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Capturing correlation with a mixed recursive logit model for activity-travel scheduling

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ABSTRACT

Representing activity-travel scheduling decisions as path choices in a time–space network is an emerging approach in the literature. In this paper, we model choices of activity, location, timing and transport mode using such an approach and seek to estimate utility parameters of recursive logit models. Relaxing the independence from irrelevant alternatives (IIA) property of the logit model in this setting raises a number of challenges. First, overlap in the network may not fully characterize perceptual correlation between paths, due to their interpretation as activity schedules. Second, the large number of states that are needed to represent all possible locations, times and activity combinations imposes major computational challenges to estimate the model. We combine recent methodological developments to build on previous work by Blom Västberg et al. (2016) and allow to model complex and realistic correlation patterns in this type of network. We use sampled choices sets in order to estimate a mixed recursive logit model in reasonable time for large-scale, dense time-space networks. Importantly, the model retains the advantage of fast predictions without sampling choice sets. In addition to estimation results, we present an extensive empirical analysis which highlights the different substitution patterns when the IIA property is relaxed, and a cross-validation study which confirms improved out-of-sample fit.

1. Introduction

Activity-based travel demand analysis consists in jointly modeling choices concerning transportation and activity participation, based on the assumption that individuals undertake trips with the intention to pursue activities. At the core of activity-based modeling is the idea that trips result from scheduling decisions within a continuous time interval: individuals dispose of a limited amount of time (often, a day) to allocate to activities and subsequent trips (Pinjari and Bhat, 2011).

Activity-based travel demand has been the subject of various studies, attempting to predict choices primarily from utility maximization econometric models (Habib, 2011) or using rule-based computational process models (e.g. Arentze and Timmermans, 2004; Miller and Roorda, 2003). Most approaches require to define utility functions, and the purpose of such studies varies between estimating parameters of a choice model and developing mechanisms for prediction. The challenge all models yet face is how to represent the immense number of possibilities to plan a day. As seen in e.g. Bowman and Ben-Akiva (2001), Bhat et al. (2004), or Cirillo and Axhausen (2010), a common approach is to decompose daily activity-travel patterns into multinomial logit or nested logit

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layers, where each layer represents the choice of a specific facet of the pattern, such as number and structure of tours, tour mode and stop location. The main criticism of these models is the lack of integrity among some of their choice dimensions, typically the independence of secondary tours in Bowman and Ben-Akiva (2001), which results in an unrealistic representation of time, or the restriction to a-priory defined patterns criticized by Karlström (2005).

Overall, most models fail to fully represent activity-travel patterns and to consider all components of individuals' decisions in an integrated fashion. A different approach has this potential and consists in associating activity-travel patterns to paths in a dynamic network describing the state of the individual at different time steps, also referred to as a multi-state network in other works (e.g. Liao, 2016; Liao et al., 2013). Several variants of such networks are conceivable, such as the activity network described in Danalet (2015). The core idea is that a link in such a network represents a choice alternative across several dimensions, such as activity type, location and transport mode. While network representations are promising, to the best of our knowledge most previous works have focused on deriving optimal paths from predefined utility functions and have not addressed the problem of estimating a probabilistic choice model.

Karlström (2005) shows how dynamic discrete choice theory allows to formulate such a model, where the choice of activity-travel pattern corresponds to a choice of path in an appropriate network. In the framework, individuals make a sequence of simultaneous choices of activity type, duration, mode of transport and location, taking into consideration both the instantaneous utility of their actions (dependent on previous actions through the current state) and the expected maximum future utility. Implementing and estimating a full-sized version of the model proved to be a computational challenge and only achieved recently by Blom Västberg et al. (2016). The resulting model has the advantage of integrating all components of an activity-travel pattern in one choice of path while avoiding restrictive assumptions on choice sets. It is also straightforward to use for prediction as paths can be simply sampled from the model using estimated link choice probabilities. This paper builds on this work and the modeling framework is further detailed in Section 2.2.

Although the approach (Blom Västberg et al., 2016) has gained attention from the state of practice (see e.g. Jonsson et al., 2014), the model still suffers from major limitations. In particular, the earlier work is rather restrictive as the model retains the property of independence from irrelevant alternatives (IIA). This assumes the absence of any common unobserved factors across alternatives, which may be an unrealistic hypothesis in this setting, as suggested by Mai et al. (2015b). A growing body of literature (Bhat, 1998; Hess et al., 2007b) has signaled the need to capture correlation in unobserved factors in order to be accurately used for policy evaluation, especially in a multi-dimensional setting with a large choice space. Our contribution consists in overcoming the identified limitations by proposing a flexible approach to relax the independence of error terms over alternatives which can be implemented on a real size application, and showing that predictive accuracy is improved.

In this paper, we propose a mixed recursive logit model which meets these expectations. The method is appropriate to accommodate correlation across alternatives in different dimensions and across repeated link choices. The challenge to estimate such a model is that due to the combinatorial explosion of the number of possible states and actions, approaches similar to Rust's nested fixed point algorithm are too computationally expensive to apply here. We propose to estimate the model via sampling of alternatives, applying recent results by Guevara and Ben-Akiva (2013) which show that mixed logit models can be consistently estimated using sampled choice sets. The key advantage is that the recursive formulation allows to use the model for prediction without sampling any choice sets of paths. The methodology is illustrated with an application based on travel diary data, and we provide an extensive empirical analysis of the results.

This paper is structured as follows. Section 2.1 reviews the literature, focusing first on activity-based modeling, while Section 2.2 details the modeling framework of Blom Västberg et al. (2016) upon which we build in Section 3 by relaxing the IIA property. In Section 4, we present extensive numerical results based on a travel survey conducted in Stockholm. In addition to estimation results, we present in Section 5 (i) an empirical analysis of activity-travel patterns in predicted activity schedules and (ii) illustrate substitution patterns (iii) a cross-validation study. Finally, we conclude in Section 6.

2. Literature review

In this section, we first give an overview of activity-based travel demand modeling approaches and in particular identify how sources of correlation are specified in existing models. In a second part, we describe formally the approach based on the recursive logit (RL) model formulated by Blom Västberg et al. (2016) on which we base our work. Then we provide some background on existing extensions of the RL model which relax the IIA property for other applications.

2.1. Activity-based models in the literature

Activity-based models emerged as an alternative to traditional four-step models with the prospect of overcoming their most fundamental limitations. As argued by Rasouli and Timmermans (2014), the most prominent criticisms surrounding these models are related to lack of integrity and assumption of independence of the four steps. Among the promises of activity-based modeling is an integrated framework which would enable the appraisal of a wider set of policies. As a result, applications of activity-based models to policy analysis have since been studied for an increasingly large variety of transport policies such as peak period tolls (Dong et al., 2006), land-use policies (Shiftan, 2008), parking policies (Habib et al., 2012) and congestion pricing schemes (Vovsha et al., 2006).

There are several approaches to activity-based modeling, which are neither exhaustive nor exclusive. It is however common in the literature to group models into one of two approaches: econometric models based on utility maximization, and rule-based computational process models. We narrow down this review to models based on the concept of random utility, which are the focus of this