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Allowing for complementarity and rich substitution patterns in multiple discrete–continuous models

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ABSTRACT

Many consumer choice situations are characterized by the simultaneous demand for multiple alternatives that are imperfect substitutes for one another, along with a continuous quantity dimension for each chosen alternative. To model such multiple discrete–continuous choices, most multiple discrete–continuous models in the literature use an additively-separable utility function, with the assumption that the marginal utility of one good is independent of the consumption of another good. In this paper, we develop model formulations for multiple discrete–continuous choices that accommodate rich substitution structures and complementarity effects in the consumption patterns, and demonstrate an application of the model to transportation-related expenditures using data drawn from the 2002 Consumer Expenditure (CEX) Survey.

1. Introduction

Multiple discrete–continuous (MDC) choice situations are quite ubiquitous in consumer decision-making, and constitute a generalization of the more classical single discrete–continuous choice situation. Examples of MDC contexts include the participation decision of individuals in different types of activities over the course of a day and the duration in the chosen activity types (see Bhat, 2005; Chikaraishi et al., 2010; Wang and Li, 2011), household holdings of multiple vehicle body/fuel types and the annual vehicle miles of travel on each vehicle (Ahn et al., 2008), and consumer purchase of multiple brands within a product category and the quantity of purchase (Kim et al., 2002).

To date, most MDC modeling frameworks, including Bhat's (2005, 2008) MDCEV model, have considered the case of imperfect substitutes and perfect substitutes, but not the case of complementary goods (the case of imperfect as well as perfect substitutes can be handled through a nested MDC-SDC model, as in Bhat et al., 2009). However, complementary goods occur quite frequently in consumer choice situations. For example, in the consumer expenditure literature, consider the case of annual household expenditures on transportation and other commodities (such as housing, clothing, and food). Also, let the transportation expenditures be disaggregated into such categories as vehicle purchase, gasoline/oil, vehicle insurance, vehicle maintenance, and public transportation. Then, there are likely to be complementarity effects in the expenditures

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on gasoline, vehicle insurance, and vehicle maintenance, as well as strong substitution effects between these three categories of auto-related expenditures and public transportation expenditures. If the public transportation category is further broken down by rail or bus, it is possible that these two sub-categories are perfect substitutes in that there is expenditure on only one or the other of these two alternatives. This example context then is a case of alternatives that are complementary, imperfect substitutes, as well as perfect substitutes. Similarly, in the activity-based travel modeling and time-use literature, an analyst may be interested in daily non-work, non-sleep time-use patterns in such activities as relaxing, running indoors, running outdoors, and eating. Here, relaxing and eating may be complements, while relaxing and running outdoors may be imperfect substitutes, and running indoors and running outdoors may be perfect substitutes.

The reason why most earlier MDC studies are unable to consider complementarity stems from the use of an additively separable utility function (ASUF) and the usual assumption of a quasi-concave and increasing utility function with respect to the consumption of goods (see Deaton and Muellbauer, 1980, page 139). Besides, the additive utility structure makes it difficult to incorporate even rich imperfect substitution patterns across alternatives because the marginal rate of substitution between any pair of goods is dependent only on the quantities of the two goods in the pair, and independent of the quantity of other goods (see Pollak and Wales, 1992). Thus, back to the activity-based travel modeling and time-use fields, consider an individual living alone with three recreation activity options: watching TV at home, visiting friends, and going to the movies. Let this individual currently spend all her time watching TV at home. As she spends more and more time watching TV, the traditional utility formulation does recognize that there is satiation and that the marginal utility of an additional unit of time spent watching TV decreases. However, the additive utility formulation assumes that the utility of visiting friends is unaffected by the amount of time watching TV. But as the time spent watching TV increases, it may increase the marginal utility of visiting friends. If the latter is true, it would imply a higher likelihood to participate in visiting friends and a higher time investment in visiting friends, relative to the case when this interaction between the investment in one alternative and the utility of another is completely ignored (as in the additive utility function). Of course, whether such an interaction exists, and the direction of such an interaction, may be an empirical issue. This suggests that one should consider a richer non-additive utility function and then examine its performance against a traditional utility function.

Overall, the additively separable assumption substantially reduces the ability of the utility function to accommodate rich and flexible substitution patterns, as well as to accommodate complementarity effects. At the same time, the literature on MDC models that adopt a non-additively separable (NAS) utility function is very limited, and research in this area has arisen only in the past five years or so. Song and Chintagunta (2007) and Mehta (2007) accommodated complementarity and substitution effects in an MDC utility function to model purchase quantity decisions of house cleaning products. However, both studies use an indirect utility approach instead of a direct utility approach. As clearly articulated by Bunch (2009), the direct utility approach has the advantage of being closely tied to an underlying behavioral theory, so that interpretation of parameters in the context of consumer preferences is clear and straightforward. Further, the direct utility approach provides insights into identification issues. Later, Lee and Allenby (2009) proposed a direct utility approach that incorporates a NAS utility structure. For this purpose, they grouped goods in categories assuming that goods in the same category are substitutes, while goods in different categories are complements. However, their modeling framework does not allow consumers to choose multiple goods within each category. Lee et al. (2010) proposed a direct utility model for measuring asymmetric complementarity. Their model formulation, however, was developed for the simple case of only two goods.

Vásquez-Lavín and Hanemann (2008) or VH extended Bhat's (2008) additively separable linear form allowing the marginal utility of each good to be dependent on the level of consumption of other goods. In this paper, we use the VH utility formulation (VHUF) as the starting point, but suppress a term used in the VHUF that can create interpretation and identification problems. The resulting utility forms remain flexible, while also being easy to estimate and expanding the range of local consistency of the utility function relative to the VHUF. We also develop several ways to introduce stochasticity in the utility specification. The stochastic forms we introduce essentially acknowledge two different sources of errors. The first source of errors arises when consumers make random "mistakes" in maximizing their utility function, and the second source of errors originates from the analyst's inability to observe all factors relevant to the consumer's utility formation. To our knowledge, this is the first time that such a distinction is being made between the two sources of errors in a NAS-MDC model. Basically, the first source assumes that the analyst knows exactly how consumers valuate goods (that is, the analyst knows the utility functions of consumers exactly), but the analyst also acknowledges that there may be a difference between the optimal consumptions as computed by the analyst based on the "exact" utilities and as actually observed to be made by the consumers. This may be because consumers do not go through a rigorous mathematical optimization process, and make random "mistakes" about (statistically speaking) what the actual consumption patterns must have been. This causes two consumers who are exactly the same, or the same consumer in exactly the same choice environment, to reveal different consumption patterns. We call this as the deterministic utility-random maximization (DU-RM) stochastic specification in the rest of this paper. The second source is the more traditional one used in the economic and transportation literature. Here the analyst introduces stochasticity directly in the utility function to acknowledge that the analyst does not know all the factors that is considered by the consumer in her/his valuation pattern for goods. However, the consumer is assumed to make a perfect optimization decision given her or his utility formation. We refer to this as the random utility-deterministic maximization (RU-DM) stochastic specification.[3] A third approach combines the random utility as well as the

[3] Of course, many other interpretations may be provided for these two sources of error.