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Total cost of ownership and its potential implications for battery electric vehicle diffusion

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ABSTRACT

Battery electric vehicles (BEVs) have been slow to diffuse on the international as well as the Swedish market. Previous studies have indicated situational factors such as economic factors, size and performance to be of major importance for vehicle purchasers in their choice of vehicle. In this paper, the authors explore a consumer centric total cost of ownership (TCO) model to investigate the possible discrepancy between purchase price and the TCO between internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs) and BEVs. The creation and testing of the TCO model reveals that computation could be a challenging task for consumers due to bounded access of relevant data and the prediction of future conditions. The application of the model to the vehicle sample found that BEVs could be cheaper compared to ICEVs and HEVs. The findings in this paper could prove to be of importance for policy and marketing alike in designing the most appropriate business models and information campaigns based on consumer conditions in order to further promoting the diffusion of BEVs in society.

1. Introduction

In the urgent need for society to reduce its CO_2 emissions, disruptive eco-innovations such as battery electric vehicles have a great potential. As now emerging in the mainstream markets, they have the potential to reduce CO_2 emissions from transports and hence benefit society at large. Despite its potential, however, electrification of the vehicle fleet has so far been slow to diffuse in the Swedish market, as represented in the 0.37% share of new vehicle sales during 2014 in Sweden, (BIL Sweden, 2015; Power Circle, 2015). In order for this share to increase, it is of great importance to understand the factors that make-up the demand for new vehicle purchases in general and BEVs in particular. This study will outline an approach to illuminating vehicle costs, that is one of several key factors for vehicle choice, one that is specifically perceived by users, but needs to be managed by policymakers and producers delivering new products to the market. This study will specifically focus on BEVs, since they are the only mass-market zero emission vehicles on the roads today.

Eco-innovations are normally not self-enforcing in their diffusion, as illustrated by the low degree of user adoption for solar power and hybrid-electric vehicles in the US (Zhang, Gensler, & Garcia, 2011). Roy, Potter, & Caird (2005) identified four barriers for cleaner vehicles. First, high purchase prices and long payback times associated with many low carbon products and systems often act as a major adoption barrier. Second, pioneering low carbon products tend to be engineering-led and hence lack ease and convenience of use. Third, a lack of system integration such as refuelling infrastructure hinders adaptation of low carbon products. Fourth, the importance of the vehicle as a status symbol is not always present with low carbon vehicles. Specifically for BEVs, extensive research has been conducted on the barriers of limited range and performance (Egbue & Long, 2012) and charging infrastructure challenges (Struben & Sterman, 2008), less so on the role of perceived and actual costs.

The general consensus within the industry, press and the public seems to be that BEVs are significantly more expensive than internal combustion engine vehicles, (ICEVs) and hybrid electric vehicles (HEVs), which following the results of previous works would then negatively affect its diffusion (Rosenberg, 1972). However, it is not clear whether this is the case and whether different pricing distribution schemes would lead to different purchasing behaviours. To explore the real cost of owning and operating a vehicle, one needs to go beyond the purchasing price to also include operating and capital cost. The total cost of ownership (TCO) calculation method has been used in numerous studies to compare cost between different vehicle technologies but not always including BEVs (Al-Alawi & Bradley, 2013a; Lin et al., 2013; Thiel, Perujo, & Mercier, 2010). However, previous studies have relied on uncertain or lacking vehicle cost assumptions and conceptualized vehicle examples, particularly in the case of BEVs, largely because of a lack of data due to the newness of BEVs on the market (Wu, Inderbitzin, & Bening, 2015). Previous studies that have relied on abstract theoretical frameworks and simulations have increased understanding among the scientific community but have not fully envisioned a TCO calculation method that could be comprehended and used by consumers. This

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study intends to extend previous research efforts by constructing a TCO model in the consumer context by using contemporary vehicle and market data that is available to the general public, and by exploring how BEVs compare to equivalent ICEVs and HEVs for the first vehicle owner when calculating TCO. This could be an important contribution in practice if such a model is disseminated to consumers. More important in research on BEVs and their diffusion: it is first with the application of data available to consumers a valid discussion on how TCO could actually affect the consumer's behaviours could be held. Therefore, the authors aim to discuss the results potential implication of the diffusion of BEVs. It is important to understand such potential since this could be the basis for new and potentially improved public policy and marketing of BEVs relying on a deepened understanding of this potential, based on real consumers' possible behaviour.

The next section will present literature regarding technological diffusion, emphasizing factors that influence vehicle choice, the energy paradox and TCO. It will be followed by sections that will present the TCO model with the factors that make up TCO and which are accessible to consumers with available data, and calculations for the sample of vehicles that are referred to in this study. The paper concludes with analysis, discussion and conclusion sections.

