Socio-dynamic discrete choice: Theory and application

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Publication date
2013

Citation for published version (APA):
Dugundji, E. R. (2013). *Socio-dynamic discrete choice: Theory and application*. [Thesis, fully internal, Universiteit van Amsterdam].

SOME CHALLENGES IN MODELING RESIDENTIAL CHOICE

How is residential choice associated with the geography of family networks? To what extent are the geographical characteristics of family networks associated with residential location, and residential re-location, and what part do socio-demographic variables and the socio-spatial context play in this association? Why is this methodologically challenging to address? What are some directions forward based on key works in the literature?[1]

The classical approach to answering the first part of the sub-question relating to residential location would be an econometric discrete choice model. Some of the early examples of this approach applied to residential location are due to Lerman (1975), Quigley (1976) and McFadden (1978). Advantages of this highly heterogeneous and disaggregate approach are the well-developed underlying theories of individual behavior, the time-proven policy application of such models over 40 years, the possibilities for precise statistical tests, and well-developed measures of goodness of model fit.

D.1 DYNAMIC CHOICE MODELING

To address the second part of the sub-question relating to residential re-location an excellent theoretical starting point within the discrete choice framework is due to Ben-Akiva and de Palma (1986). Provided the availability of suitable data, there are strong reasons to consider a dynamic model as motivated by the authors:

> "... A static choice model assumes the existence of an equilibrium stat that can be considered as the stationary solution of a dynamical process. A static model is a valid approach if at least the following two conditions are met: (i) the dynamical adjustment process must be sufficiently rapid relative to typical time scales of changes in the exogenous variables; and (ii) the psychological and monetary transition costs are negligible.
>
> In the case of residential location behavior, it is unreasonable to assume that these conditions are even approx-

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1 This appendix is based on a conference paper presented at the Annual Meeting of the Transportation Research Board, Washington, DC, 2006. There have been numerous advances since then which are beyond the scope of this thesis to review. Nonetheless, this appendix provides an overview of scientific considerations and some directions which the interested reader may find useful.

imately true. The annual residential mobility rate (i.e. the percentage of households that move during one year is low, e.g. in the U.S. it is usually less than 20 percent); and the transaction costs of moving, buying and selling are significant even relative to the price of expensive homes.

Thus, static choice models assume that the change from an alternative i to a different alternative j is instantaneous and independent of i. Long adjustment periods and significant transition costs that strongly depend on i imply that a decision to change to alternative j takes time, and must depend on i and, hence, require the use of a dynamic choice model. ..."

A key issue here however would be the availability of either panel data (that is, cross-sectional data repeated among the same set of survey respondents over time, at least 2 waves preferably more), or of retrospective data, or of stated preference/choice data.

D.2   TEMPORAL CORRELATION, STATE DEPENDENCE AND HETEROGENEITY

There is a very important issue to address when attempting to consider temporal models. This issue is expounded clearly in a seminal paper by Heckman (1981a):

"... it is often noted that individuals who have experienced (an) event under study in the past are more likely to experience the event in the future than are individuals who have not experienced the event. The conditional probability that an individual will experience the event in the future is a function of past experience. There are two distinct explanations for this empirical regularity.

One explanation is that as a consequence of experiencing an event, preferences, prices or constraints relevant to future choices are altered. In this case past experience has a genuine behavioral effect in the sense that an otherwise identical individual who did not experience the event would behave differently in the future than an individual who experienced the event. This explanation applies even in an environment of perfect certainty so that all relevant information is available to the individual but not necessarily to the observing economist. Structural relationships of this sort give rise to true state dependence, ...

A second explanation for this phenomenon is that individuals may differ in their propensity to experience the event. If individual differences are correlated over time, and if these differences are not properly controlled, pre-

vious experience may appear to be a determinant of future experience solely because it is a proxy for temporally persistent unobservables that determine choices. Improper treatment of unmeasured variables gives rise to a conditional relationship between future and past experience that is termed spurious state dependence. ..."

The control for (unobserved) heterogeneity in the sample plays a crucial role in distinguishing "true" state dependence from "spurious" state dependence. Failing to do so can seriously bias coefficient estimates. The Biogeme software developed by Bierlaire has the functionality to flexibly test for unobserved heterogeneity with a variety of functional forms and with a variety of model specifications.

