Transportation Research Part A 69 (2014) 315–328

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

An integrated model for discrete and continuous decisions with application to vehicle ownership, type and usage choices

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ARTICLE INFO

Article history:
Received 1 September 2013
Received in revised form 8 September 2014
Accepted 9 September 2014

Keywords:
Discrete–continuous model
Monte-Carlo simulation
Vehicle ownership
Vehicle miles traveled
US National Household Travel Survey

ABSTRACT

This paper proposes an integrated econometric framework for discrete and continuous choice dimensions. The model system is applied to the problem of household vehicle ownership, type and usage. A multinomial probit is used to estimate household vehicle ownership, a multinomial logit is used to estimate the vehicle type (class and vintage) choices, and a regression is used to estimate the vehicle usage decisions. Correlation between the discrete (number of vehicles) and the continuous (total annual miles traveled) parts is captured with a full variance–covariance matrix of the unobserved factors. The model system is estimated using Simulated Log-Likelihood methods on data extracted from the 2009 US National Household Travel Survey and a secondary dataset on vehicle characteristics. Model estimates are applied to evaluate changes in vehicle holding and miles driven, in response to the evolution of social societies, living environment and transportation policies.

1. Introduction

Increasing mobility demand, especially in urban areas, has resulted in growing levels of motorization, congestion and pollution. Modern societies are still highly dependent on private vehicles to satisfy demand for activities, while the fastest growing economies in the world are experiencing a rapid increase in motor vehicle ownership. It is clear that vehicle demand has to be optimally managed and regulated in order to reduce the adverse impacts of transportation. In this context, the role of analysts and researchers is to expand the basic knowledge of the problem, to develop better analytical tools and to support decision makers in their strategic choices.

The importance of modeling household vehicle fleet choices has been recognized for several decades (Hensher et al., 1992; Brendemoen, 1994; TNO-Inro, 1999), though the urgency in terms of GHG emissions and fossil fuel energy dependence is more recent (Vyas et al., 2012).

Car ownership models play an important role in transportation and land use planning and are a critical component of Transportation Modeling Systems. In the classical four-step forecasting model, the trip generation module uses the outputs from car ownership models (Golob and van Wissen, 1989; Kitamura, 2009) as its inputs. Furthermore, vehicle ownership greatly impacts mode choice (Dissanayake and Morikawa, 2010), trip frequency (Kitamura, 2009; Shay and Khattak, 2012), destination choice, trip timing, activity duration and trip chaining properties (Hatzopoulou et al., 2007; Roorda et al., 2009; Paleti et al., 2013).

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http://dx.doi.org/10.1016/j.tra.2014.09.001
0965-8564/

Models for car ownership are of interest to both public agencies and private organizations. The US Department of Energy, the State Departments of Transportation, the auto industry, and the World Bank have supported studies on vehicle ownership and used their results for policy analysis (Train, 1986).

A number of agencies have implemented vehicle ownership in their regional transportation models. The State of California has developed the Motor Vehicle Stock, Travel and Fuel Forecast (MVSTAFF) model that uses a macroeconomic approach to modeling statewide motor vehicle holdings, vehicle miles traveled (VMT) and total fuel consumption. Other model systems that include a car ownership component are: the Maryland Statewide Transportation Model, the Coordinated Travel-Regional Activity Based Modeling Platform (CT-RAMP) for the Atlanta Region from Atlanta Regional Commission (2009), the activity based model from the Puget Sound Regional Council (2008), etc.

National governments use car ownership models to forecast tax revenues and the regulatory impact of changes in the level of taxation (Hayashi et al., 2001; Brannlund and Nordstrom, 2004; Giblin and McNabola, 2009). This type of model system examines the changes in the car market configuration, the life cycle CO_2 emission from automobile transport and the tax revenues due to different taxation policies (Hayashi et al., 2001).

Vehicle ownership models are also used by policy makers to identify factors that affect VMT, and therefore address the problems related to traffic congestion, gas consumption and air pollution (Dargay and Gately, 1997; Schipper, 2011). Models for car ownership growth in developing countries are important to estimate the implications on energy demand and price and on the global CO_2 emissions (Dargay and Gately, 1997).

This paper develops an integrated modeling framework for household decisions on vehicle ownership, class/vintage, and use. The proposed model structure allows the simultaneous analysis of both discrete and continuous dependent variables, that are potentially correlated. For instance, the number of vehicles owned by a household, their class and vintage is a typical *discrete* problem, while the total number of miles driven is represented by a *continuous* distribution. The analysis is based on a large number of policy variables and the estimates obtained are used for the evaluation of alternative scenarios.

The remaining of this paper is organized as follows. Section 2 contains a review of studies on discrete–continuous models for the vehicle ownership problem. Section 3 introduces the model formulation, and in particular (1) derives the model's properties (2) proposes a Full Information Maximum Likelihood (FIML) for discrete and continuous joint decisions and (3) describes the simulation method adopted to solve this non-closed form maximum log-likelihood estimation problem. Section 4 describes the data extracted from the 2009 National Household Travel Survey. In Section 5 and 6 the integrated model (household vehicle holding, vehicle class and vintage and total vehicle miles traveled) is estimated and applied to the Washington Metropolitan Region. Finally, Section 7 presents concluding remarks and avenues for future research.

2. Literature review: Discrete–continuous models for car ownership and use

A large number of studies have investigated vehicle ownership choices using discrete–continuous simultaneous equations. These models (Train, 1986; Mannering and Winston, 1985; de Jong, 1989) are based on the hypothesis that households choose the combination of vehicle ownership and vehicle usage that provides the highest utility. Roy's identity is applied to estimate vehicle usage and the relationship between the two modeling stages. These studies based on the indirect utility function, are consistent with the economic theory and are able to capture the interdependence between the vehicle holding and the corresponding mileage by means of observed variables.

The earliest generation of unified frameworks for car ownership and use were based on methods developed and applied in economics starting from the 70's. Heckman (1978) developed a class of econometric models for simultaneous equation systems with dummy endogenous variables; this general model includes simultaneous probit as a special case. Discrete–continuous models of consumer demand were formulated by Hanemann (1984) to jointly model the discrete choice among different brands of a commodity and the continuous choice of how many units to buy. The problem of non-linear budget sets in discrete continuous models for consumer demand was studied by Hausman (1985) and the methods proposed were applied to a labor supply model. In the same paper, the author also discusses the case of a nonlinear budget set for a household facing the decision to purchase a durable good (car), where the price per mile driven depends on the fuel efficiency of the car being used.

Dubin and McFadden (1984) consider the estimation of the Heckman selectivity problem under the assumption that the utility in the first stage model (discrete part) has a logistic rather than a normal distribution; the selection equation is of the logit rather than the probit form (Dubin and River, 1990). The model belongs to the class of single disturbance models. Because these models involve only one error term, identification of the parameters can proceed under rather weak conditions, such as symmetry of the error distribution (Chamberlain, 1986).

A micro-economic utility model was developed by de Jong in 1990. The model simultaneously determines private car ownership and private car use (measured as the annual number of kilometers), but is limited to the single car case. Both fixed and variable car costs enter the model system through the budget restriction. The model was then applied to micro-simulate increases in those costs and to test policy issues in the Netherlands. Results show that both fixed and variable car costs are effective measures for reducing traffic (growth), the former working primarily through decreasing car ownership levels, the latter having a more direct effect on car use (de Jong, 1990).

Multiple discrete–continuous extreme value (MDCEV) models, developed by (Bhat, 2005) and further applied in (Bhat and Sen, 2006; Bhat et al., 2009) are utility-based econometric models that jointly estimate the holding of multiple vehicle types