives may go to the station by car.

4.3 Independent, unitary and collective mode choice of spouses

In order to analyze in more detail mode choice within couples and evaluate the importance of competition for using the car for commuting trips, we compare three models. In the first model, mode choice of the two spouses is estimated independently, as is done in a (too large) majority of articles interested in mode choice. The estimation results are reported in Table 4. In the right-hand side of the table, the model is estimated separately and independently for households owning only one car and for households owning at least two cars (independent binary Logit model). The households owning no car are not considered in the sample since the only mode available for the members of these households is public transport, so there is no mode choice decision in these households. The “all” columns on the left correspond to a model imposing equal preferences whatever the number of cars available to the household.

The explanatory power of the models is measured by the pseudo-R^2 reported in the bottom row. This explanatory power is very low in the 1-car case because this simplistic model assuming that spouses’ mode choices are independent misses the most important determinant of mode choice, which is competition for the unique car. The models presented in Table 5 will address this problem.

Table 4: Independent mode choice

	All		At least 2 cars		1 car	
	Woman	Man	Woman	Man	Woman	Man
Intercept (private car)	0.118***	0.774***	1.723***	2.086***	-0.816***	0.163***
*# children aged 0-3	0.041		0.098*		0.082**	
*# children aged 4-6	0.080***		0.120**		0.071*	
*# children aged 7-11	0.171***		0.085**		0.143***	
*# children aged 12-16	0.212***		0.178***		0.175***	
Travel time by public tr.	-2.101***	-1.226**	-2.114***	-1.859***	-1.985***	-1.043***
Woman-to-Man VOT (PT)	1.713		1.137		1.903	
Travel time by car	-3.469***	-2.076***	-4.248***	-3.261***	-3.218***	-1.899***
Woman-to-Man VOT (car)	1.671		1.303		1.695	
*(age-40)/10	-0.138***	0.047	0.387***	0.491***	0.045	0.140***
*(occup="employee")	0.320***	-0.674***	0.502**	0.159	0.090	-0.993***
*(occup="professional")	-0.839***	-0.721***	-0.660***	-0.226	-0.564***	-0.671***
*(occup="manager")	-0.583***	-0.930***	-0.488***	-0.459**	0.085	-0.411***
*(occup="self-employed")	-2.254***	-3.554***	-1.176***	-2.307***	-2.867***	-3.750***
*foreign	1.391***	0.661***	1.596***	0.506**	0.956***	0.369***
# observations	34,915	34,915	18,377	18,377	16,538	16,538
log-likelihood	-20,180	-18,345	-6,882	-5,986	-9,793	-10,439
pseudo-R^2	0.1661	0.242	0.4597	0.5301	0.1457	0.0894

*: Slightly significant (10% level).
**: Significant (5% level).
***: Highly significant (1% level).

Mode choice is explained by travel time. We assume that the value of time (VOT) depends on gender, mode, age (expressed in number of decades after 40), occupation (reference=blue collar) and nationality (reference=French). The coefficients are negative since the utility (and not the costs) are estimated. The coefficients estimated are proportional to the marginal disutility of commuting time, that is to the opposite of the VOT. Note that the coefficients estimated do not measure directly the value of time, but are only proportional to it, since the coefficients in a Logit model are defined up to a multiplicative constant.

The model imposing that preferences do not depend on the number of cars available (columns "all") shows that woman's VOT is 70% larger than man's VOT, and that this ratio is the same by public transport and by car. In the 1-car sample, this ratio is the same by car, but VOT by public transport is 90% larger than man's VOT by public transport. By contrast, in the 2-cars sample, VOT by public transport is only 14% larger for women than for men whereas, VOT by car is 30% larger for women than for men. Such differences can hardly be explained by something else than by an endogenous selection bias related to the number of cars.

In addition to the value of time, we consider a fixed utility (for a null commuting time) for travelling by car rather than by public transportation. The negative value of this coefficient in the 1-car sample could suggest that women dislike driving, but the fact that this coefficient is positive in other models suggests that the negative coefficient in the 1-car sample rather results from the competition for the unique car. Consistently with the results in Subsection 4.2, when there is only one car in the household, this unique car is generally used by the man rather than by the woman.