D.3   INITIAL CONDITIONS PROBLEM

There is also a second critical issue to consider when attempting to consider temporal models. This issue is similarly clearly expounded by Heckman (1981b):

"... Before parameters generating a stochastic process with dependence among time-ordered outcomes can be estimated, the process must somehow be initialized. In much applied work in the social sciences, this problem is treated casually. Two assumptions are typically invoked: either the initial conditions or relevant presample history of the process are assumed to be truly exogenous variables, or else the process is assumed to be in equilibrium.

The first assumption is valid only if the disturbances that generate the process are serially independent or if a genuinely new process is fortuitously observed at the beginning of the sample at the analyst's disposal. If the process has been in operation prior to the time it is sampled, and if the disturbances of the model are serially dependent, the initial conditions are not exogenous variables. Treating them as exogenous variables results in inconsistent parameter estimates. the confluence of serial dependence in unobservables and state dependence in the process results in an important and neglected problem...

The second assumption – initial stationarity of the process – does lead to a tractable solution to the problem. But this assumption is unattractive in many applications, especially when time-varying exogenous variables drive the stochastic process. ..."

In the case of residential re-location, it would be ideal for example to have retrospective residential history for each surveyed respondent back to their residence at place of birth, as such could be considered

a clear initial condition. If such retrospective data is not available, there are approximate estimators which could be considered based on a stream of work stemming from Heckman's seminal work in this area.

D.4   SAMPLING OF OBSERVATIONS

Another data-related question which would guide the choice of model specification and econometric estimator used has to do with sampling considerations. Is the data sample stratified by residential location? Is so, for a residential location choice model, we will thus have the case of choice-based sampling.

If it can be assumed that sampling fractions in each of the strata have been chosen a priori to equal the population shares, we have a convenient simplification. The maximum likelihood estimator for simple random samples is in this case entirely appropriate, otherwise known as exogenous sample maximum likelihood (ESML) estimation.

If the sampling fractions in each of the strata have *not* been chosen a priori to equal the population shares, but we are willing to restrict ourselves to a simple multinomial logit choice model with a full set of $J - 1$ alternative specific constants, where J is the number of alternatives, we have result derived by McFadden that the standard ESML procedure yields consistent estimates for all parameters except the constants. If each choice is a separate stratum and if the population shares are known, then the constants for each alternative can also be consistently estimated by subtracting the natural logarithm of the ratio of the sampling fraction to the population share from the exogenous sample estimate. Cosslett (1981) has shown the estimates obtained in this way are in fact the maximum likelihood estimates. Koppelman and Garrow (2005) have extended this result to derive a procedure for efficient estimation of nested logit models with choice-based samples.

Nonetheless, even the nested logit model may prove to be too limiting for the purposes of the research question, particularly given the potential model framework chosen for the treatment of temporal aspects, as well as for critical aspects of treatment of the relationships between respondents in the sample to be discussed below. In such case, we will need to consider other appropriate estimation procedure options. One possibility may be weighted exogenous sample maximum likelihood (WESML). The WESML estimator is computationally tractable and consistent under very general conditions, but not in general asymptotically efficient (Manski and Lerman, 1977; Lerman and Manski, 1979). Another possibility may be to address the sample likelihood of a general stratified sample with non-overlapping strata

described in Ben-Akiva and Lerman (1985), via simulation drawing on modern day computational capabilities.

In the case of so-called enriched sampling, that is, the pooling of exogenously stratified samples with one or more choice-based samples, Cosslett (1981) has derived analogous results for the multinomial logit model as in the case of choice-based sampling described above. For models other than the multinomial logit, a tractable option may be a combined ESML–WESML estimator, as long as a consistent estimator of the parameters exists for each sample. Another approach to combining information in different samples is to estimate different parameters from each of the subsamples and then to take a weighted average of the various estimates. This "weighted average" estimator will in general however not be asymptotically efficient even if the estimated parameters from the individual samples are (Ben-Akiva and Lerman, 1985).

D.5 DEFINITION OF THE CHOICE ALTERNATIVE

An important feature to understand about discrete choice models is that the attributes of not only the respondent's actually-made choice must be known, but also the attributes of other choice alternatives that the respondent may have reasonably had at the respondent's disposal when they made their choice. In a stated preference or stated choice survey framework the modeling problem is largely fixed in advance by the survey designer's considered choice of attributes to include in the survey. Occasionally in a revealed preference framework, the survey will specifically ask detailed attribute information about other alternatives that a respondent had considered. If neither of these are the case with a particular given data set to be analyzed, the researcher must make reasonable assumptions regarding the attributes of other choice alternatives which the respondent may have considered. There are several issues to be addressed in turn in this regard.

