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Simultaneous estimation of a joint time use, expenditure allocation and mode choice model: A simulated maximum likelihood approach

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Motivation and objectives

As a key valuation indicator, the value of travel time savings (VTTS) has always been subject to extensive debate in both academia and politics, because savings in travel time have accounted for the biggest share of user benefits in most cost-benefit analysis (CBA). Recent research has shown a trend towards a potentially more insightful measure by decomposing VTTS - typically derived from mode, route and/or destination choice models - into two separate parts. Following Jara-Diaz and Guevara (2003), the value of time is the sum of two components: 1) the subjective value of travel time savings (VTTS), representing the willingness to reduce travel time in favor of other activities that generate more utility and 2) the direct (dis)-utility derived from the time assigned to travel (VTAT). Both may differ according to characteristics of the trip, travel mode and the user (Mackie et al., 2001). The sum of VTTS and VTAT equals the value of time as a resource (VOR), which is the marginal utility of an additional unit of leisure. Therefore, the VTAT cannot be derived from travel decisions alone, but requires the integration of travel decisions into a framework of consumers' time allocation, goods consumption and home production (Jara-Diaz and Guevara, 2003).

The estimation of such models is not easy to handle and requires sophisticated econometric methods: Munizaga et al. (2008) presented the first results of a simultaneously estimated time use and mode choice model by allowing for possible intercorrelations between discrete and continuous decisions. In this paper we go a step further and present the first joint time use, expenditure allocation and discrete mode choice model, which includes all the required components of the complete Jara-Diaz model formulation (Jara-Diaz et al., 2008).

Data

Data was collected for a representative sample of 748 working respondents in Austria between 2015 and 2016, using a seven-day mobility, activity and expenditure diary (MAED; Aschauer et al., 2017) to get information about individual time use, expenditure allocation and travel behavior. From this, 17'156 RP mode choice observations were generated. The reporting period of one week was a compromise between response burden and accurate representation of an individual's long-term equilibrium, especially with regard to expenditure allocation, for which it would be desirable to have longer observation periods as usually done in conventional expenditure surveys.

Model formulation

In this paper we further refine the micro-economic modeling framework proposed by Jara-Diaz et al. (2008) and Munizaga et al. (2008), allowing for 1) correlations between continuous time use and expenditure allocation 2) correlations between continuous equations (time use and expenditures) and discrete mode choices and 3) correlations within individuals' mode choices by accounting for the panel structure.

Respondent's time use and expenditure allocation utility is assumed to have Cobb-Douglas form with weak complementarity (e.g. Zellner et al., 1966), which is a function of the time assigned to work, the time assigned to freely chosen activities and expenditures assigned to freely consumed goods. The analytic solution of this constrained maximization problem leads to a system of three equations, which are translated into a maximum likelihood estimation problem, estimating the baseline utility parameters of the Cobb-Douglas utility function.

Respondent's mode choice for either car, public transportation, walk or bike is assumed to have a linear-additive indirect utility function in mode-specific attributes such as travel time and cost, individually accounting for the availability conditions of different modes. The conditional choice probability is of Mixed Logit type (e.g. Train, 2009) including three random error components for unobserved heterogeneity in mode-specific preferences.

As discussed in Munizaga et al. (2008), discrete and continuous choices can be correlated either due to the use of common parameters or correlation between the error terms. In contrast to the authors using a very complex analytical framework to account for these interdependencies, our approach is new in the sense that we allow for correlations between the random time use and expenditure allocation coefficients and the random intercepts from the mode choice model using a simulated maximum likelihood approach. This is done by applying a Cholesky decomposition to a multivariate normal distribution generated by independent pseudo-random draws (e.g. Train, 2009). By combining the time use and expenditure allocation equation system with individual

mode choices over one week, this approach also allows for a dedicated treatment of the panel structure which has not been accounted for in previous work.

Preliminary results

The time use and expenditure allocation model is first estimated and evaluated independently of the mode choice model, and vice versa. Without random coefficients, the VOR is 10 Euro/hour ($p < 0.01$), which is below the average wage rate of 12 Euro/hour. This means that the value of time assigned to work is negative with an average value of -2 Euro per hour ($p < 0.1$), indicating that at the margin, on average respondents only work for earning money. The inclusion of random coefficients leads to a decrease in VOR by roughly 10%, which is mainly driven by an increase in the average baseline utility coefficient of the time assigned to work, exhibiting a significant amount of taste heterogeneity among respondents ($p < 0.01$).

VTTS derived from an independent mode choice model indicates a mode-specific ranking also observed in other recent studies e.g. for Switzerland (Weis et al., 2017): The willingness to pay for a reduction in travel time by one hour is about 10.40 Euro for car ($p < 0.01$), 4.20 Euro for public transportation ($p < 0.01$), 7.70 Euro for bike ($p < 0.01$) and 14.70 Euro for walk ($p < 0.01$). Accounting for the panel structure yields to slightly (but not significantly) larger VTTS of about 1 Euro/hour for all modes (see also e.g. Hensher, 2001), again exhibiting a significant amount of taste heterogeneity among respondents captured by the random error components.

The simultaneous estimation of correlated time use, expenditure allocation and mode choice equations yields a highly significant increase in model fit of 220 units in log-likelihood compared to an approach without correlations, including twelve additional degrees of freedom. However, in contrast to Munizaga et al. (2008), the correlations are never exceeding +/-0.1, indicating rather small (but still significant) dependencies between the two domains. On the other hand, similar to Munizaga et al. (2008), results of the time use, expenditure allocation and mode choice coefficients only change marginally (and not significantly) when comparing the simultaneous with the independent estimation approach, leading to qualitatively identical conclusions.

Literature

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