For the woman, the fixed utility of commuting by car depends on the number of children, by age group, in order to reflect the fact than women often drop children to child daycare or to school while they go to work in the morning, or pick them when they come back in the evening. The fact that these coefficients are positive and generally increasing with children's age is consistent with the fact that child daycare facilities are usually very close to households, whereas the distance to households tends to increase when going from preschool to primary school and secondary school.

Table 5 presents a more realistic model in which spouses jointly choose their mode. We develop a multinomial Logit model estimated by maximum likelihood. We consider a bargaining model in which the household maximizes the weighted average utility of the woman and of the man. The weight of woman's utility corresponds to her bargaining power, whereas the weight of man's utility is normalized to 1 minus woman's weight. The model could be further enriched by considering that the bargaining power depends on each spouse's characteristics such as age, nationality or education

The models presented in Section 2 consider a weighted average of commuting times and interpret them as a weighted average of individual utilities. However, in such models, the weights associated to spouses' commuting times in the household utility function merge the effect of individual-specific preferences (VOT) and of bargaining powers. By contrast, our structural model explicitly takes into account the bargaining process and disentangles individual preferences (both VOT and fixed cost of commuting by a given mode) from bargaining power.

Our structural joint model recognizes that the choice set of the couple depends on the number of cars available, and that there may be competition for the use of the car when the household has only one car.

Three alternatives are available whatever the (positive) number of cars, and perfectly observed:

- Both spouses use public transport (reference case, with the utility of both spouses normalized to 0
- The woman commutes by car and the man by public transport
- The man commutes by car and the woman by public transport

The fourth case in which both spouses commute by car corresponds to 3 sub-cases involving different travel times:

- Drive alone: Each spouse uses his/her own car: this alternative is available only in households with at least 2 cars
- (CP,CD) = Car Passenger for the woman, Car Driver for the man: The man drops the woman in his way to his own job. This implies a detour for the man, that is a trip longer than his trip in the drive alone case
- (CD,CP) = Car Driver for the woman, Car Passenger for the man: The woman drops the man in her way to her own job. This implies a detour for the woman, that is a trip longer than her trip in the drive alone case

The data do not say which of these three sub-cases is selected by the household when both spouses answer that they commute by car, but the model computes different travel times (and therefore different utility levels) in each of these three sub-cases.

Table 5. Spouses' joint mode choice in a structural bargaining model

	All		At least 2 cars		1 car	
	Woman	Man	Woman	Man	Woman	Man
Intercept (CP,CD)	0.419***		2.852***		-0.810***	
Intercept (CD,CP)	0.251***		2.373***		-0.934***	
Intercept (drive alone)	0.689***	2.026***	2.195***	3.195***	-1.788***	0.144*
Weighted average intercept	1.333		2.692		-0.917	
***# children aged 0-3**	0.094		0.237**		0.131*	
***# children aged 4-6**	0.138**		0.269**		0.105	
***# children aged 7-11**	0.263***		0.171**		0.258***	
***# children aged 12-16**	0.346***		0.353***		0.305***	
Travel time by public tr.	-3.945***	-2.738***	-4.160***	-3.658***	-3.653***	-2.463***
Woman-to-Man VOT (PT)	1.441		1.137		1.483	
Travel time by car	-6.393***	-4.459***	-7.869***	-6.208***	-5.379***	-3.945***
Woman-to-Man VOT (car)	1.434		1.267		1.363	
***(age-40)/10**	0.104	0.379***	0.848***	1.014***	0.277***	0.481***
***(occup="worker")**	0.654***	-1.229***	1.047***	0.401	0.318	-2.002***
***(occup="professional")**	-1.588***	-1.180***	-1.470***	-0.417	-1.368***	-1.181***
***(occup="manager")**	-1.195***	-1.673***	-1.268***	-0.848*	-0.479*	-1.116***
***(occup="self-employed")**	-3.643***	-5.545***	-1.695**	-3.732***	-4.530***	-5.903***
***foreign**	2.571***	1.310***	3.241***	0.774*	1.871***	0.968***
Woman's bargaining power	**0.518***		**0.503**		**0.549****	
2 cars in hh: # obs	18,377		18,377		-	
log-likelihood	-13,811		-12,758		-	
pseudo-R^2	0.228		0.287		-	
1 car in hh: # obs	16538		-		16538	
log-likelihood	-21541		-		-20113	
pseudo-R^2	0.107		-		0.166	
All : # obs	34915		-		-	
log-likelihood	-35352		-		-	
pseudo-R^2	0.158		-		-	

*: Slightly significant (10% level).
**: Significant (5% level).
***: Highly significant (1% level).
Note: For woman's bargaining power, significance is for the difference with equal weights (0.5).