First and foremost, while in a given data set precise attribute information about a respondent's actual residence and the actual geographical location of this residence may be known, even if precise data at the same level of detail were well-known about every other particular individual residence in this study area and its geographical location, and even if there were the computational capacity to handle all the attribute information for all of the particular individual residences in the study area, depending upon the size and scope of the study area, we may still want to aggregate this data to some level for any practical forecasting application. In most cases the choice between elemental residences would typically be aggregated to the level of a residential locational zone, for which there is reliable data for every zone in the study area during at all relevant time periods of the

study and there would be expected to be reliable data at foreseeable periods in the future for forecasting purposes. In principle the "best" residential location choice model possible, would still be one at the smallest scale available, and thus most homogeneous within the unit of analysis, provided residential location is known for all surveyed respondents and all (retrospective) time periods at this level. In practice, this choice may be largely dictated by available secondary data, by the model structure chosen, the complexity of the model, the size and scope of the study area, the intended use of the model whether descriptive or predictive, and the computational capacity available.

D.6 AGGREGATION OF ELEMENTAL ALTERNATIVES

Lerman ([1975](#)) has derived a key result that with simple multinomial logit choice model, it is possible to obtain estimates of the underlying parameters of respondents' true individual utility functions even when the only data available refers to aggregated groups (residential zones) of true behavioral elemental alternatives (residences). Namely, the mean values of independent variables describing these groups can be used without introducing major bias into the estimates, provided we have access to information about the size of the group, in this case, number of residences per zone, which we enter in the utility function as a natural logarithm with coefficient constrained to unity.

Thus, to repeat, it is critical in the consideration of what secondary data and what zonal scale we wish to study, to determine not only at what geographical level there is reliable data about mean values of independent variables, but also at what geographical level there is information about the raw number of residences per zone.

Usefully, no theoretical requirement is placed in Lerman's derivation of the aggregated elemental alternative model that a respondent actually perceive the group (residential zone) as a behavioral unit. In Lerman's words: "... perception of the grouping method is neither a necessary nor a sufficient condition for obtaining consistent estimates of the parameters of the utility function." However, a key assumption in Lerman's derivation is that higher order terms in the expansion of the expected maximum utility of the group could be safely ignored. Lerman has shown by way of some simple numerical examples that the first order Taylor series approximation of the utility of aggregated elemental alternative is fairly accurate when alternatives within the group are relatively homogeneous. Careful consideration must therefore be given to whether homogeneity of alternatives is reasonable in the case of the actual empirical study at hand. Nonetheless as Lerman himself notes:

> "... In reality, given the need for some grouping of alternatives imposed by limitations in the available data, it is unlikely that any single grouping will be optimal

in all dimensions. Some geographical groupings would be extremely homogeneous with respect to transportation level of service, but may cross jurisdictional boundaries. Others might be extremely homogeneous with respect to neighborhood characteristics, but would be ... subject to extreme variability in transportation services. ... Clearly, some tracts will be extremely heterogeneous, perhaps to an extent which violates the assumption inherent in the first order Taylor expansion to an unacceptable degree. This may be particularly true for a tract drawn to include the classical right side and wrong side of the tracks. In such a case, the average price and other characteristics will tend to exhibit a bimodal distribution and the mean will not be a good estimate of the attributes of either type of unit (on one side of the tracks or the other)."

The goal is thus in Lerman's words: "a fair compromise between extremes."

D.7 SPATIAL CORRELATION OF ALTERNATIVES (ZONES)

Diametrically opposite to the desired homogeneity of elemental alternatives within a residential zone is the issue of spatial correlation of the elemental alternatives between zones. Paradoxically the more homogeneous the zones under consideration are, very often the more likely that these zones are correlated in their unobserved attributes with neighboring zones. What can be done about this?

McFadden and Train (2000) have established an important hallmark result which forms the basis for a direction for solution:

"...Under mild regularity conditions, any discrete choice model derived from random utility maximization has choice probabilities that can be approximated as closely as one pleases by a mixed, or random coefficients, multinomial logit (MMNL) model. Practical estimation of a parametric mixing family can be carried out by Maximum Simulated Likelihood Estimation or Method of Simulated Moments, and easily computed instruments are provided that make the latter procedure fairly efficient. The adequacy of a mixing specification can be tested simply as an omitted variable test with appropriately defined artificial variables. An application to a problem of demand for alternative vehicles shows that MMNL provides a flexible and computationally practical approach to discrete response analysis."

