Will Corporate Average Fuel Economy (CAFE) Standard help? Modeling CAFE’s impact on market share of electric vehicles

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ARTICLE INFO

Keywords:
EV market penetration
Fuel economy
Agent-based modeling
CAFE standards
Consumer choice

ABSTRACT

The purpose of Corporate Average Fuel Economy (CAFE) Standards is to enhance the fuel efficiency of passenger vehicles in the United States. Although these standards had been set constant for years, the National Highway Traffic Safety Administration (NHTSA) and Environmental Protection Agency (EPA) issued a joint regulatory proposal, addressing fuel consumption of and greenhouse gas emissions (GHG) of light-duty vehicles (EPA and NHTSA, 2011). The following year, NHTSA and EPA published a joint final rule for the second phase of the regulation in order to both further improve vehicle fuel economy and reduce GHG emissions. According to this final rule, the new CAFE targets are calculated based on vehicle’s footprint, which is defined as a vehicle’s wheelbase multiplied by its average track width (EPA and NHTSA, 2012).

With the new CAFE standards, the average fuel economy of passenger cars is aimed to increase to 55.3 miles per gallon (mpg) or greater for model year (MY) 2025 (EPA and NHTSA, 2012). However, a manufacturer might produce a car with either less or more mpg than the level established in the standards. To avoid the need to monitor the compliance of each car manufactured, the determination of a manufacturer’s compliance with the CAFE regulation is instead based on the annual production volume-weighted average fuel economy of a manufacturer’s vehicle fleet. In the event a manufacturer produces a fleet that includes a large number of AFVs (which generally have better fuel economy levels than the corresponding CAFE levels, and reduce the costs of CAFE compliance (Al-Alawi and Bradley, 2014), then a credit is granted and thereby positively influences its benefits. Conversely, if the average mpg of manufactured vehicles cannot satisfy the standards, then the manufacturer is fined for each 1 mpg that falls below the CAFE levels (EPA and NHTSA, 2012). This system creates an incentive for manufacturers to adjust the design of their vehicles in order to comply with the CAFE standards.

Concurrent with the findings of the study carried out by Whitefoot and Skerlos (2012), a recent scientific research has revealed that the footprint-based standards might lead manufacturers to make design changes in favor of increasing the vehicle’s footprint in order to reduce the stringency of the applicable requirements, which might influence vehicle size and also eventually influence production costs (Ullman, 2016). Hence, there is a chance that, in the long run, the CAFE standards incur a “co-impact”, resulting in consumers not being able to

1. Introduction

Corporate Average Fuel Economy (CAFE) standards were first enacted by the Congress in 1975, during the oil crisis of the 1970s as a part of policy measures to decrease the U.S. reliance on foreign oil (McConnell, 2013). While the standards had previously been relatively static for years, in 2011 National Highway Traffic Safety Administration (NHTSA) and Environmental Protection Agency (EPA) issued a joint regulatory proposal, addressing fuel consumption of and greenhouse gas emissions (GHG) of light-duty vehicles (EPA and NHTSA, 2011). The following year, NHTSA and EPA published a joint final rule for the second phase of the regulation in order to both further improve vehicle fuel economy and reduce GHG emissions. According to this final rule, the new CAFE targets are calculated based on vehicle’s footprint, which is defined as a vehicle’s wheelbase multiplied by its average track width (EPA and NHTSA, 2012).

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find or afford a vehicle that best meets their needs. One reason therefor is the hypothesis that consumers may focus more on visible attributes of vehicles such as size when purchasing a vehicle (U.S. EPA, 2015). Another reason why this may be the case is the increased costs of more fuel-efficient vehicles as a result of the implementation of CAFE standards (Bezdek and Wendling, 2005; McConnell, 2013). Furthermore, auto manufacturers may attempt to meet the CAFE standards by lightweighting their vehicles, which may result in consumers having concerns over vehicle safety, and thus negatively affect consumers’ preferences (Liu, 2017).

Despite evident discussions on the environmental benefits of fleet electrification, there are several barriers to their widespread adoption (Noori and Tatari, 2016). One of these barriers is, without a doubt, the consumer behavior, which, once accounted for, can provide useful insights into the market responses to CAFE regulation (Shiau et al., 2009). Additionally, as pointed out by Ullman (2016), further research on the impacts of CAFE standards on the vehicle market is significant to enable improved policy analysis of the implications of CAFE. Furthermore, the time that it takes vehicle manufacturers to switch their vehicle portfolios to the ones with electric powertrainst, and that it takes consumers to adopt to such a transformation presents another barrier (Zielinski et al., 2016). Hence, using the agent-based modeling technique, this study aims to contribute to the relevant literature by investigating the consumer behavior as well as the manufacturers’ reaction to CAFE standards, and by estimating the market penetration of EVs under various real-life scenarios, such as those mentioned above, as recommended by the National Research Council (National Research Council, 2015). In addition, this study also attempts to answer the question whether the implementation of the CAFE standards will be helpful in expanding the U.S. market for AFVs. It is hoped that the findings of this study will also help with the need to determine the potential impacts of AFV market under policies such as government incentives and CAFE standards, as pointed out by Zielinski et al. (2016).