This structural model gives estimates of the spouses' values of time which are more consistent than those resulting from Table 4. The bias resulting from the endogenous selection of the 1-car and 2-car samples is at least partly corrected; the differences across samples in the ratios of woman-to-Man VOT are considerably reduced and become non-significant. Woman's VOT is now estimated to be 40% larger than man's VOT, which is more plausible than the 70% estimated by independent models for spouses' mode choice. Recall that, in a Logit model, coefficients are estimated only up to a multiplicative constant, and this constant differs across models which coefficients are reported in Table 4 and Table 5.

As a result, coefficients in Table 4 and Table 5 cannot be compared directly, but ratios of coefficients can be compared across these tables.

The estimation of the bargaining power is slightly in favor of the woman, who has 51.8% of the bargaining power, which leaves 48.2% for the man. However, the difference is significant only at the 10% level. The advantage of the woman is more important (54.9% compared to 45.1% for the man) and more significant (5% level) in the 1-car sample.

The negative coefficient of constant of the drive alone alternative for the woman in the 1-car sample confirms that, when there is only one car in the household, the man has a strong priority to use it.

Our structural model also allows to estimate the fixed benefit (controlling for mode-specific travel times) of commuting by car rather than by public transport. This fixed benefit can be identified separately for each spouse when they drove alone, but only the average benefit for the household can be identified when they drive together. Controlling for the number of cars, the weighted average benefit for the household when both spouses commute together in the same car is larger when the man drives (line "Intercept (CP,CD)") than when each spouse drives his/her own car (line "*Weighted average intercept*"), but it is lower when the woman drives (line "Intercept (CD,CP)"). This means that the household is globally happier when the man drives the woman than when each one drives alone, and the household is even less happy when the woman drives the man. This reflects the fact that the man prefers driving than being driven, and the woman prefers being driven than driving the man, but it is not possible to identify each effect separately. The comparison of the constants in the "All" columns could mean that the spouses dislike commuting together in the same car (since the weighted average fixed benefit of commuting by car separately is larger than the weighted average fixed benefit of commuting together, whoever drives). We rather believe that this comes from the endogenous selection bias related to the number of cars.

Table 6 shows that the structural model better predicts who will commute by car, especially when we impose the natural condition that preferences do not change when a second car is bought by the household (left-hand side of the table). The first lines suggests that, all together, the "Individual model", which assumes that spouses choose independently their mode, predicts the probability that both spouses commute by car slightly better than the structural model (45.47% versus 43.92%, whereas the actual probability is 49.54%). However, the subsequent lines show that the individual model strongly overestimates (41.24% instead of 21.82%) the probability that both spouses commute by car in the 1-car sample, and strongly underestimates it in the 2-cars sample (49.27% instead of 74.50%). The predictions of the structural model are far closer to reality. This means that the natural assumption that preferences do not change when a second car is bought by the household is strongly rejected when combined with the less realistic but too common assumption that spouses choose individually and independently their mode. But the natural assumption combined with our structural model is approximately consistent with the observations.

The right-hand side of the table shows that, when we relax the assumption that preferences are the same in the 1-car and 2-cars samples, the predictions of the individual model are only marginally farther from reality than the predictions of the structural model. This implies that modeling errors would lead to the wrong conclusion that preferences change dramatically when the households buys a second car. By contrast, our structural model correctly predicts joint mode choice even under the quite realistic assumption that preferences are not affected by car ownership.