Bhat and Guo (2003) have proposed an extension of the mixed multinomial logit model which can be used as an approach to addressing

spatial correlation by building the generalized extreme value model originally derived by McFadden (1978) and on recent computational developments in the simulation of advanced choice models:

> "...The MMNL class of models is very general in structure and can accommodate both relaxations of the independent and identically distributed assumption as well as unobserved response heterogeneity within a simple unifying framework. Consequently, the need to consider a mixed generalized extreme value (MGEV) class may appear unnecessary. However, there are instances when substantial computational efficiency gains may be achieved using a MGEV structure. Consider, for instance, a model for household residential location choice. It is possible, if not very likely, that the utility of spatial units that are close to each other will be correlated due to common unobserved spatial elements. A common specification in the spatial analysis literature for capturing such spatial correlation is to allow alternatives that are contiguous to be correlated. In the MMNL structure, such a correlation structure will require the specification of as many error components as the number of pairs of spatially-contiguous alternatives and leads to a high dimension of integration. On the other hand, a carefully specified GEV model can accommodate the spatial correlation structure within a closed-form formulation. However, the GEV model structure cannot accommodate unobserved random heterogeneity across individuals. One could superimpose a mixing distribution over the GEV model structure to accommodate such heterogeneity, leading to a parsimonious and powerful MGEV structure. ..."

An alternative to Bhat and Guo's approach has been proposed by Vichiensan and Miyamoto (2004), using a specialized factor analytic error structure with a mixed multinomial logit model.

Bhat and Guo's approach is directly implementable using the earlier-mentioned Biogeme software developed by Bierlaire. Vichiensan and Miyamoto's approach requires self-written estimation code.

D.8   SAMPLING OF ALTERNATIVES (ZONES)

A second dilemma in addition to spatial correlation that can arise when striving towards the consideration of homogeneity of housing units with residential zones, is the handling of the proliferation of the number of zones. Clearly the smaller the zones are, the more of them to be dealt with in model. The denominator in individual choice probability in a simple multinomial logit model, for example, in principle

includes the sum of the exponentiated utility functions for each and every possible zone in the full universe of zones in the study area. With a very large number of zones, this computation may become impractical depending on the available computational capacity.

Fortunately, there are some simplifying results enumerated in Ben-Akiva and Lerman (1985) regarding the estimation of choice models using a sample of the alternatives (zones) in the computation of the individual choice probabilities, instead of the full universe of zones. Various sampling schemes are possible, including simple random sampling of alternatives, importance sampling of alternatives, independent importance sampling of alternatives, importance sampling with replacement, and stratified importance sampling. Note that this sampling of discrete alternatives (residential zones) for each observation in the data set to be used in the computation of the individual choice probabilities is distinctly different from and not to be confused with any sampling of observations applied in the initial survey design as discussed above in the Section D.4 "Sampling of observations."

An early application of simple random sampling of alternatives dates back to a report by Rijkswaterstaat in the Netherlands (1977) on a study of destination choice (zones) in the framework of a transportation demand model. An application of the same time-tested simple random sampling of alternatives approach is by Waddell and Nourzad (2002) in a residential location model as part of a larger integrated land use and transportation model development effort in the Salt Lake City greater region. They predict the probability that a household will choose a housing unit defined by a grid cell of 150 meters by 150 meters, representing thus a highly disaggregate choice model with over 500,000 alternatives.

> "The effect of accessibility on residential location is a research topic with a long and venerated tradition in the literature within urban economics, planning, geography and transportation. The recent surge of interest in integrated land use and transportation planning and modeling and in the potential for new-traditional neighborhood design to curb Americans' appetite for auto travel, or at least to stimulate more walking, have renewed research activity on this topic. The question that this paper seeks to answer is how accessibility at a traditional regional scale interacts with accessibility at the local neighborhood scale to influence residential location choices. Households must trade off multiple dimensions of a residential location choice, including commute times to work, access to shopping and other maintenance and leisure activities, the quality and price of housing, and other amenities associated with the location of housing. This is the first paper to our knowledge to explore the degree to which local, or

> neighborhood accessibility influences residential location,
> controlling for regional accessibility and other housing
> and neighborhood characteristics. We also examine the
> interaction between auto ownership and regional acces-
> sibility in influencing residential location. The approach
> presented in this paper significantly extends an earlier ap-
> proach to modeling residential location, by adding sub-
> stantially greater geographic detail and examining neigh-
> borhood effects and vehicle ownership. ..."

