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What are the value and implications of two-car households for the electric car?

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ABSTRACT

The major barriers to a more widespread introduction of battery electric vehicles (BEVs) beyond early adopters are the limited range, charging limitations, and costly batteries. An important question is therefore where these effects can be most effectively mitigated. An optimization model is developed to estimate the potential for BEVs to replace one of the conventional cars in two-car households and to viably contribute to the households' driving demand. It uses data from 1 to 3 months of simultaneous GPS logging of the movement patterns for both cars in 64 commuting Swedish two-car households in the Gothenburg region.

The results show that, for home charging only, a flexible vehicle use strategy can considerably increase BEV driving and nearly eliminate the unfulfilled driving in the household due to the range and charging limitations with a small battery. The present value of this flexibility is estimated to be on average $6000–$7000 but varies considerably between households. With possible near-future prices for BEVs based on mass production cost estimates, this flexibility makes the total cost of ownership (TCO) for a BEV advantageous in almost all the investigated households compared to a conventional vehicle or a hybrid electric vehicle. Because of the ubiquity of multi-car households in developed economies, these families could be ideal candidates for the initial efforts to enhance BEV adoptions beyond the early adopters. The results of this research can inform the design and marketing of cheaper BEVs with small but enough range and contribute to increased knowledge and awareness of the suitability of BEVs in such households.

1. Introduction

Electrified vehicles are one of the options to achieve less use of fossil fuel and reduced emissions of greenhouse gases and other pollutants from transport, especially in countries or regions with clean electricity production systems. Mainly due to expensive batteries, most battery electric vehicles (BEVs) currently available have limited ranges compared to conventional cars, and they also have the disadvantage of a relatively long charging time. Due to its comparably low operational but high fixed costs, the relative economic viability of BEVs is more advantageous with high annual driving, but this, in turn, tends to aggravate the range and charging limitations. These limitations set by the range and charging time hamper the uptake in private households, whose members highly value the option to occasionally drive longer trips, or shorter trips without necessary long stops in between. For instance, in Sweden so far (Oct 2016), around 8000 BEVs (≈0.2% of the total car fleet) have

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been sold[1]. Most of these are used as fleet vehicles or provided by business or government as "company cars" to employees, and only a few are registered on private persons. There is, though, a Swedish goal of having a "fossil-independent" vehicle fleet in 2030 (Swedish Government, 2009).

But could potential private BEV buyers beyond early adopters be two-car (or multi-car) households? There could be four reasons or options related to factors connected to the car movement patterns. Firstly, *confinement*: it has been argued that while the "first car" or "main car" is also used for the household's longer trips, such as vacation trips, the "second car" is used mainly for shorter trips such as daily commuting. Replacing a car with a more confined driving pattern with a limited-range BEV may lead to fewer unfulfilled driving occasions and thus suit the BEV better[2]. Secondly, *extension*: a BEV can be used for also fulfilling some of the driving of the other car, especially when the BEV is not used anyhow, leading to a decrease in the household's operational costs due to the lower fuel cost of a BEV. Thirdly, *backup*: the other car in the households, which is assumed to be a conventional vehicle (CV), can be used as a backup for unfulfilled driving, at least when this car is not used. Fourthly, *flexibility*: a BEV can be utilized flexibly such that a BEV is replacing both cars' driving as much as possible to maximize its driving and thus minimizing the household's operational costs, while still keeping down the unfulfilled driving with backup by the CV. The flexibility option is thus an optimized combination of choice of car and the three first options.

Although multi-car households have early been identified as potential BEV buyers, it has been difficult to quantify these three factors, their value or implications directly. Detailed data for the driving patterns of multi-car households are seldom available, markets data for conventional cars do not reveal demand for cars with BEV-specific attributes such as range and recharge limitations, and survey data may be unreliable because of the lack of pronounced preferences among respondents, especially those based on knowledge or experience. Still, for instance, Beggs and Cardell (1980) tried projecting the demand for BEVs from market data for small cars in multi-vehicle households. Calfee (1985) used survey data to predict the potential market shares for various BEVs as a second car. Kurani et al. (1996) also focused multi-car households but tried to circumvent the limitations of earlier studies and extended the survey method to include a 3-day household trip diary as well as a reflexive session based on how different BEVs could contribute to fulfilling the logged driving. They thus tried to capture and illustrate the implications of the factors and estimate the preferences. Their results indicated that a BEV with a smaller battery could be preferred in "hybrid households", i.e., households with both BEVs and conventional cars. Hidrue et al. (2011) included different types of households and did not find higher stated preferences for BEVs specifically in multi-car households, or even a slight tendency towards the opposite, while Deloitte (2010) identified multi-car ownership as a characteristic of early adopters of BEVs. Rather than showing the unimportance of multi-car households for BEVs, stated preferences may point to the immature market for BEVs and the widespread BEV ignorance among potential consumers.

Recent studies also point in various directions. Javid and Nejat (2017), using US Travel Survey Data to identify plug-in electric vehicle (PEV) buyers, claimed that the number of vehicles in the household has had no significant effect on the households PEV purchase. But the recent development in Norway beyond-early-adopters-market for BEVs has demonstrated the importance of multi-car households there. According to the survey presented in Figenbaum and Kolbenstvedt (2016), in Norway, with its unique high BEV share of around 15% of new car sales, 79% of the households having a BEV had more than one car compared to around 48% for owners of only conventional vehicles. It was even higher when excluding the long-range Tesla Model S, which to a much larger share is situated in one-car households. Coincidentally, a somewhat larger fraction of BEVs has been bought as an additional car rather than a replacement compared to other new vehicles.

Many studies have investigated the options for a BEV to replace a conventional car, but there are relatively few that have specifically looked at the options in multi-car households. Khan and Kockelman (2012) used available GPS-logged car movement data from the Seattle region for a period of around a year to analyze the possibility for a BEV (160 km range) to replace the least-driven car only in multi-car households and found that for the daily driving the range limit is reached less often than in single car households. Jakobsson et al. (2016a) based analysis on Swedish daily driving distances derived from GPS-logged movements for randomly chosen cars for around two months each (Karlsson, 2013; Karlsson and Kullingsjö, 2013). They found that a BEV replacing the 2nd car only, determined as the least-driven car as stated by owners in a two-car household, results in fewer range-limited days, due to the shorter and more confined driving of the 2nd car, as well as on average lower total cost of ownership (TCO) for a BEV than when replacing the 1st car. Similar results were observed in their parallel analysis of a larger dataset for one week's driving in German households. Both these above-mentioned studies only replaced one of the household's cars and thus only investigated the confinement factor. Recently, though, Tamor and Milačić (2015) examined the flexibility option using the same Seattle data as Khan and Kockelman by analyzing the possibility of letting one BEV replace both/all cars in multi-vehicle households. They concluded that a BEV with a modest range (160 km) appears to be viable at costs that are likely to be achieved in the near future.

We have completed a data acquisition and analysis project with the overall objective to assess the potential for a BEV replacing one of the conventional cars to viably contribute to the accomplishment of the car movements in Swedish commuting two-car households.

[1] http://elbilsstatistik.se/ Acc. Nov 24, 2016.

[2] Note that the confinement, contrary to the other options, is here not strictly defined, but more a general argument that some car movement patterns fit a range- and charge-limited BEV better than others.