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Modeling household energy consumption behavior: A comparative analysis

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ABSTRACT

Household decisions on the energy consumption behavior are with regard to the situations that multiple end-uses (e.g., domestic appliances and vehicles) are simultaneously hold and consumed. To deal with this issue, the multiple discrete–continuous models are the best choices from the behavioral perspective. This study compared two types of utility theory-based multiple discrete–continuous models, which are widely applied in the literature: multiple discrete–continuous extreme value (MDCEV) model and the improved resource allocation model based on the multi-linear function (RAM-MLF). A household energy consumption survey was carried out in Beijing in 2010, and the comparative analysis on the performance of these two models is carried out based on the survey data. Results show that the overall performance of RAM-MLF is slightly superior to the MDCEV model due to the incorporation of the inter-end-use interaction and the relative importance of end uses. Moreover, the utility structure by using the satiation parameters to represent the diminishing marginal utility with the increasing consumption shows better fitness than the structure only using the logarithmic function. These findings can be contributed to understand the household energy consumption behavior, while suggest the potential improvement of the model structure, which is mainly focused on the utility form and the decision making mechanism.

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Introduction

Practically, lots of consumer decisions are under the situation that multiple alternatives are simultaneously chosen and consumed. One example is the time use across varied activities within a given time period (e.g., a day, a week). Individuals always choose to participate in several types of activities and meanwhile allocate certain time on them. Another example could be the energy expenditure on several end uses. Under the constraint of the total available money, individuals/households decide to purchase a set of end uses and spend some amount of money on them so as to support their service demand. Of course, in addition to these two cases, there are still many other decisions which are related to multiple choices, such as the vehicle ownership and usage, brand choice and purchase quantity, and tourism destination group choice and the time/money allocated in each selected destination. In these contexts, traditional discrete–continuous models that usually deal

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with choice situations in which a household can choose only one alternative from a range of mutually exclusive alternatives in a choice set might be inappropriate. Instead, the multiple discrete–continuous models which explicitly incorporate the limited resource (e.g., time and money) should be utilized from the behavioral perspective.

Recently, more and more attention is turned to model the multiple discreteness issues. This study aims to compare two types of multiple discrete–continuous models, deriving from random utility maximization, which are currently very popular in the literature: one is the multiple discrete–continuous extreme value (MDCEV) model proposed by Bhat (2005) and extended in Bhat (2008), the other is the resource allocation model based on the multi-linear function (RAM-MLF) developed by Zhang et al. (2002, 2005). In the MDCEV model, the continuous part (e.g., the duration of the activities or the expenditure on the end uses) is a choice variable in the upper level and the discrete part (e.g., the participation in each activity or the ownership of each end use) is captured by a multinomial logit component in the lower level (Fang, 2008). By embedding the upper level into the lower level, the MDCEV model is formulated. As for the RAM-MLF, although Zhang et al. (2002, 2005) treated the zero-consumption which should be a result of the discrete choice as one part of continuous values, this problem actually can be easily figured out by using some estimators (e.g., Kuhn–Tucker conditions, and Amemiya (1974) estimator) which endogenously carry out the integration of the discrete and continuous components (similar with the Tobit model). In the empirical application, these two types of models have their own strengths and weaknesses. Specifically, apart from the simple manipulation of the MDCEV model, the flexible description of the utility which assumes diminishing marginal utility as the consumption of any particular alternative increases (not only the logarithmic utility form), makes it being widely adopted recently. However, the additive-type utility function results in that increasing or disposing any alternative in the choice set will not influence the continuous decision for other alternatives, in other words, the inter-alternative interaction is not properly included in the model (similar with the IIA issue). Although the MDCEV model can be expanded to the mixed structure which is able to represent the correlation derived from the unobserved factors (i.e., error terms) between alternatives, it is only the statistical interaction without any behavioral rationality. In contrast, the RAM-MLF can incorporate diverse behavioral interactions by formulating the multi-linear group utility function. In addition, the relative importance of each alternative to the subject (e.g., individual, household, and other entities) can be also reflected in the model. But the utility function is only defined as the log form and the interactions due to the unobserved factors are always ignored given the complex error terms after the transformation of the model structure.

By considering the unique characteristics of the MDCEV model and the RAM-MLF, this study first extends the RAM-MLF to incorporate the discrete choice behavior, after that the comparative analysis on the performance of these two types of models is conducted based on an empirical context of the household energy consumption behavior. It is easy to understand that households choose to purchase a basket of end uses (including both in-home appliances and out-of-home vehicles) and spend some money on them. Meanwhile, the usage on the end uses might be correlated with each other probably due to the income rebound effects, and/or the self-selection effects derived from the household social-demographics, or some subjective factors (e.g., environmental awareness, preference, and lifestyle) (Yu et al., 2012, 2013a), an/or the function substitution or complementation between end uses. In this sense, the multiple discrete–continuous models which can incorporate such interaction might be more appropriate than the traditional models. Therefore, the MDCEV model and the RAM-MLF are developed to describe the above issue, respectively. These two models are estimated and compared by using the data collected in a household energy consumption survey conducted in Beijing in 2010. The information in the questionnaire includes the ownership and usage of the main durable end uses in the household, housing characteristics, household social-demographics, built environment attributes, and the end-use specific factors (e.g., efficiency, purchase year, size, capacity, temperature setting degrees, etc.). Totally, 775 valid samples were finally collected.

The remaining part of this paper is organized as follows. The next section introduces the respective model structures of the two models under study. Section 'Data' explains the survey data. The model estimation results are shown and the comparative analysis are carried out in Section 'Results'. This study is concluded in Section 'Conclusion' along with a discussion about future research issues.

Model

MDCEV model

The MDCEV model is proposed by Bhat (2005, 2008). It is assume that there are I different end uses that a household can potentially allocate its income to. Let e_{ni} index the monetary expenditure consumption on end use i ($i = 2, 3, \ldots I$) for household n. Considering households will never run out of their income for the energy expenditure, implying residuals always exit, the model structure with an outside goods which is always consumed is adopted here (Bhat, 2008). The term "savings" indicating the money calculated by deducting the energy expenditure from total household income is regarded as the outside goods and it is labeled as the first end use (i.e., $i = 1$) in the model. The sum of the utilities derived from spending money on end uses as well as savings u_{ni} is used to explain the overall utility u_n that household n obtains from energy consumption, see Eq. (1).

$$u_n = \sum_{i=1}^{I} u_{ni} = \frac{1}{a_1}\varphi_{n1} e_{n1}^{a_1} + \sum_{i=2}^{I} \frac{\gamma_i}{a_i}\varphi_{ni}\left\{\left(\frac{e_{ni}}{\gamma_i}+1\right)^{a_i} - 1\right\}, \quad \alpha_i \in (-\infty, \infty), \gamma_i > 0 \tag{1}$$

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