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Socio-Dynamic Discrete Choice: Theory and Application

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SOCIO-DYNAMIC DISCRETE CHOICE

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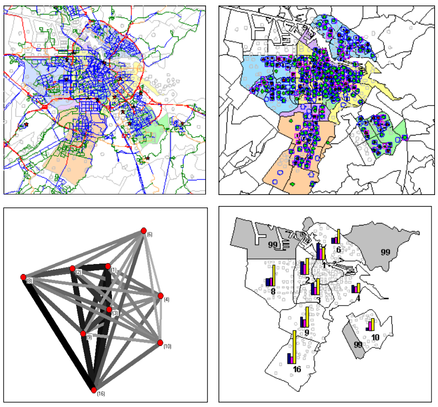

Theory and Application

TOPICS:
Discrete choice analysis, Dynamical systems, Network interaction effects, Travel demand modeling, Multi-agent based social simulation, Information and decision in social networks and spatial networks

SUMMARY

Suppose you have the possibility to choose to adopt one of a number of different behaviors or to choose to buy one of a number of different products. Moreover, suppose the choice is multi-dimensional or more generally, that there are common unobserved attributes of the choice alternatives. A classic approach to statistical prediction in such a situation given an observed sample of decision making agents in a population is the nested logit model, proposed by Ben-Akiva (1973) in the context of passenger travel demand modeling and generalized by McFadden (1978) in the context of modeling the choice of residential location. The utility that a given decision making agent is presumed to associate with a particular elemental alternative is assumed to be comprised by a deterministic (to the modeler) or so-called "systematic" utility and an error term. The nested logit derives its name from the partitioning of the choice set into mutually exclusive and collectively exhaustive "nests" of elemental alternatives which are assumed to be correlated.

Now suppose your choice is additionally influenced by your individual perception of the average choices made by your neighbors, colleagues and/or socioeconomic peers. Such a specification is interesting because of the inherent dynamic that could arise if the choice model were to be applied repeatedly in successive time steps with the shares of decision makers continuously updated as a result of the choice in the previous time step. If the social influence is not important relative to other contributions in the utility, then the distribution of decision makers' choices may not effectively change over time. However, if the social influence is strongly positive and "dominant enough" relative to other contributions in the utility, there may arise a runaway situation after several repeated time steps with a large share of decision makers flocking to one particular choice alternative. In short, the specification captures feedback between decision makers that can potentially be reinforcing over the course of time. In diverse literature this is referred to as a social multiplier, a cascade, a bandwagon effect, imitation, contagion, herd behavior, etc. (Manski 1995). Blume et al. (2011) give an extensive literature review of social interactions models in economics, including notably a section on discrete choice models of social interactions. The relative lack of attention to such models in the field of transportation is surprising. Namely, if there is theoretical or qualitative reason to believe that a feedback effect exists, it can have very important implications for the prediction of (system-wide) results over the course of time. For example, in the introduction of a new transportation mode alternative, if there is a

"dominant enough" feedback effect, this can propel the adoption of the new mode over time.

How dominant is "dominant enough" under different conditions? Our starting point in considering interdependence of various decision makers' choices is a trio of papers by economists Aoki (1995), Brock and Durlauf (2001) and Blume and Durlauf (2003). They introduce social interactions in binary discrete choice models by allowing a given agent's choice for a particular alternative to be dependent on the overall share of decision makers that choose that alternative. Such formulation with perfectly homogeneous agents permits the derivation of analytical results for when runaway flocking will occur. Using different approaches, all three papers show the existence of multiple equilibria depending on the values of the parameters of the model.

In moving from an idealized homogeneous agent setting towards a practical empirical setting with heterogeneous agents, there are various extensions that can be addressed, such as: i) the complexity of the discrete choice model kernel; ii) the complexity of the feedback effect; and iii) the complexity of the utility specification. Each of these extensions offers possibility to add additional types of heterogeneity to the model. In this thesis we systematically explore each of these extensions in turn.

- *Complexity of the discrete choice model kernel*. Brock and Durlauf (2002, 2006) have extended their results on the behavior of binary choice models with global social interactions to multinomial choice with global social interactions. As in the case of binary choice, also in multinomial choice, they show the existence of multiple equilibria depending on the values of the parameters of the model. In Part II of this thesis, we make Brock and Durlauf's multinomial results precise for the case of trinary multinomial choice and extend the results for the case of nested logit with global interactions. Hereby a previously unnoticed hysteresis regime in midrange parameter space is revealed when there are more than two choice alternatives in the multinomial logit model. By considering the nested logit model, a possibility to account for unobserved heterogeneity between choice alternatives is allowed via the nesting of alternatives that are assumed to be correlated. Our analysis of the nested logit model with global social interactions yields rich bifurcation diagrams demonstrating several major additional new emergent steady state regimes where symmetry is broken by the scale parameter for the level of correlation between alternatives.

- *Complexity of the feedback effect*. While the behavior over time derived in early work assumed each decision maker to be influenced by all other decision makers (so-called global interactions), Ioannides (2006) derives more general behavior for the case of binary choice where each decision maker is influenced by only a subset of decision makers (so-called local or non-global interactions). By considering local interactions, heterogeneity is induced since different agents will perceive different shares of agents making each choice dependent on the local network of each agent. This is important since in an empirical setting, a feedback effect defined globally would be perfectly correlated with a set of alternative specific constants in the discrete choice model. In Part III of this thesis, we illustrate the multi-agent based simulation of a discrete choice model with local interactions using microdata on transportation mode choice of households in the Netherlands as a testbed, highlighting some hypothesized network interaction effects first on the basis of abstract classes of networks in a sociodynamic binary logit model, and then on the basis of socioeconomic peer group, spatial proximity of residential location and spatial proximity of work location in a sociodynamic trinary nested logit model. Much empirical work in understanding local social-spatial feedback is still needed as the computational results prove to be highly dependent on the presumed structure of the local feedback in the econometric model estimated.

- *Complexity of the utility specification*. A key aspect in the theoretical results in Part II of this thesis is the assumption that the only observed heterogeneity in the systematic utility for the elemental choice alternatives is the feedback effect. While such a specification may be plausible for a fad, it is much less intuitive for transportation mode choice where other explanatory variables would be assumed to be significant, including attributes of the alternatives such as travel time, as well as characteristics of the decision making agents such as gender, age and income. In Part III of this thesis, a multi-agent based simulation model is therefore presented which gives straightforward possibility to test more realistic empirical cases. The multi-agent based model is docked against the analytical results in Part II for the special case of homogeneous agents as a means to verify the implementation of the computational model, before proceeding to add additional heterogeneity. In Part IV of the thesis, issues in the econometric estimation of discrete choice models with feedback effects are also explored.

We observe that the extensions of adding all three different types of heterogeneity, namely, unobserved heterogeneity captured via the nesting structure, induced heterogeneity via local interactions, and the observed heterogeneity via the fully specified systematic utility, produce dramatically different results.

We have found in this thesis that careful specification of both observed and unobserved heterogeneity matters critically for emergent temporal outcomes when there is sociodynamic feedback in the

model, even when the feedback takes the simple form of an aggregate field variable. Agent heterogeneity impacts the magnitude of the mode shares, the speed of the transition to the steady state as well as very fundamentally the number of possible observable steady state solutions. Also the detailed effect of induced heterogeneity is important to understand in different network structures, including the speed of information flow across them. Misrepresentation of the appropriate scale at which social influence occurs and of the appropriate network structure can yield strongly flawed policy implications when studying social feedback.

We conclude highlighting recommendations for future research, having extended previous work on discrete choice with social interactions in important ways.