2. Perspectives from literature

2.1. Technological diffusion

This study is concerned with the adoption of the BEV technology on an aggregate scale, often called technical diffusion. Kemp & Volpi (2008) describe technological diffusion as the adoption of a technology by a population over time. Diffusion analysis does not seek to find answers as to why a particular unit (firm or consumer) has adopted an innovation at a particular time in any detail, but concerns itself with the adoption decisions of a population of potential adopters. Rogers's (1962)) work on the diffusion of innovations is one of the foundation blocks of modern diffusion research. He describes diffusion of a particular innovation as a gradual process largely dependent on five factors: *Relative Advantage*, *Compatibility*, *Complexity*, *Trialability* and *Observability*. Rogers also describes the diffusion process with the by now familiar diffusion curve where adopters are divided into *Innovators*, *Early Adopters*, *Early Majority*, *Late Majority* and *Laggards* according to their time of adoption. Several schools of diffusion have followed, such as the epidemic model and the probit model. The epidemic model builds on the premise that what limits the speed of usage is the lack of information available about the new technology, how to use it and what it does (Geroski, 2000). The probit model follows from the premise that different actors, with different goals and abilities, are likely to want to adopt the new technology at different times (Geroski, 2000). These models point to a need to put the consumer in centre to understand which factors are of relevance to a possible diffusion and how consumer act due to variances in factors.

2.2. Factors that influence vehicle choice

In order to understand what drives technological diffusion for BEV, it is important to investigate the factors that influence vehicle-purchasing behaviours, which are numerous both for fleet and private buyers. Lane & Potter (2007) divide these into situational factors and psychological factors. Situational factors include: economic and regulatory environments, vehicle performance and applications and the existing fuel/road infrastructure. The fuel/road infrastructure is especially important in the case of BEVs, since it to a large degree cannot use the existing infrastructure for refuelling/charging. Hence, it has been found to be an important factor affecting consumer choice in the case of BEVs (Struben & Sterman, 2008). Psychological factors include: for private drivers – attitudes, lifestyle, personality and self-image; and for fleet drivers – risk-perception, corporate culture and company image. Other studies have found that private vehicle purchases are predominantly driven by situational factors such as price, fuel economy, comfort, size, practicality and reliability (Low Carbon Vehicle Partnership, 2010).

2.3. Fuel economy and the energy paradox

Fuel economy constitutes one of the situational factors, and has been found to be an important factor during the decision-making process (Lane & Potter, 2007; Low Carbon Vehicle Partnership, 2010). However, it seems to be the case that most vehicle buyers expend little effort in comparing the fuel economy of different vehicles during the decision-making process (Low Carbon Vehicle Partnership, 2010). As a consequence, many consumers will consistently undervalue fuel economy savings, which in turn leads to a lower adoption rate of “eco innovations” than theoretical market theory would predict, in the literature this phenomena is called the “energy paradox” (Boardman et al., 2000; Green, Evans, & Hiestand, 2013; Turrentine & Kurani, 2007).

Several possible explanations for the energy paradox have been suggested, including imperfect information, bounded rationality, limited mathematical skills, principle agent problems, and the heterogeneity of consumers' preferences, as explained by Green et al. (2013). Lane & Potter (2007) suggest that consumers of all types have a very low knowledge base regarding the potential impacts of low carbon and fuel-efficient vehicles. This can be attributed to the greater importance of other factors in the vehicle purchasing process. As Lane et al. (p.1089), conclude, “Although it appears that fuel economy influences vehicle choice, other non-environmental issues (cost, performance, styling, image, etc.,) continue to play a more crucial role” (Lane & Potter, 2007).

2.4. Total cost of ownership (TCO)

TCO is defined by Ellram (1995), as a purchasing tool and philosophy, which is aimed at understanding the true cost of buying a particular good or service from a particular supplier. TCO is a useful calculation for consumers and firms alike to assess the direct and indirect cost associated with a purchase. TCO is important, since the purchasing price of most capital goods is not the only cost associated with their use and ownership. Traditionally, firms have mostly used TCO analysis; tools for consumers have so far been limited. As a result, there are reasons to suspect that consumers have limited knowledge regarding the TCO concept that potentially could lead to uneconomical vehicle purchases decisions. This is also interesting from the perspective of the epidemic model (Geroski, 2000), addressing the notion that new technology may not be used due to a lack of information for users.

Literature on vehicle TCO is a fairly new field and therefore also limited in its scope. Wu et al. (2015) contribute with a review of different studies that reveal a large variety in framing of vehicle TCO analysis also including a number of different assumptions concerning applied data. Such previous vehicle TCO analyses have found that plug-in hybrid electric vehicles (PHEVs) and BEVs can be both cheaper or more expensive to own compared to their ICEV competitors depending on cost assumptions and time scales (Al-Alawi & Bradley, 2013b; Electric Power Research Institute, 2013; Propfe et al., 2012; Wu et al., 2015). The electric drive train generally has lower service and maintenance costs, better fuel economy and lower taxes compared to ICEV, but a significantly higher purchase price. Hence, the relevance of investigating the TCO's relation to the purchasing process for BEVs, rather than just fuel economy or purchasing price. The US-based Consumer Report could be claimed to be the leading authority with regards to vehicle TCO, with annual updated calculations and on-going consumer information regarding vehicle TCO. Fig. 1 indicates the relative size of each cost factor for the average new vehicle in the US over a 5-year ownership and have been added for illustrational purposes.