Until recently, the results for sampling of alternatives wereknown
only for simple multinomial logit models. Guevara (2010) presents
a method that allows for consistent estimation of parameters belong-
ing to the GEV family, when only a true choice set is available. He
employs the method in detail for nested logit and cross-nested logit
models. McConnel and Tseng (2000), Nerella and Bhat (2004) and
Chen et al (2005) have studied the impact of sampling of alternatives
in mixed logit models. However, in order to account for spatial cor-
relation between zones as described above, it may be interesting to
experiment with a mixed GEV structure as described in Bhat and
Guo (2003). Since we don't (currently) have results for sampling of
alternatives for such structures, this is a ripe area for further research
contribution. Alternatively, with sufficient computing power and a
distributed approach, we might attempt to apply the "brute force"
method of compiling attributes, and calculating utilities and individ-
ual choice probabilities for all realistically possible residential zones
for each respondent - although this may simply prove to be a compu-
tationally prohibitive task depending on the number of zones mod-
eled and the model structure.

D.9   CORRELATION BETWEEN DECISION MAKERS, STATE DEPEN-
       DENCE AND HETEROGENEITY

Until now, we have reviewed critical aspects of potential temporal
correlation of observations in a dynamic choice model as well as po-
tential spatial correlation of alternatives in a highly disaggregate lo-
cation choice model. With this particular research question we will
have yet another important aspect of correlation to consider, namely
a potential correlation between respondents. Furthermore, the same
issue of separating out "true" state dependence from "spurious" state
dependence described lucidly in the earlier cited quote by Heckman
(1981a), will apply similarly when considering interactions between
respondents. Manski (1995) draws attention to this dilemma:.

> "There is a long-standing interdisciplinary split between
> economists and sociologists on the channels through
> which society affects the individual. Whereas sociologists

hypothesize that society affects individuals in myriad ways, economists often assume that society acts on individuals only by constraining their opportunities. Many economists regard such central sociological concepts as norms and reference groups as spurious epiphenomenon explainable by processes operating entirely at the level of the individual. ...

Sociologists, social psychologists and some economists have long been concerned with reinforcing endogenous effects, wherein the propensity of an individual to behave in some way increases with the prevalence of that behavior in the reference group. ... Economists have always been fundamentally concerned with a particular non-reinforcing endogenous effect: an individual's demand for a product varies with price, which is partly determined by aggregate demand in the relevant market. Contextual effects became an important concern of sociologists in the 1960s, when substantial efforts were made to learn how youth are influenced by their school and neighborhood environment. The recent resurgence of interest in spatial concepts of the underclass has spawned new empirical studies.

Distinguishing among endogenous, contextual and correlated effects is important because these hypotheses have differing implications for the prediction of social interactions. ... Contextual and correlated effects [cannot] generate [a] social multiplier. ... [A] problem ... arises when a researcher observes the distribution of behavior in a population and wishes to infer whether the ... behavior in some group influences the behavior of the individuals that compose the group. I refer to this as a reflection problem because it is similar to the problem of interpreting the almost simultaneous movements of a person and his reflection in a mirror. Does the mirror image cause the person's movements or reflect them? An observer who does not understand something of optics and human behavior would not be able to tell."

Chapter 8 addressed in detail five strategies for introducing social and spatial network interdependencies into choice models, focusing on feedback effects and on correlated effects. We consider aggregate agent interdependencies and apply the model strategies for nine hypothetical variations on three network treatments, one of these defined by socioeconomic group and two defined spatially. As discussed previously in the case of dynamic models, control for (unobserved) heterogeneity in the sample plays a crucial role in distinguishing "true" state dependence (what Manski terms "endogenous"

effects) from "spurious" state dependence (what Manski terms "contextual" and "correlated" effects). According to likelihood ratio and non-nested specification tests, the best performing model strategy for the particular case study is what we have termed a "random field effect" model, namely one with unobserved individual heterogeneity on the group mean state dependence.

D.10   BOUNDARY CONDITIONS PROBLEM

In a typical choice model application with panel data, the model specification captures correlation across multiple responses from the same individual over time. The "panel" implementation applied in Chapter 8 captures correlation among different decision-makers based on their connectivity in a social and/or spatial network. One important distinction between the social-spatial causality and correlation discussed here and the time causality and correlation traditionally understood in panel data literature is however that the concept of initial values (Heckman 1981a, 1981b) can be less obvious. Time generally points in only one direction (unless foresight is considered), whereas inter-agent dependencies can point in dual directions (decision-maker A influences decision-maker B, and decision-maker B influences decision-maker A). Furthermore inter-agent dependence is clearly not necessarily one-dimensional. Nonetheless if it can be assumed that the aggregate field variable can be seen as being effectively self-contained and not incurring bias in pointing by definition to unobserved decision-makers outside of the data set, the case is similar to one with a time series which is observed from the beginning. In such case there is no "Initial conditions problem" as these values are well-defined.