Finally our structural model leads to plausible predictions of the probabilities that spouses commute in separate cars or together, and of the probabilities that the man drops the woman, and that the woman drops the man. Recall that the information about who is driving is not available in the database. In our approach, this information can be computed exploiting the structure of the model and the observed influence on the probability that both spouses commute by car of the extra time implied by the detour (when the man drops the woman or when the woman drops the man).

Table 6. Probability that both spouses commute by car, by model

	Preferences independent of the number of cars				Preferences dependent on the number of cars			
	VA, VA	VP, VD	VD, VP	V,V	VA, VA	VP, VD	VD,VP	V,V
All households (34,915 couples)								
Observed from Census	49.54			49.54	49.54			49.54
Individual model	45.47			45.47	48.59			48.59
Structural model	23.99	12.31	7.62	43.92	22.08	17.79	9.23	49.10
Households with 1 car (16,538 couples)								
Observed from Census	-	21.82		21.82	-	21.82		21.82
Individual model	-	41.24		41.24	-	21.84		21.84
Structural model	-	15.66	9.95	25.60	-	13.09	8.74	21.82
Households with 2 cars (18,377 couples)								
Observed from Census	74.50			74.50	74.50			74.50
Individual model	49.27			49.27	72.66			72.66
Structural model	45.57	9.29	5.53	60.40	41.95	22.03	9.68	73.65

4.4 Couple residential location conditional on spouses workplaces

We now discuss the results obtained by [16] in a structural collective model assuming that spouses first choose their workplaces (anticipating the effect it will have on residential choice) and then the household collectively chooses the residential location conditional on each spouse's workplace. Like in Section 4.1, residential location then depends on the spouses' actual commuting times between the current workplace and the potential residential locations contemplated. However, by contrast with the reduced-form model estimated in Section 4.1, we analyze here a structural model explicitly taking into account both spouses individual preferences and respective bargaining powers rather than mixing them in a household utility function which may or may not be consistent with rationality. To the best of our knowledge, this the only contribution to the literature that takes into account the role of the within-family decision process and spouses bargaining powers in a residential location choice, and more generally in the measurement of the spouses values of time. The other contributions such as [1] or [10] do consider the influence of individual characteristics on residential location choices, but the associated coefficients mix the influence of individual preferences and bargaining powers.

The objective here is to analyze the within-family decision process involving bargaining between members with diverging preferences, objectives and constraints. Spouses may or may not have diverging preferences concerning local amenities, and these preferences probably differ from the preferences of singles. The same individual will tend to enjoy bars and discos when he is single, and open spaces when he is married with children. Given this change in preferences of the same individual when he marries, it is not possible to disentangle respective bargaining powers and spouses' preferences for local amenities, and we will not try to do so. Instead, we consider a joint preference of the household for local amenities.

On the opposite, it is obvious that the husband preference for his own commuting time (let's call it Value of Time, although it is more complex when utility is not linear in travel time because then VOT is given by the local derivative of utility with respect to commuting time, and it varies with commuting time) is different from the wife's preference for the husband commuting time. The influence of the husband's commuting time on household residential location mixes (1) the role of the husband's VOT, which a priori depends only on the husband's individual characteristics and (2) the role of respective spouses bargaining powers, which a priori depends both on the husband and wife individual characteristics. Similarly, the influence of the wife's commuting time on household residential location mixes the role of the wife's VOT and of the respective spouses bargaining powers. As a result, neglecting spouses' respective bargaining powers leads to biased estimates of the values of time of the household members.

In [16], we develop a method to disentangle the bargaining power and the spouses VOTs, and to measure separately the influence of explanatory variables on the bargaining power and the value of time. We apply this method to the same data as in subsections 4.1 and 4.2. Each spouse's bargaining power is normalized to 1/2 in the reference case (the two spouses are French and 20 years old), and the husband and wife bargaining powers always sum to 1, so that bargaining powers can be interpreted as percentages. Any increase in the woman's bargaining power corresponds to a decrease of the same percentage for the husband's bargaining power. The econometric results show that the woman's age and man's nationality play a crucial role in determining bargaining power. The magnitude of the effects depends on the covariates considered, but some general patterns emerge. Each spouse bargaining power increases with age, but the increase is faster for the wife than for the man. Consider two equally old men. The wife of the first man is 10 years older than the wife of the second. Our estimates show that, in this case, the bargaining power of the first wife is 4.28% larger than that of the second woman. Consider now a third couple, in which the wife has the same age as the wife in the first couple, but the husband is 10 years older than the husband in the first couple. Then, the bargaining power of the husband in this third couple is 0.78% larger than that of the first husband. Consider now the first couple 10 years later. Each spouse is 10 years older and, as a result, the wife's bargaining power has increased more than the man's. As a consequence, the wife's bargaining power tends to increase over time (by 4.28%- 0.78%= 3.5% each 10 years).

