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The use of electric vehicles: A case study on adding an electric car to a household

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A B S T R A C T

The market share of battery electric vehicles (EVs) is expected to increase in the near future, but so far little is known about the actual usage of this emergent technology. Consumer preference studies have indicated that the current limitation on driving distance is important. At the same time studies on the actual use of household vehicles indicate modest requirements for daily travel. An unresolved issue is to what extent these range limitations affect daily travel in EVs. In this study, we use real electric vehicle trip data to study the distribution of daily use and types of home-based journeys where a household decides to use an electric vehicle instead of their conventional vehicle. The results show how several factors related to distance and number of necessary charging events have plausible effects on electric vehicle travel behaviour. Further, the modelling indicates that the EV alternative is mostly used for well-planned transport and that EV use will not be the same as use of the conventional vehicle in two-vehicle households.

1. Introduction

Many governments see a greater use of battery electric vehicles (EVs) as an important way to fulfil their environmental goals. The absence of local exhaust emissions can contribute to less local air pollution, and with a higher share of renewable energy sources in the electricity production, EVs can also contribute to reducing global emissions from transport. However, the environmental impact of large-scale EV adoption is not obvious as it cannot be assumed that conventional vehicles (CVs) currently on the road are simply replaced by EVs and that individual behaviour otherwise stays the same.

Potential EV users benefit from an increasing availability of EV models with greater comfort and better driving performance. Furthermore, EVs have the potential to be cheaper to run and maintain than comparable CVs. To obtain these benefits, however, the consumer must presently accept a limited driving distance between charges and that charging time, depending on the available facilities where the car is parked, takes minimum 20 min for recharging up to 80% battery capacity and usually several hours to reach full capacity. As a result, there are limits to the travel that can be performed with an EV, and for many car users it would not be possible to exchange their current CV with an EV without some level of adaption in their daily way of travel. For example, commuters with more than 75 km distance to work (15% of commuting trips (TU, 2015)) would have uncertainty about getting home, e.g. in cold weather after work if they use a EV with today's battery capacity. Therefore, they would need to either find charging possibilities during the day, which could include detours, or to use other transport alternatives. Both the benefits and limitations will most likely have an effect on the EV market and it is therefore very useful to know more about potential users' EV travel.

Recent decades have provided a number of studies regarding the use of EVs using different methodologies. Due to a lack of information about *actual* EV usage, many studies have instead been based on information about current usage of CVs with the

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assumption that car users do not change behaviour whether they use a CV or an EV. Such information has then been obtained from CV odometer readings at refuelling (see e.g. Greene, 1985), from national travel surveys (see e.g. Christensen, 2011), or from CV journeys measured with GPS (see e.g. Pearre et al., 2011; Greaves et al., 2014). These studies find that with the driving distances possible with the EVs currently available, a large share of the households would be able to maintain their current way of travel with only a minor level of adaption. These studies rely on simple assumptions about the effect of range limitations on usage that may be problematic. This is also indicated in the results of research from consumer choice studies on EV consumer acceptance, which show that the driving distance possible to cover on a fully charged battery is of great importance to the potential users (see e.g. Jensen et al., 2013; Dimitropoulos et al., 2013; Mabit and Fosgerau, 2011; Bunch et al., 1993).

The above mentioned studies on car usage base their conclusions on data from CV usage or data from hypothetical settings, which might not be representative for actual EV user behaviour. As the EV market is still quite immature in most countries, personal vehicle trials are instead often used to obtain information about EV usage, including daily distances, location, charging activity and driving behaviour. Data is then collected by monitoring households driving an EV in their usual routines over an extended period of time. Golob and Gould (1998) use such a trial to assess the changes in daily vehicle usage if households were using an EV instead of a CV. They conclude that for everyday trips, excluding infrequent long trips, a two passenger EV with a 100 mile driving range requiring overnight recharging at home would be used 88% as much as the CV it would replace in terms of daily distances. In a three month field study in Germany, Franke and Krems (2013a) found that the daily distance driven in the EVs was similar to German CV users. In another 3-month field study, Jensen et al. (2014) interviewed household members before and after a three month trial with EVs and found that even though the participants with EV experience had a more positive view on the EVs driving characteristics (such as comfort and acceleration) and found charging less problematic, they expressed a higher concern with being able to maintain their current mobility need if they had to fulfil them with an EV.