That said, we can also easily imagine alternative constructions not discussed in Chapter 8 which could much more obviously incur bias. For example, social-spatial boundary conditions could be critical in the case of modeling social-spatial Markov random field state dependence (Kindermann and Snell, 1980) instead of group mean field state dependence, and in the case of modeling social-spatial auto-regressive correlation instead of unobserved group heterogeneity. This is in fact one driving motivation for the particular strategies presented in Chapter 8.

In addressing residential choice and the geography of family networks, we would have to look carefully at boundary conditions and whether or not state dependence points to persons outside of the data set for which we have insufficient or no information.

D.11 DECISION-MAKING WITHIN A HOUSEHOLD

Until now we have considered aspects of decision-making at the household level and subtle issues related to separating out potential correlation between households from the direct dependence of a given household's choice behavior on the choice behavior of other households. But what about the level of decision-making within a household? There are many possible approaches to this question ranging from conditional or nested choice structures to the use of indicator variables to specification of (factor analytic) error terms to market segmentation to combinations of these approaches.

To our knowledge, Lerman (1975) is the first to address decision-making within a household in the discrete choice modeling of residential location. Due to the additional behavioral complexity in the mobility decision process for multi-worker households, Lerman estimates separate models for single-worker households and multi-worker households. He proposes four behavioral hypotheses for the location decision of multi-worker households:

> "(1) complete primary worker dominance; (2) a primary worker with the remaining workers secondary (i.e. without fixed workplace) in the location decision; (3) some or all workers with fixed workplaces but each with different weights; (4) complete equality in the perception of the work trip attributes."

Note that even though the first hypothesis logically reduces to a single-worker model, Lerman still applies market segmentation for single-worker versus multi-worker households, reasoning that the fact that multiple members of the household work might alter the importance of various location and housing attributes to the household. Nonetheless, models reflecting both the first and second hypotheses performed poorly in Lerman's study, pointing to the necessity to consider the workplace of some or all workers in the household as fixed in the mobility decision. The third hypothesis proved too computationally demanding to test at the time of Lerman's study. The fourth hypothesis greatly simplifies the form of the utility function by avoiding the need to identify each worker's travel times and costs separately; when there are equal weights, travel times and costs for individual workers in a household can be summed into a total household travel time and total household travel cost. This gave plausible results in Lerman's study, although the statistical significance of many estimates were low, a problem exacerbated by the smaller sample size of multi-worker households versus single-worker households in his study. Drawing on modern computational capacity and advances in estimation procedures, Abraham and Hunt (1997) are indeed able to apply Lerman's third hypothesis in a nested logit model of home

location, workplace location and home-to-work transportation mode choice:

> "Household behavior in the selection of home location and the selection of workplace locations and commuting modes for employed members involves trade-offs among the attributes of the available alternatives for the different household members. A modified form of nested logit model representing this behavior has been developed and estimated using disaggregate revealed preference observations collected in Calgary, Alberta, Canada. Three categories of choice – choice of home location for the household, choice of workplace location for each worker in the household, and choice of mode for the trip to work for each worker in the household – are treated as a joint choice made by the household, allowing for differing numbers of workers in different households. A nesting structure that takes into account the greater similarity among mode alternatives is combined with a system for weighting, by age and gender, the contributions of different individual workers' utilities to the total household utility. This leads to a nested logit model in which each household has its own nesting structure that is based on age and gender of the household members. The utility function coefficients and weighting function parameters were estimated with full-information maximum likelihood by using purpose-built software. The resulting model extends consideration of household spatial behavior at the disaggregate level beyond the one-worker and sequential-conditional choice paradigms and provides various insights into the nature of this behavior."

D.12   ACTIVITY-BASED MODELING

Both Lerman's multinomial logit approach (1975) and Abraham and Hunt's nested logit approach (1997) cited in the previous section consider only households with workers in their residential location choice models. Lerman motivates his decision at the time as follows:

> "... Almost all urban location models assume that every household has workers. However, the 1968 Washington Home Interview Survey indicated that approximately 12.3% of all households had no full time workers at all. These households consist primarily of retired persons, but may also include the long term unemployed, households on welfare, or the unemployable handicapped. Such households have locational decision processes which are

completely unaffected by work trip level of service. Instead, the other factors such as jurisdictional attributes, access to spatial opportunities, ... probably dominate their location choices.

