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Market introduction strategies for alternative powertrains in long-range passenger cars under competition

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ABSTRACT

Alternative powertrains are considered as a promising option to significantly reduce CO_2 emissions from passenger cars. One major prerequisite is their successful market introduction. In this paper, we present a system dynamics model that allows for the evaluation of strategies for the market introduction of alternative powertrain technologies in long-range passenger cars ($\geqslant$400 km) under competition. The model considers two competing manufacturers, one first-mover and one follower, each introducing plug-in hybrids and fuel cell electric vehicles according to exogenously defined strategies, which comprise timing, pricing, and technology parameters. The manufacturers can learn from each other due to technology spillover, leading to cost reductions of the powertrains. We use an exemplary dataset for the German car market to study the manufacturers' influence on the market success of alternative powertrains as well as the underlying mechanisms. The results indicate that in general more competition leads to higher market shares of alternatively powered vehicles and thus allows for a higher reduction of emissions. However, this might cause decreasing profits for both manufacturers, especially if the follower pursues an aggressive pricing strategy when entering the market to gain market shares from its competitor. Also, technology spillover has a positive effect on the market penetration. This particularly holds true for a low level of technology experience where high cost reductions can be achieved and for fuel cell electric vehicles where the costs of the powertrain are much higher compared to plug-in hybrids.

Introduction

Motivation

The combustion of fossil fuels for transport purposes is a major source of anthropogenic CO_2 emissions. According to statistics of the International Energy Agency (IEA, 2013), the transport sector accounted for 22% of total energy-related CO_2 emissions in 2011. About 75% of these emissions were related to passenger and freight road transport (IEA, 2013), with the fraction attributed to passengers being much higher than the fraction attributed to freight in most countries (ITF, 2010). Moreover, CO_2 emissions due to road transport have increased by 52% from 1990 until 2011 (IEA, 2013) and global transport demand is unlikely to decrease in the foreseeable future. Projections by the World Business Council for Sustainable

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Development (WBCSD, 2004) indicate that the personal transport activity with passenger cars will grow at an annual rate of 1.7% until 2050.

One promising option to limit the CO_2 emissions from passenger cars is the transition to alternative powertrain technologies, such as natural gas vehicles (NGV), plug-in hybrid electric vehicles (PHEV), battery electric vehicles (BEV), and fuel cell electric vehicles (FCEV). Pasaoglu et al. (2012) show that the deployment of such technologies can decrease the well-to-wheel CO_2 emissions in EU-27 passenger road transport by 35–37% until 2050, compared to 2010 levels. The underlying calculations are based on certain assumptions regarding the future energy mix and the prospective market shares of alternative powertrains. One prerequisite for achieving these market shares, however, is that the required vehicle models are actually offered by the automotive industry in the right way, which is not necessarily given. From a manufacturer's point of view, the development and market introduction of new powertrain technologies involves considerable risk due to high investments and uncertain customer demand. At the same time, those manufacturers who manage to offer the right vehicle models at the right time at prices that customers are willing to pay might achieve competitive advantages in terms of market shares, profitability, or emissions.

When comparing alternatively powered vehicle models that are already available on the market, major differences between the manufacturers regarding powertrain technology, market introduction timing, and pricing can be observed. For example, Toyota launched their first hybrid electric vehicle (HEV) model 'Prius' in 1997, whereas BMW waited until 2009 to introduce their 'X6 Active Hybrid'. The base version of the first 'Prius' generation was offered at about $20,000 in the United States, a price close to the average for a standard compact car. In contrast, the first 'X6 Active Hybrid' had a price tag of almost $90,000, clearly targeting the premium segment (MSN Autos, 2014). By the time when BMW entered the hybrid market, Toyota had already sold more than one million units of the 'Prius' (AFDC, 2014). Regarding the future powertrain portfolio, Toyota focuses on PHEV and FCEV models compatible for the mass market. They announced to launch the first commercially-available hydrogen-fueled 'FCV' in 2015 at a price below $70,000 (Toyota, 2014). On the other hand, BMW emphasizes the introduction of premium PHEV and BEV models, such as their PHEV flagship model 'i8' to become available in 2015 at a price above $130,000 (BMW, 2014). This brief comparison already illustrates the manifold strategies that car manufacturers can pursue to introduce alternative powertrains.

While it is possible to assess the consequences of a particular market introduction strategy from an ex-post perspective, this is a challenging task from an ex-ante perspective. The automotive market is characterized by dynamic complexity (Kieckhäfer et al., 2012) since the market development of any powertrain is influenced by various interrelated and time-varying factors, including customer preferences, technological and economic characteristics of the powertrain, availability of complementary infrastructure, fuel prices, and political targets. In addition to that, the interdependencies between competing manufacturers and their product portfolio need to be considered. For example, advancements in the fuel efficiency of internal combustion engines achieved by one manufacturer might deteriorate the advantageousness of the alternatively powered vehicle models in the competitor's portfolio.

Literature

To gain a better understanding of the market dynamics and to assess the consequences of strategy decisions regarding the market introduction of alternative powertrains, simulation models of the automotive market have received increasing attention in the literature. Al-Alawi and Bradley (2013) give a review of penetration rate studies for hybrid, plug-in hybrid, and electric vehicles. Typical questions that have been addressed in these studies concern the influence of regulatory policies and incentives (e.g. Mueller and de Haan, 2009; Walther et al., 2010; Sikes et al., 2010; Shepherd et al., 2012), customer behavior (e.g. Struben and Sterman, 2008; Zhang et al., 2011; Eppstein et al., 2011; Keith, 2012; Kieckhäfer et al., 2014), vehicle offer (e.g. Walther et al., 2010; Zhang et al., 2011; Lebeau et al., 2012), and infrastructure availability (e.g. Keles et al., 2008; Struben and Sterman, 2008; Achtnicht et al., 2012; Keith, 2012; Ito et al., 2013). Approaches that are commonly used in market simulation include system dynamics, agent-based simulation, consumer choice models, and diffusion rate and time series models (Kieckhäfer et al., 2014; Al-Alawi and Bradley, 2013). System dynamics takes an aggregated perspective focusing on endogenous feedback structures. These are modeled as differential equations that are solved with the help of numerical integration methods to determine the corresponding system behavior. Contrary, agent-based simulation is based on a disaggregated modeling approach. To simulate the system behavior, the relevant stakeholders, such as customers, manufacturers, and/or policymakers, are represented as individual agents who interact in a virtual environment according to specified rules. Consumer choice models focus on consumer preferences and the influence of product and consumer characteristics on the purchase decision. From that, purchase probabilities related to the attributes of each alternative within a choice set can be derived. Diffusion rate models describe the customer acceptance of a new technology or product over time. More often than not, these approaches are combined in existing simulation models of the automotive market. For example, consumer choice models are integrated into both, system dynamics models (e.g. Struben and Sterman, 2008; Walther et al., 2010) and agent-based models (e.g. Mueller and de Haan, 2009; Zhang et al., 2011). Furthermore, Shafiei et al. (2013) and Kieckhäfer et al. (2014) develop hybrid system dynamics and agent-based models to consider individual consumer behavior and aggregated feedback structures simultaneously.

Only few of the aforementioned simulation models consider the manufacturers' decisions regarding the market introduction of alternative powertrains explicitly. For example, the system dynamics model of Walther et al. (2010) as well as the hybrid simulation model of Kieckhäfer et al. (2014) include decisions on powertrain technology, time and segment of market