2. Literature review, and objectives of the study

Agent-Based Modeling (ABM) has been acknowledged as a powerful tool to model socio-technical systems as a collection of subsystems comprised of a social network of actors and a physical network of technical artifacts, allowing researchers to analyze system behaviors arising from interactions between each of the many different parts of the system as a whole (Van Dam et al., 2013). ABM is widely used to study the market adoption of AFVs, and Table 1 summarizes the related studies that utilized ABM as a part of their approach.

As can be seen in the literature, the likely effects of the CAFE standards on the dynamics of the AFV marketplace have not yet been sufficiently explored. Hence, the main objective of this study is to extend the previously developed EVReMP model (Noori and Tatari, 2016) to be able to analyze the EV market penetration under the influence of CAFE regulation and existing government incentives, taking into account the associated uncertainties with the implementation of such regulations.

3. Methods and materials

The extended AB model developed in this study, in which five different agents (manufacturers, consumers, government, vehicles, and regions) interact in a virtual environment, is used to predict the future market share of EVs under the implementation of the CAFE standards. The model is calibrated based on real-time vehicle sales data, and validated through a comparison with existing market penetration models in the U.S. as well as a sensitivity analysis with regard to consumers’ driving pattern. Finally, different policy scenarios are applied, and the results are discussed as applicable to the objectives of this study. These four policy scenarios include: 1) No Policy Action, 2) Implementation of CAFE Regulation Only, 3) Implementation of Government Incentives Only, and 4) Implementation of both CAFE Regulation and Government Incentives. It is important to note, however, that the WOM effect will be applied to each scenario analyzed in this study. Furthermore, five different vehicle types are studied as previously discussed by Noori and Tatari (2016), and Noori, Gardner, and Tatari (2015): internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), extended-range electric vehicles (EREVs), and battery electric vehicles (BEVs).

3.1. Electric Vehicle Regional Optimizer (EVRO)

The EVRO model, explained under the section S1, sets the foundation for the development of the EVReMP model. As shown in Fig. 1, such vehicle attributes as M & REF costs, and EDC are taken from the EVRO model’s database.

3.2. Agent-based modeling

Introduced for the first time by Axelrod and Hamilton (1981) in their study on cooperative behavior, AB modeling is a simulation technique that has been widely applied in the last couple of decades now to model complex and dynamic systems that comprise of multiple actors (Fagiolo et al., 2006). These actors in an agent-based model are autonomous and adaptive agents, who make decisions based on a set of rules, and can adapt a behavior assessing their states against system properties emerging from their interactions (Bonabeau, 2002; Van Dam et al., 2013). ABM is therefore regarded as a bottom-up approach to modeling such systems since it is capable of capturing this emergent phenomena through agent interaction (Axelrod, 1997). In other words, the behavior of agents at the micro-level determines the behavior of the system at the macro-level (Schiowitz and Milling, 2003). Bonabeau (2002) mentions that the use of ABM is appropriate, and can be used to analyze emergent properties of the system under consideration when agent behavior includes learning and adaptation, and generates network effects.

Table 1

<table>
<thead>
<tr>
<th>Reference</th>
<th>Short description of the article</th>
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<tbody>
<tr>
<td>Sullivan et al., 2009</td>
<td>Introduced the Virtual Automotive Marketplace (VAMMP) model, which was then used to examine PHEV penetration in the U.S.</td>
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<tr>
<td>Eppstein et al., 2011</td>
<td>Studied the adoption of PHEVs under different social-spatial circumstances in the U.S.</td>
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<tr>
<td>Zhang et al., 2011</td>
<td>Investigated what factors accelerate the diffusion of AFVs, as affected by market pull, technology push, and regulatory push</td>
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<tr>
<td>Choi et al., 2012</td>
<td>Analyzed the market penetration of eco-friendly vehicles, including EVs, HEVs, PHEVs, and FCVs</td>
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<tr>
<td>Shafiei et al., 2012</td>
<td>Analyzed how the passenger vehicle market for ICEVs and EVs has evolved in Iceland</td>
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<tr>
<td>McCoy and Lyons, 2014</td>
<td>Conducted a spatial and temporal investigation of the EV adoption behaviors of Irish households</td>
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<tr>
<td>Querini and Benetto, 2014</td>
<td>Analyzed the deployment of EVs in Luxembourg with respect to the country’s 2020 objectives</td>
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<tr>
<td>Adepele et al., 2016</td>
<td>Examined how different policy and technology scenarios, (EV rebates, charging at work, charging station planning, and battery size) influence the adoption of EV technology in San Francisco</td>
</tr>
<tr>
<td>Noori and Tatari, 2016</td>
<td>Developed the Electric Vehicle Regional Market Penetration (EVReMP) model to analyze EV adoption under WOM effect and provision of governmental subsidies</td>
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