The only country in the world where the EV market is mature enough to base EV studies on revealed data from EV owning households is probably Norway. Klöckner et al. (2013) base their study on revealed data from the Norwegian Public Roads Administration (Statens Vegvesen) database and self-reported car use from private households who purchased either a CV or an EV. They show that an EV is generally used in multi-car households (In less than 10% of the EV households, this is their only car) and that the EV is used for the major share of the total amount of trips in the household, except when the purpose is holiday. Furthermore, a lower level of car use is only found for single car EV households compared to single car CV households.

In this study, we seek to answer how the current technological differences might affect households' daily vehicle use. More specifically, we analyse the factors that affect EV use in a different way than CV use and quantify how these factors affect the daily distances driven in a household where both an EV and a CV are available. EVs have some obvious limitations compared to CVs, which we hypothesise will affect several aspects of transport behaviour. For example, the limited driving range provided by a fully charged battery could affect both the distance travelled and the type of trips conducted (as in Klöckner et al., 2013). Furthermore, as it has been observed that the driving distance of EVs is highly affected by temperature (see e.g. Zahabi et al., 2014) we investigate how EV usage is affected by temperature and other weather variables. Finally, as EVs are an emerging technology, and most of the households in the trial would therefore most probably not have tried an EV before, we investigate how experience with the EV affects daily use. Previously, Franke and Krems (2013a) found from their vehicle trial study that the stated acceptable minimum driving range for an EV in a purchase situation became lower for more experienced users, indicating that the users will adapt to the vehicle technology with time. However, in the stated choice experiment in Jensen et al. (2013), experienced users were seen to value driving range higher than inexperienced users. We note that even though these studies seem contradictory, the results cannot be directly compared as the first refers to absolute valuation of driving range while the latter refers to the marginal valuation.

The simplest indicator of car usage is the distance travelled in the household. Greene (1985) and Lin et al. (2012) specifically investigate the distributions of daily vehicle usage for CVs in order to study the implications for EV and hybrid electric vehicle use, respectively. They suggest the gamma distribution to be best at representing vehicle use in households, but to our knowledge, similar analyses have not been conducted on actual EV data to investigate whether the daily vehicle usage is different when using an EV compared to a CV. Another indicator of usage would be to look at individuals' decision to travel by a certain mode instead of other modes. The literature contains many mode choice studies (see e.g. Bhat, 1995; Koppelman and Sethi, 2005) but we are not aware of such studies particularly looking at which factors would affect the choice of EV for a trip or a journey.

We utilise data collected from participants of a large-scale EV trial conducted in Denmark in which participating households already owning a CV had access to an EV for a period of three months. With GPS data collected before and after the beginning of the trial period and in both the EV and the CV, we are able to analyse factors related to daily distances driven for both the EV and the CV. We do this by estimating and comparing the parameters of the gamma distribution as suggested in Lin et al. (2012) but in addition we also include explanatory variables describing household characteristics, type of day, and weather conditions. We advance the research on the use of EVs through an analysis of which factors are important in the choice between an EV and a CV for home-based journeys conducted by the participating households. This model allows assessment of how the share of EV journeys are affected by various explanatory variables, e.g. number of necessary charging events. This will especially be important for predictions of EV use conditional on car ownership for the next 5–15 years where EV households will probably own both CVs and EVs as indicated in a recent study (Klöckner et al., 2013). Furthermore, as the data collection for both car alternatives took place over an extended period of time, it is possible to investigate potential changes in behaviour when users obtain more EV experience. Based on these analyses we can investigate the assumption of previous literature that behaviour from CV use can be transferred to EV use.

The remainder of the paper is organised as follows. In Section 2, we describe the data available for this study and present the methods used. In Section 3, we present descriptive statistics and the results of the two models showing factors important for daily

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