



How long to own and how much to use a car? A dynamic discrete choice model to explain holding duration and driven mileage

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ABSTRACT

We develop a dynamic discrete choice model of car holding duration and use for French households owning only one car over the 2000–2007 period. We consider income, fuel prices and cumulated mileage as stochastic state variables. It is found that accounting for forward-looking economic agents greatly improves the understanding of the underlying logic that drives such choices whenever theoretical assumptions and used data may appear as a sketchy description of a more complex reality.

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1. Introduction

The defining characteristic of a durable good, here a car, is that it yields productive services over multiple time periods but it wears also out with age and use. As pointed out by CCFA (2006), the average holding duration of a car has increased over the last decades in France. It is often explained by an overall improvement in the quality of its features that extends its lifecycle and that gives therefore the possibility to use it over a longer period of time. It is also characterized by a higher initial expenditure (see for instance Julliard, 2007, Fig. 1) that may imply to need a longer period of time to return on investment. On the other hand, as the cost of operating a car increases with its age because of its physical depreciation (e.g. Baron, 2002), there may therefore be temptation to use it more intensively in the short run to return on investment more quickly. All the same, the scrap/sell-off value of the asset is also higher in the latter situation.

Car use depends also on fuel prices. The rising cost of petrol contributes to people cutting back on car use (Graham and Glaister, 2002; Julliard, 2007). We expect therefore a variation of fuel prices to have two effects: one on the amount of driving with a car and one on its holding duration. It acts like a leverage effect on the holding duration as it becomes more expensive to operate a car.

All in all, households have to balance the costs and benefits of owning a car and using it over a period of time. In our approach, each has to find an optimal sequence of mileages, including the length of the sequence, to maximize a related expected discounted utility with respect to future evolution of fuel prices and income until the car is finally disposed.

Modeling of car demand and use is still an important topic of research even though it is analyzed since long ago. The existing literature is wide and deep and deals with the several dimensions at stake at different levels of aggregation. As already highlighted by Train (1986), car ownership, fleet size and variety, fuel efficiency and mileage are important considerations to manage transport-related policies in line with sustainable development. It is of great importance to understand the underlying logic that drives demands of consumers for these key aspects to better advise agencies and organizations on the consequences of what they plan to do in terms of investment and regulation. As it concerns our purpose, and to cite only a few, Berkovec and Rust (1985), de Jong (1990, 1996), Gilbert (1992), Hocherman et al. (1983), Mannering (1983), and more recently de Jong and Kitamura (2009), analyzed the dynamics of car ownership, holding duration and use at the disaggregate level using different data and different techniques. However, to our knowledge and up to very rare exceptions (e.g. Rust, 1987), dynamic discrete choice models of holding duration and use assuming forward-looking economic agents are still not systematically implemented when data are available. Almost all developed models were or are still turned backward to explain dynamics, hence subject to Lucas (1976)' critique.

This paper formulates a finite-horizon optimal stopping problem under uncertainty to describe the behavior of a household as regards

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car holding duration and its driven mileage accounting for the uncertain evolution of fuel prices and income. In the present approach, the decision to dispose a car coincides with an optimal stopping problem and the optimal stopping rule is the solution to a stochastic structural dynamic programming problem. The theoretical solution to such a problem is rather standard. It is characterized by a threshold-type of rule: the car is disposed if the optimized continuation value (the effect of holding and using it one more period) is less than its current scrap/sell-off value.

The proposed model belongs to the class of discrete Markov decision processes. It is specified as a dynamic discrete choice model of a forward-looking economic agent with five observed state variables and two decision variables. The observed state variables are of two types: three of them model beliefs about the evolution of fuel prices (one for petrol and one for diesel) and income. The others are deterministic. They evolve endogenously and model cumulated mileage and age. The first decision variable models the decision to either dispose the owned car or to keep it. The second decision variable models the choice of a level of mileage given that the car is kept. The chosen mileage at the beginning of a period affects the cumulated mileage at the beginning of the next period hence the decision to keep (and how much to use) or to dispose the car at the beginning of that next period. The stochastic aspect of the problem comes from the modeler's lack of knowledge about beliefs and preferences of the observed decision maker.

We demonstrate the model by drawing data from the French "Parc Auto" (Car Fleet) panel survey, the most comprehensive database about car ownership and use that is available in France. We focus on the population of households that owned only one car and that disposed it over the period 2000–2007 and we restrict the set of used variables to capture the most prominent effects that may explain our problem. To our knowledge, it is the first time that such a model is implemented using this dataset. From a general perspective, thanks to the results we obtain, it is also a call to use more systematically the Rust (1987)'s approach when data are available. Note that we however consider a very specific dimension of car ownership and use. We restrict our approach to the population of households that owned only one car during the observed period. We do neither consider car fleet size nor its variety (e.g. make/model/type). We are aware of our sample selection issue and our focus on a specific decision that is made in a sequence of a more general framework that may consider decisions that regard car ownership per se (own vs. not own one or more cars) and make(s)/model(s)/type(s) chosen. These problems are left aside for further research work: in our application, they are considered as given and constitute initial values. Our approach is conditional to these choices. It is pre-conceived in that we choose to stay simple in understanding the basics of car holding and use in a very simple framework where there is neither substitution effect between various types of cars once owned nor substitution effect between owning or not a car. This study is of an explorative nature and aims at partly understanding the complicated process that generates decisions about car ownership and use. As the approach is a finite-horizon, it is solved by backward induction. The parameters of the structural model are estimated using a nested fixed point algorithm. Once the model is estimated, one is able to advise decision-makers about the effects of the different policies that may affect car holding and car use behaviors, given the conditionality of our approach as regards other dimensions of car ownership and use behavior. Our results confirm the relevance of the original Rust's framework of analysis, given that we only consider car holding and use.

