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How much do incentives affect car purchase? Agent-based microsimulation of consumer choice of new cars—Part I: Model structure, simulation of bounded rationality, and model validation

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ABSTRACT

This article presents an agent-based microsimulation capable of forecasting the effects of policy levers that influence individual choices of new passenger cars. The fundamental decision-making units are households distinguished by sociodemographic characteristics and car ownership. A two-stage model of individual decision processes is employed. In the first stage, individual choice sets are constructed using simple, non-compensatory rules that are based on previously owned cars. Second, decision makers evaluate alternatives in their individual choice set using a multi-attributive weighting rule. The attribute weights are based on a multinomial logit model for cross-country policy analysis in European countries. Additionally, prospect theory and the notion of mental accounting are used to model the perception of monetary values. The microsimulation forecasts actual market observations with high accuracy, both on the level of aggregate market characteristics as well as on a highly resolved level of distributions of market shares. The presented approach is useful for the assessment of policies that influence individual purchase decisions of new passenger cars; it allows accounting for a highly resolved car fleet and differentiated consumer segments. As a result, the complexity of incentive schemes can be represented and detailed structural changes can be investigated.

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1. Introduction

Two main future challenges are associated with energy use. On the one hand, climate change caused by anthropogenic emissions of greenhouse gases (IPCC, 2007a). On the other hand, energy supply security with increasing energy demand worldwide, diminishing fossil fuel sources, and increasing dominance of a small number of major producers (IEA, 2006). Both the International Energy Agency's World Energy Outlook 2006 (IEA, 2006) and the Fourth Assessment Report of the Intergovernmental Panel of Climate Change (IPCC, 2007b) draw a picture of urgency and resolve with which action in the policy arena should be taken. IEA (2006) and IPCC (2007b) identify the improvement of new vehicle energy-efficiency as the dominant policy in the transport sector and as an overall key strategy in order to respond to the twin challenges mentioned at the outset.

Significant gains in energy-efficiency of new passenger cars are feasible at an acceptable cost from an engineering point of view (Greene and DeCicco, 2000). Technological advances can be used either to improve energy-efficiency or to increase power and weight (IEA, 2006; IPCC, 2007b). Historic developments of energy-efficiency, weight, and power of new passenger cars show that market forces often favor increases in power and weight (de Haan et al., 2009; Turrentine and Kurani, 2007; Zachariadis, 2006). Government policies can play an important role in promoting energy-efficiency.

Models of car choice predominantly rely on random utility maximization and a rather low level of detail with regard to the choice alternatives; i.e., car types are specified on a vehicle segment level (de Haan et al., 2009; de Jong et al., 2004; Peters et al., 2008). Due to the huge number of individual decision makers involved and alternatives offered, Peters et al. (2008) motivate microsimulation for the assessment of policies that influence individual purchase decisions of new passenger cars. Proceeding with their line of argument, we present an agent-based microsimulation with a highly resolved car fleet and differentiated consumer segments. Furthermore, regarding the individual-level behavioral response to policy measures, there is a robust and compelling body of evidence of the bounds to rationality of actual decision makers; decision processes are often governed by heuristics, cognitive rules of thumb, rather than analytical deliberation (Bettman et al., 1998; Kahneman, 2003). Van den Bergh et al. (2000) review and highlight the need to explore alternative models of behavior for environmental policy;

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e.g., non- and semi-compensatory models have been applied to travel choice modeling (Arentze and Timmermans, 2007; Cantillo and Ortúzar, 2005; Chorus et al., 2008). A central goal of the presented work was to enrich the microsimulation with a behavioral model of consumer decision processes based on the above-mentioned empirical evidence.

This article presents the theoretical background and derivation of a conceptual two-stage model of the decision process (Section 2), its operationalization in and the general structure of the microsimulation (Section 3). In Section 4, the full-scale microsimulation is compared against reduced model versions and actual market observations. Finally, in Section 5, we discuss the methodology, the implications and the limitations of the introduced microsimulation and present our conclusions in Section 6. De Haan et al. (2009) report the results of a concrete application of the microsimulation model.