Furthermore, for retired households in particular, the dynamics of location decisions may be very important. These households may have made location decisions while one or more members was employed, and the adjustment process may be extremely slow. The location in which they may presently reside is not necessarily optimal for them; rather, it reflects the difficulties associated with relocating if one is elderly, and the strong social ties which developed after living in a location for an extended period.

Because the locational decisions of households without workers are more subtle than those of households with workers and are poorly understood, the empirical study ... does not include any such households. ..."

Presumably the development of a residential location model which includes households with no workers will be important in residential choice and the geography of family networks, both to be able to dock the existing research on elderly migration and distances to children, as well as generally to be able to answer questions regarding elder care given the burgeoning population of elderly to be expected as the post World War II baby boomers move into old age. One point that is reinforced however in the quoted passage by Lerman is the importance of developing a dynamic choice model, as noted already earlier here.

An important stream of research that may be able to be drawn upon in the development of a model for households with no works is so-called activity-based modeling. It shifts the focus in travel demand modeling from typical home-to-work commuter models to consider the whole range of activities carried out by a household over the course of a day. In fact Waddell and Nourzad (2002) conclude their earlier quoted article as follows:

"The limitations of the current four-step travel models, and advances in activity-based travel modeling suggest that over the next few years we will begin to see the emergence of more fundamentally integrated land use and activity-based travel models. Residential location choices are, after all, highly dependent with the labor force choices of household members, the vehicle ownership choices of the household, and the activity and travel patterns chosen. Further research on these interdependencies and their representation in operational models presents an important challenge."

In fact, related to the topic of Section D.11 "Decision-Making within a Household," within the stream of activity-based modeling research, an important new direction for research is indeed intra-household interactions. There are various reasons why we might expect a priori that intra-household interaction would be important in travel demand behavior. For example, Vovsha, Bradley and Bowman (2004) and Vovsha, Gliebe, Peterson and Koppelman (2004) highlight research on coordination of individual daily activity patterns, joint participation in activities and travel, and intra-household mechanisms for allocation of maintenance activities.

D.13   MARKET SEGMENTATION

As outlined earlier in Section D.11 "Decision-making within a household," Lerman (1975) drew attention to the necessity to apply market segmentation across single-worker versus multi-worker households. Clearly this reasoning would also extend to the necessity for a separate model for households with no workers. However, there may also be other dimensions along which we might hypothesize would fundamentally structurally alter the importance of various location and housing attributes to households. Some such examples may be regional variation, dependent on the geographical scope of the study area, and/or race, ethnicity or recent immigration status. Market segmentation when applied in the form of separate models per market segment comes however at the expense of smaller sample sizes for the separate models, potentially leading to high unreliability in (some) parameter estimates, a problem which Lerman also faced. An alternative to market segmentation may be a random coefficients model, where estimated parameters for observations from the same market segment differ from the population means by the same unobserved amount for a given explanatory variable.

A more straightforward model specification possibility which captures some utility variation due to market segments without fundamentally structurally altering the importance of various location and housing attributes to households, may simply be the inclusion of a (limited) set of dummy variables for the market segments directly in the specification of the utility function, or the estimation of particular (sets of) explanatory variables crossed with market segment dummies.

One particular instantiation of this last approach is detailed in Chapter 8 namely the inclusion of a complete set of variables for the market segments defined by the fractions of households per segment choosing a particular alternative for households in that segment (and zero otherwise). See the above Sections D.9 "Correlation between decision makers, state dependence and heterogeneity," and D.10 "Boundary conditions problem." The instantiation is interesting

because it implies an endogenous set of variables. In the case study in the dissertation, it proves to be a very powerful approach, however absolute care must be taken to control for unobserved heterogeneity in the error terms across the market segments to avoid bias. Likewise attention must be paid to boundary conditions.

