Dynamic vehicle ownership forecasting: advances in modeling inter-temporal choice

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1 Motivation

The car market offers a unique forecasting problem to solve. A multitude of vehicles at different stages of technology innovation cycles are available to consumers in any given time. On the consumer side, the choice of vehicle involves a significant expenditure that forms a durable possession, entails lengthy planning and is influenced by past choices and expectations about future market developments. Arguably the study of vehicle acquisition behavior is increasingly complex given recent expansion of innovative technologies such as hybrid power trains, emergence of alternative fuels and appearance of new car segments. These phenomena are likely to increase uncertainty where consumers are forced to also consider fluctuation in complementary goods such as fuel prices and infrastructure availability. Hence, future market developments as well as the value of the acquired vehicle is more difficult to predict. The problem of understanding consumer behavior in this sector is given further relevance in view of the sizable institutional investments to promote alternative vehicle markets with a final aim to improve energy efficiency in the transportation sector.

The described context calls for an urgent need to consider inter-temporal aspects of choice when formulating models of vehicle choice. Indeed, it is increasingly clear that such models need to accommodate complex substitution patterns both across products and

over time. Simultaneously, a fuller understanding of technology adoption and acceptance of new fuel types require the consideration not only of traditional features characterizing vehicle choice, such as individuals' socio-demographics, but also prompt us to consider a wealth of factors that modulate the purchase planning, risk acceptance and preference for new technologies such as attitudes, life-event changes, status aspirations and perceptions associated with the acquisition such as securing a discount. This work proposes a model framework to analyze dynamic vehicle choice enriched by behavioral variables.

2 Literature

The literature on car demand is extensive. Early vehicle choice models incorporating information on the shares of different car segments are investigated by Train (1980). Several papers propose scenario-testing to predict effects of policy changes on purchase behavior. In the context of demand for alternative fuel vehicles, this has been investigated by Daziano & Bolduc (2011) among others. Despite a rich literature on standard and alternative fuel vehicle choice, studies critically rely on static frameworks with data collected at one point in time, lacking explorations of the time-dimension that is essential in vehicle buying behavior. Some aspects of a dynamic approach is present in the vehicle transaction model by Brownstone et al. (1996) who account for the dependence on currently held vehicles. A limited number of models integrate a longer time dimension into the behavioral model based on dynamic optimization principles. Among these Schiraldi (2011) and Cirillo & Xu (2011) explore the incorporation of a Markov Process to estimate consumer expectations over future market characteristics. This is an ideal approach to start considering forward-looking models where consumers form ideas of innovative technologies or car models. In the current work we build on these approaches and drawing on a rich dataset extend the analysis to also explain the dynamic behavior within the model using additionally collected variables.

3 Objective

The added behavioral realism inherent in a vehicle choice model with dynamic features forms the motivation for the current work. The paper provides a dynamic model frame-

work of car demand that accounts for inter-temporal effects to assesses market changes for different car segments where literature is very scant. The main focus is on forecasting the vehicle-type choice and the timing of the decision. The model jointly accounts for behavioral variables (observables and attitudes or perceptions), institutional factors (e.g. incentives) and market factors (vehicle technology-cycle) to forecast timing of acquisition and type of vehicle. The final goal is to obtain a formalized model structure that allows to seize on gradual changes in behavior in view of the complex set of factors that characterize the vehicle market.

4 Data and Methodology

Beyond the formulation of an innovative dynamic forecasting model structure the project benefits from empirical testing drawing on a unique database recording new car purchases. The data derives from a large-scale disaggregate longitudinal survey with a representative sample of new car buyers in all major european markets. The dataset contains rich information on recently acquired vehicles, personal socio-demographics, attitudes and motivations of the buyer, data on the household characteristics and vehicle fleet for a range of years. At the disaggregate level the data contains detailed information on the current and past vehicles of each respondent. At the aggregate level it contains serial cross-sectional data on new vehicle acquisition behavior for over two decades.

The paper proposes joint modeling of type and timing of vehicle ownership with dynamic features. The model for vehicle type choice is a logit based discrete choice model. The decision model is formulated as such; people choose between retaining their current vehicle or replacing based on utility evaluation. Utility depends on u_{ijt}=U($\beta_1$personal features$_{it}$, $\beta_2$current car features$_{it}$, $\beta_3$new car features$_j$), for individual i, time t and vehicle j. The structure can be enriched to consider dynamic features of the new vehicle, such as incentives for buying a hybrid vehicle and additionally incorporate unobserved features of the choice context, such as the motivation for ownership or environmental sensitivity. In the dynamic model of decision timing a consumer has expectations over market evolution. In this model $pr(S_{t+1}|S_t)$, that is, the state of the vehicle market S evolves according to some first-order Markov process from time t to $t+1$. The transition probability matrix is derived empirically from decades of aggregate vehicle acquisition data. The behavioral

hypothesis is that consumers maximize discounted expected utility with a discount factor δ s.t. max $\mathrm{E}(\sum \delta^t u_{ijt})$ where the Bellman equation is used to obtain the value function. The model foresees the estimation of a first-order process which is in line with the data availability where respondents describe only their recent acquisition and previous vehicle. This condition can be relaxed in future work to allow state-dependence for more than one time-period.

5 Contribution

A dynamic model of vehicle choice allows us to account for realistic features of the vehicle choice process by representing the persistence of durable goods over time, rapid changes in value across product and ownership cycles and uncertainty about future market developments. The proposed framework allows us to shed light on the timing and type of vehicle ownership and illustrates the benefits of taking the first steps away from a static approach. The model is applied to a rich dataset containing disaggregate observations of new car ownership with detailed personal and vehicle information. The application allows us to identify the relevant factors that explicates how different consumers trade various vehicles features against each other in a dynamic market characterized by strong technology uncertainty. Such findings will aid the prediction of consumer behavior with regard to critical policy variables such as incentives and aid the understanding of diffusion of novel technologies. Such understanding is essential from the perspective of a society trying to manage the transition towards alternative mobility patterns.

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