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Utilization of reproducing Kernel Hilbert Spaces in dynamic discrete choice models: an application to the high-speed railway timetabling problem

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Abstract

This paper introduces a generalized nested logit model that results from combining discrete and continuous response variables. Reproducing Kernel Hilbert Spaces are used to define the (dynamic) systematic utilities, allowing correlations between alternatives close together on the continuous spectrum, and reconciliation mechanisms between both types of response variables are established. The seminal motivation of this model is the passenger-centric train timetabling problem. For this reason, the discussion in this paper focuses on a high-speed railway (HSR) demand-forecasting model.

The model proposes a maximum likelihood approach to estimating the parameters, and a Monte Carlo simulation study is conducted to test the proposed methodology.

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Keywords: Generalised nested logit model, Reproducing Kernel Hilbert Spaces, High-speed railway timetabling problem

1. Introduction

European Union competition policy is promoting an ongoing liberalization process in the rail market and the setting up of an EU air market. Currently high-speed railway (HSR) systems are expanding their rail networks in the EU and incrementing their demand share. However, in order to meet the new scenario of competition between transport operators, the rail industry should focus the railway service on addressing passenger needs. In this scenario, the so-called *passenger-centric train timetabling models* (pTTP) are crucial in improving the competitiveness of the rail industry. A key element of pTTP is the high-speed demand forecasting model to learn the behavior of passengers with respect to the endogenous factors of the proposed timetable.

The so-called *disaggregate, schedule-based, multimodal, multiservice* HSR demand-forecasting models consider the individual as the basic unit of observation. These models are consistent with travel choice theory and allow passenger flows for each train in a competition scenario between transport operators to be simulated. These models

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account for the *diverted demand*, which represents the choice of a passenger between other modes of transport (plane, car, other rail services, etc) and the *induced demand*, which depends directly on the characteristics of the HSR services offered (ticket cost, travel time, timetable, etc). This type of model is scarce in the literature (see Cascetta and Coppola (2012), Cascetta and Coppola (2014), Espinosa Aranda (2014)) and this paper proposes a novel approach.

These HSR demand models require departure time modeling. A review of departure time modeling is beyond the scope of this paper (see Lemp et al. (2010)). Roughly, these models can be classified by the way they consider the set of departure instants. A first cluster of models tackles the temporal continuous spectrum explicitly, but other models use a discretization of the continuum. The first group are developed on the basis of utility theory but also the majority of the models of the second group have a heuristic nature. An exception is the work of Lemp et al. (2010) which proposes the continuous cross-nested logit model, adding behavioral flexibility over the continuous logit by allowing correlations across alternatives close on the continuous spectrum. For an HSR demand-forecasting model, the desired departure time of a user should be combined with the effective departure time of the railway services. For this reason, a generalised nested logit, combining discrete and continuous response variables, is described in this work. Moreover, an RKHS approach has been introduced for the specification of the dynamic utility.

2. Methodology

Nomenclature

Sets and indexes

i Index associated with the type of supply
I Set of the types of supply
$Trip/Non{-}Trip$ Indexes associated with the alternatives of traveling or not.
j Index associated with the sub-alternatives (railway services)
J_i Set of alternatives for the type of supply i
k Index for the observation
K Set of observations
K_i Subset of observations in which the supply i is posed

Functions

$D(t)$ Potential demand function for instant t
$D_i(t)$ Induced demand function for the supply i at the instant t
$K(t,\tilde{t})$ A kernel function, in particular in this paper the radial basis function is used

Parameters and variables

$[b_1,b_2]$ Time planning period
$\bar{g}$ Total potential demand
$\bar{g}_i$ Induced demand by the supply i
$\boldsymbol{\alpha}$ Vector of coefficients of the function $D(t)$ in the basis $\{K(t,\tilde{t})\}_{\tilde{t}\in[b_1,b_2]}$
$\boldsymbol{\alpha}_i$ Vector of coefficients of the function $D_i(t)$ in the basis $\{K(t,\tilde{t})\}_{\tilde{t}\in[b_1,b_2]}$
$V_{s/a,b,\cdots}$ Systematic utility of the sub-alternative s conditioned to the alternatives $a,b\cdots$ given

2.1. A generalised nested logit model

The nested logit model have applied a wide array of transport-related choice problems (García and Marín (2005)). In this section we introduce a generalized nested logit model. The novel feature of this model is that combines a decision level with a continuum spectrum of alternatives with decision levels based on discrete sets of alternatives. Figure 1 illustrates this hierarchical choice type using an HSR demand model. We assume that the HRS system provides a set of railway services with a set of attributes (timetable, ticket cost, travel time, etc) for a given day k. The timetable and its characteristics define the supply side. We refer it as the supply i. Given the supply i the users make their decisions. At the upper level a user chooses between the alternatives 'make' or 'not make' his/her trip (by HS train) during the time interval $[b_1,b_2]$. The alternative `Non-trip` takes into account the trips made by other means of transport and the decision not to make the trip by any mode of transport. The user chooses the departure time at