The outline of the article is as follows. The model is developed in Section 2. The different constituting parts of the approach and how the parameters of the primitives are estimated are discussed. Data are then presented in Section 3. Once estimation is done following the advices of Aguirregabiria and Mira (2010) and Rust (1987), the results are debated in Section 4. The last section draws conclusions and defines a roadmap for future research work.

2. Model

2.1. Framework

We build up our specification on the five assumptions that define what is known as the "dynamic programming – conditional logit" model of Rust (1987): additive separability of utility functions, the unobserved state variables which are iid with cdf F , the conditional independence of future observed state variables with current unobserved state variables, the unobserved state variables which are iid extreme value type 1 distribution, and the discrete support of observed state variables. This is the simplest framework for estimation: it is computationally manageable but it comes at the cost of rather restrictive assumptions on the interpretation of the model.

The purpose of household i is to choose how long to keep and how much to use a car. To circumvent any substitution effect between multiple owned cars, we assume that household i owns only one car when observed. Neither is the choice of the make/model/type of the car (or any simplified variant) modeled nor what the car is disposed for (e.g. renewal, temporary or definitive exit from the car market). What is modeled are therefore the choices of an ownership horizon and a history of driven mileages over it, once given the attributes of the owned car. The modeled decisions are about the optimal lifecycle of an owned car conditional to its attributes at the first date of ownership.

The problem is an optimal "use and stop" problem. Household i determines simultaneously the optimal horizon $\bar{t}_i \in \{1, \dots, T\}$ of its car and the sequence of mileages $m_{i,t} = (m_{i,1}, \dots, m_{i,T})$ to be driven. We assume that all decisions, car disposal or car keeping (d) and use (m), are made as a function of the state of the household and its environment at the beginning of each period. To that extent, the vector of state variables is labeled $\mathbf{z}_{i,t}$.

Households' preferences over possible sequences of state variables can be represented by a time separable discounted (indirect) utility function $\sum_{t=1}^T \gamma^t u(\mathbf{z}_{i,t}, d(\mathbf{z}_{i,t}), m(\mathbf{z}_{i,t}))$ where γ is the discounting factor and $u(\mathbf{z}_{i,t}, d(\mathbf{z}_{i,t}), m(\mathbf{z}_{i,t}))$ is the per-period utility function.

At the beginning of each period t , the information available for the household is the outcomes of the state variables for the period. It chooses whether to dispose ($d_{i,t} = 1, D$) its car or to keep ($d_{i,t} = 0, K$) it. If kept, it chooses an amount of mileage $m_{i,t}$. If it disposes it then no mileage is driven ($m_{i,t} = 0$), it receives a sell-off/scrap value and the decision process stops. The decisions at period t affect the evolution of future values of the state variables, but the household faces uncertainty about these future values. The beliefs of household i about sequences of states are modeled by a Markov transition distribution function $G_{\mathbf{z}}(\mathbf{z}_{i,t+1} | \mathbf{z}_{i,t}, d_{i,t})$. For simplicity, we note $d_{i,t} = d(\mathbf{z}_{i,t})$ and $m_{i,t} = m(\mathbf{z}_{i,t})$. The sequence of decisions is made to maximize the expected utility with respect to the distribution of the sequences of the state variables:

$$\max_{\bar{t}_i} \left\{ \mathbb{E}_{\mathbf{z}_{i,0}} \left(\sum_{t=1}^{\bar{t}_i} \gamma^t u(\mathbf{z}_{i,t}, d_{i,t}, m_{i,t}) \mid \mathbf{z}_{i,0} \right) \right\} \quad (1)$$

where $\mathbf{z}_{i,0}$ is a set of initial conditions.

Without delving into technical considerations, see for instance Bellman (1957), Bertsekas (2000), Rust (1996), we assume that the intertemporal optimization problem can be formulated as a sequential decision problem whose solution is the same by using its Bellman representation. Let $V(\mathbf{z}_{i,t})$ denote the maximum value of all utility flows to household i when the state variables are given by $\mathbf{z}_{i,t}$ at date t . $V(\mathbf{z}_{i,t})$ is defined recursively by the solution to the following Bellman equation:

$$V(\mathbf{z}_{i,t}) = \max \left\{ v_D(\mathbf{x}_{i,t}) + \epsilon_{D,i,t}, v_K(\mathbf{x}_{i,t}) + \gamma \mathbb{E}_{\mathbf{z}_{i,t+1}} [V(\mathbf{z}_{i,t+1}) \mid \mathbf{z}_{i,t}] + \epsilon_{K,i,t} \right\}. \quad (2)$$

The optimal demand for mileage $m^*(\mathbf{z}_{i,t})$ and the decision to keep or dispose the car, $d^*(\mathbf{z}_{i,t})$, are the arguments that maximize Eq. (2). It

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