The bargaining power of the husband is reduced by about 4.5% when he is foreign, whereas the wife's bargaining power does not significantly depend on her nationality.

The econometric results of this model also show a large bias in the measurement of spouses' VOT when the bargaining power is not taken into account in a residential location model. For example, there is a 20% underestimation of the value of time for a 40-year-old French man, which becomes a 18% overestimation for a 40-year-old French man. For the wife, the VOT is always overestimated when the bargaining power is omitted, and the bias is 15% for a 40-year-old French woman and 10% for a 20-year-old French woman. There is an additional bias upwards in the measurement of the VOT of foreign men, when the bargaining power is omitted.

The commuting cost estimated in the model is a concave function of commuting time for each spouse. The value of time for a man (respectively woman) of 20 years old is about €11 (respectively €8) per hour at the origin (i.e. when the travel time tends to 0). The value of time is a decreasing function of age.

4.5 Accessibility in a residential location, workplace, and job type model in one- and two-worker households

We now discuss the extension to dual-earner households of the single or one-worker household structural model developed by [23]. By contrast to Subections 4.2 and 4.4, this model assumes that residential location is chosen before individual workplaces. This model analyzes a three-level nested Logit model of residential location, workplace, and job type choice. Residential location is the upper-level choice, workplace the middle-level choice, and job type is chosen at the lower level.

The decision tree is fully consistent and rational: on one hand, workplace choice is anticipated at the upper-level residential location choice; on the other hand, the middle-level workplace choice is made conditional on the residential location actually chosen. This model allows defining and computing an individual-specific measure of attractiveness of geographical units, which takes into account the local distribution of job types, and individual preferences for job types. This measure of attractiveness of geographical units is fully consistent with the model, from the theoretical and econometric points of view. It corresponds to a log-sum term going up the decision tree from the lower level to the middle level. Going one step up in the decision tree, we obtain an individual-specific measure of accessibility to jobs, which takes into account the heterogeneity in VOT and preferences for different job types captured in the measure of attractiveness of potential workplaces.

The model is estimated on single or one-worker households, using the same data as in subsections 4.1 to 4.4. At the lower level of the decision tree, preferences for job types depend on gender, education and number of children (for women only). The same variables also explain observed heterogeneity in the Values of Time at the middle level of the decision tree. At the upper level, observed heterogeneity in preferences for local amenities is even richer, with the introduction of profession of household dead, and household composition and income, crossed with the local distribution of the same characteristics, in order to reflect the tendency of households to locate close to similar households.

5 Conclusion

We have discussed in this article different models describing the choice of mode, residential location and workplace of the various members of a family, mainly the husband and wife, but more sophisticated models should also take into account the children. The key concept introduced in this paper is the negotiation within the couple, that is to say, the decision-making process related to joint choices, such as the residential location, which is usually, but not always, unique in couples.

The tools we have discussed in this paper are based on the work developed during recent decades in the field of economics of the family. They will revolutionize discrete choice models used in transport and urban economics, in the sense that the decisions are no more described as the outcome of a unique decision maker. Instead, in collective discrete choice models, the decisions depend on preferences and constraints of two individuals tied by economic, but also emotional ties. Discrete choice theory still has to be adapted to this new way of approaching the individual decisions. Current literature in transportation [1] has developed a few intra-family decision models. However these models ignore the bargaining process within the family, as studied by family economists ([14], [15]).

An objective of the research is to provide new tools for researchers in urban and transportation economics, as well as in engineering. In particular, we plan to provide collective choice models to the integrated transport and land use tool, UrbanSim. This article begins a search path that may be still very long and hopefully fruitful.

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