D.14   COHORT ANALYSIS

An important and timely scientific contribution with potentially strong possibility for application in addressing residential choice and the geography of family networks is that in Bush (2005):

> "... [As the] 78 million people in the United States born between 1946 and 1965... move into old age, they will square the age pyramid and double the current number of senior citizens. The Boomers will not only increase the numbers of people 65+, their lifestyles and associated travel behavior are expected to differ from those of the current 65+. When compared with today's 65+ population, the Boomers are expected to carry with them into old age a higher propensity for auto ownership use, increased female independence, as well as higher levels of education, increased economic stability, and improved health. These differences would cause one to expect that the Boomers, when they comprise the 65+ population, will travel more than the 65+ population of today.
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> The possibility that the aging Boomers will have increased travel demand has personal, public safety and policy implications. According to Rosenbloom: *for the last two decades, every auto-related travel indicator for the elderly has gone resolutely up.* However, with aging, people experience physical, financial, emotional and mental barriers to driving, and most people eventually have to stop driving. When seniors can no longer drive, maintaining mobility becomes a health issue. Seniors who remain active and mobile live longer. There is a significant correlation between mobility and well-being; holding demographic, psycho-social and medical factors constant, mobility loss has been shown to be significantly related to declines in activity levels as well as substantial increases in depression. Therefore, as increasing numbers of Boomers with higher mobility expectations face the reality of post-driving life, the associate personal cost may be high. ...
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> As children [the Boomers] caused the physical expansion of communities, and as adults they have driven social and market change. When they move into retirement,

baby boomers will expect public policy to address their transportation needs.

Yet, forecasts to inform policy decisions with respect to anticipating these needs and addressing the safety and personal implications of increased 65+ travel, are currently limited. Previous demand models of 65+ travel have failed to incorporate generation differences and have forecasted only broad travel characteristics. Drawing on the theory of generations and previous work modeling cohort (or generation) effects, this paper investigates empirically whether generation differences exist in travel between the Boomers and current 65+ population. In particular, it incorporates theoretically motivated cohort variables related to the historical processes of motorization and gender role evolution over the last century. Second, the paper provides a forecast of the aging Boomers' travel demand with respect to activities requiring travel. ..."

Bush summarizes her findings:

"In the estimated models, the cohort variables are significant, and cohort variable inclusion increases forecasted travel. The implication for transportation modeling is that historical location and generation membership affects transportation behavior. The implication for planners is that in preparing for future 65+ transportation needs, studying the current 65+ population is not adequate. The Boomers will comprise a new generation of 65+ with different associated travel needs."

The implication for the given research question is that if there is an intention to move beyond descriptive research to consider forecasting, careful attention will likely be necessary to account for cohort effects.

D.15   EXOGENOUS VERSUS ENDOGENOUS NETWORK

An interesting finding with respect to the particular case study in Chapter 8 is that the specifications allowing agents to weigh both any influence from their socioeconomic peers as well as any influence from their spatial network, and furthermore allowing the possibility to weight these influence differently, all outperform models where each agent belongs to one and only one group. Also interesting is that the specifications allowing agents to weigh any influence from their fellow district residents differently from any influence from their more immediate neighbors also perform better than a uniform spatial network.

The importance of distinguishing social versus spatial influence networks in transportation mode choice behavior can be especially

relevant if the model would in turn be coupled to, for example, a residential choice behavior model. Transportation mode choice, in itself, does not necessarily affect a decision-maker's reference position in a social-spatial network. Whether an agent decides to travel by car versus public transit will not change in a directly causal sense who his/her neighbors are, nor who his/her fellow district residents are, nor will it have consequences for who the decision-maker's age, income and education level peers are. Here, the network is wholly static with respect to the choice dimension. This is what is we term an exogenous network relative to the research question under study. Residential location choice, on the other hand, will per definition impact a decision-maker's reference position in a spatial network. In moving to a new neighborhood, a decision-maker per definition acquires new neighbors, and potentially also new fellow district residents if the move of house is out of the existing district. In this case the spatial network, in particular, is dynamic with respect to the choice dimension. This is what is we term an endogenous network relative to the research question under study.

Although there may be some subtleties in accounting for changing network size due to births and deaths, the family relationship network is in principle exogenous, with one major exception. This exception is marital relation. Whether a household decides to live in one province or another, one municipality or another, one neighborhood or another, will have no affect on who the parents or siblings of any members of this household are. What the residential location decision may have an effect on, is who a future spouse of a member of the household will be. Depending on the nature of the data, there may not be sufficient information to estimate the marital relation endogenously, however. In such case we would need for practical purposes need to consider the entire family relationship network as exogenous.

Another consideration, depending on the sampling scope of the data set, is if we would like to consider potential influences from neighbors or fellow district residents on residential choice. As shown by Hooimeijer and van Ham (2000) on the basis of the national Woningbehoefte Onderzoek 1998 in the Netherlands, both nuisance from neighbors as well as conversely satisfaction with neighbors are very strong factors in the inclination to move house, both for under 55 and over 55 age groups in the Netherlands. In such case we would then per definition need to address the endogenous nature of the (spatial) reference network in an empirical application of residential re-location.