2. Decision process and car choice

2.1. Consumer choice of new passenger cars

Choice of new passenger cars has received constant attention in the consumer research literature. Considering the high purchase price of a new passenger car, one would expect extensive external search for information and elaborate decision processes. A surprising, yet consistent finding of consumer research is that pre-purchase search activity is limited, even for major consumer durable goods (Beatty and Smith, 1987; Katona and Mueller, 1955; Newman and Staelin, 1972; Olshavsky and Granbois, 1979). Taxonomies of individual search strategies identified distinct external information search patterns and refined the picture of lower-than-expected search effort (Claxton et al., 1974; Furse et al., 1984; Kiel and Layton, 1981; Newman and Staelin, 1973). Furse et al. (1984) hypothesized these strategies to be a result of heuristic decision processes. Another explanation of little explicit search is that information gathering is a continuous process not limited to the actual purchase process (Bloch et al., 1986; Claxton et al., 1974). Punj and Stewart (1983) highlighted the importance of situational and individual characteristics and interaction effects thereof. This focus on characteristics of the decision-maker and his adaptation to the task is in line with the notion of bounded rationality coined by Simon (1955, 1956).

2.2. Rationality and bounded rationality

Discussing the terms rationality and bounded rationality equals walking on a tightrope; their usage is, at least, controversial, as a result of different interpretations across and even within disciplines. Omniscience is an adequate term to describe the neoclassical concept of rationality, assuming perfect information and the capacity to perform complex optimization algorithms. Simon (1955, 1956) pioneered the distinction between perfect and bounded rationality. The concept of bounded rationality embraces the limits of human information-processing capabilities and their need for adaptation to different task environments.

One interpretation of bounded rationality is an extension of the model of the perfectly informed, optimizing individual. If time, knowledge and computational power are limited, optimization needs to account for these constraints (Stigler, 1961; Wilde, 1980). Simon's work inspired another major research theme, the heuristics and biases approach, prominently advanced by Kahneman and Tversky (Kahneman, 2003; Kahneman and Tversky, 2000). Strongly guided by an analogy of perception, this interpretation of bounded rationality delivered major insights in the areas of heuristics of judgment, risky choice and framing effects (Kahneman, 2003; Tversky and Kahneman, 1981). Applications of this research program's core ideas to riskless choices revealed its relevance to consumer choice (Thaler, 1999). The need for adaptation of decision behavior to the decision environment and the underlying processes of choice are at the core of the adaptive decision-making approach to the study of consumer choice (Bettman et al., 1998). The foundation of this additional offshoot of bounded rationality is that consumers apply a variety of cognitive processes to decision making.

In order to elicit facets of bounded rationality relevant to financial incentives aimed at influencing new passenger car choice, we adopt an integrative viewpoint, exploring both the adaptive decision-making and the perceptual approach. The adaptive decision-making approach is informative about how consumers use and process information (Subsection 2.3). The perceptual approach reveals much about the perception of monetary values (Subsection 2.4).

2.3. Two-stage model of the decision process

The decision processes underlying consumer choice were shown to be contingent on the complexity of the task, first and foremost determined by the number of alternatives available (Olshavsky, 1979; Payne, 1976). For complex task environments, a consistent finding over a number of studies is the utilization of multistage strategies, namely a two-staged decision process (Bettman and Park, 1980; Olshavsky, 1979; Payne, 1976; Ursic and Helgeson, 1990): a screening stage in which alternatives are eliminated using simple non-compensatory rules, followed by a compensatory evaluation of the remaining alternatives. This distinction between screening and actual choice is in line with image theory (Beach, 1993), in which the importance of prechoice screening of alternatives is analyzed in great detail.

Fig. 1 presents our resulting conceptual model of the decision-making process. It serves as a template for the implementation of choice processes in the microsimulation model in Section 3.

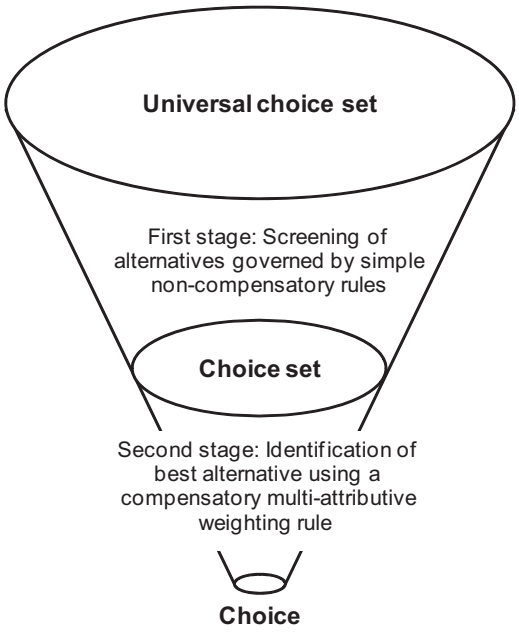

Fig. 1. Conceptual two-stage model of the decision process. The universal choice set is the set of all available alternatives. The choice set is the set of alternatives considered by the decision-maker.

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