The impact of battery electric vehicles on vehicle purchase and driving behavior in Norway

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ABSTRACT

Battery electric vehicles (BEVs) represent a promising solution to carbon emissions within the transportation sector, but relatively little is known about how limited-range vehicles will change consumer behavior. This study evaluates the impact of large-scale introduction of BEVs on the new car market in Norway, and seeks to determine whether BEVs lead to an increase in household vehicle ownership. Analysis of online survey responses from 4405 new car owners suggests that BEVs lead to an increase in household vehicle ownership of approximately 15–20%. We arrive at this finding using three independent methods: logistic regression of the likelihood of replacing a vehicle on vehicle type, analysis of correlation between the rate of vehicle replacement and BEV market share across municipalities, and linear regression of changes in total new car sales on changes in BEV sales across counties and years. Survey responses on driving habits also suggest that BEV purchases lead to a moderate increase in vehicle miles traveled. These results suggest that real-world emissions savings may be somewhat less than those predicted by life-cycle analysis. Policy recommendations include focusing incentives for BEVs on those bought as replacements for a conventional vehicle.

1. Introduction

1.1. Electric vehicles and greenhouse gas emissions

As climate change accelerates and demand for personal transportation skyrockets in emerging countries, the need for sustainable personal transportation has never been so great. It is predicted that global car sales will more than double by 2050 (Hao et al., 2016), potentially outweighing all other mitigation measures unless transportation emissions can be decoupled from demand for mobility (Sims et al., 2014). Battery electric vehicles (BEVs) have recently emerged as a technology with the potential to greatly reduce transportation emissions, replacing internal combustion engine vehicles (ICEVs) with transportation powered by renewably-generated electricity, stored in batteries. Despite greater emissions from manufacturing, BEVs have been found to significantly reduce emissions per kilometer traveled as compared with conventional vehicles (Hawkins et al., 2013). Using the average European generation mix as the source of electricity and comparing between vehicles of similar size, recent research shows that BEVs reduced carbon emissions by 20–47% over a 180,000 km lifetime (Ellingsen et al., 2016; Nordelöf et al., 2014). Real-life emissions savings may be much higher when accounting for decreases in ICEV efficiency in heavy traffic (Karabasoglu and Michalek, 2013). Naturally, BEV emissions vary greatly depending on the carbon intensity of the electricity source, ranging from 25% of gasoline vehicles when...
powered by renewable electricity, to 125% when powered by coal (Bauer et al., 2015; Nordelöf et al., 2014). In areas like the EU with cap-and-trade frameworks that include electricity generation, in theory BEVs should reduce emissions from vehicle usage by 100%, but controversy remains as to how well these policies succeed in increasing the deployment of renewable energy (Figenbaum, 2016).

However, most predictions of BEV emissions savings to date have assumed that BEVs will be used in exactly the same way as ICEVs, ignoring the potential for various rebound and spillover effects. For example, as electricity is typically much cheaper than gasoline per mile of driving, and maintenance costs for BEVs will likely be significantly lower (Propfe et al., 2012), the total cost of ownership (TCO) of BEVs may ultimately be much lower than that for ICEVs. In most instances today, reduced operating costs for BEVs are offset by higher purchase prices, such that BEVs do not have significantly lower TCO than ICEVs (Vivanco et al., 2014). However, as battery technology improves, BEV purchase prices are likely to decrease, and the TCO gap may become significant. In addition to increased monetary savings, it is possible that BEVs could reduce guilt associated with environmental impact, thus reducing the social cost of driving (Ryghaug and Toftaker, 2014). This decrease in cost could lead to an increase in vehicle ownership and driving, as consumers who otherwise would have traveled with public transit or carpooling start to purchase BEVs as additional vehicles. The negative feedback we describe here is a form of a rebound effect, whereby increased efficiency leads to decreased costs, which in turn lead to increased usage (Gillingham et al., 2016).

While BEVs may lead to several different kinds of rebound effects, for the sake of coherence, in this paper we focus on the measurement of a rebound effect with respect to household vehicle ownership (HVO): does the availability of BEVs with low TCO lead to a society-wide increase in vehicle ownership?

If such a rebound exists, emissions reductions from BEVs will be lower than predicted, especially given high energy consumption from battery production. Life-cycle analyses of BEVs have shown that manufacturing a BEV produces 33–85% more emissions than manufacturing an internal combustion engine vehicle (ICEV) (Hawkins et al., 2012; Bauer et al., 2015; Ellingsen et al., 2016). Greater levels of vehicle ownership will also likely lead to more travel by personal vehicle, which in turn could lead to a rebound in usage emissions as well.

1.2. Norwegian BEV market

There is at least one country where the TCO of an electric car is already lower: Norway. Over the past 20 years, Norway has developed an extensive system of incentives that drastically lowers the relative TCO of BEVs. To begin with, BEVs are exempt from purchase taxes that often make up over 50% of the total price of a new ICEV (Figenbaum et al., 2015; Figenbaum, 2016). This means that the purchase price of a BEV is typically lower than that of a comparable ICEV—for example, the MSRP for the 2016 Volkswagen e-Golf is $32,157, while that for the basic diesel Golf is $33,226 (Volkswagen, 2016). BEVs are also exempt from some toll and ferry fees, receive free parking and charging in many public areas, and have access to bus lanes in some places. Based on survey data, Figenbaum and Kolbenstvedt (2016) recently estimated that these usage incentives amount to about $1600 USD per year for the average BEV owner in Norway. Meanwhile, in Norway, electricity costs $0.10/kWh, as opposed to $0.18/kWh for gasoline and $0.14/kWh for diesel (SSB, 2016). With an energy consumption of 0.18 kWh/km for a 2015 Volkswagen e-Golf, 0.72 kWh/km for the gasoline version and 0.67 kWh/km for the diesel version (DOE, 2015), this equates to savings of $0.07 to $0.11 per kilometer for the BEV, not including any incentives or reduction in maintenance costs. With an annual driving distance of 15,000 km, this could lead to combined savings of over $3000/year.

As a result of these incentives, over the past 5 years Norway has experienced explosive growth in the BEV market. The BEV market share in Norway, which topped 20% for several months in 2015, is now several times higher than in any other country (see Fig 1b). As of December 2016, there had been 93,472 cumulative sales of BEVs in Norway, more than in any other country in Europe (NPRA, 2016). Rapid growth is widely expected to continue at least through 2017, when the government is planning to start scaling back the purchase tax incentives (NAF, 2016).

1.3. Impact of BEVs on vehicle purchase behavior

Norway thus serves as a key case study for examining the impact of BEVs on car purchase behavior. Given that the TCO of BEVs in Norway is so low, we must then ask, did all of this massive growth in BEV sales offset ICEV sales, or did it partially increase overall car sales as well? Several previous surveys of BEV owners in Norway have noted unusually high levels of household vehicle ownership. Halvorsen and Frøyen (2009) found that 93% of EV owners had at least one other car in the household. Likewise, Klöckner et al. (2013) found that over 90% of new BEV owners had at least one other car, as opposed to 50.6% of new ICEV owners.

Given that the penalties incurred by limited range are much less in households with an ICEV in addition to a BEV, households that already have two cars are presumably much more likely to replace one of them with a BEV than households with only one vehicle. Meanwhile, BEV owners come from a different demographic group than car owners in general. For example, they tend to have higher income and more people in the household, both of which one would expect to lead to more cars (Figenbaum and Kolbenstvedt, 2015). Thus, it is likely that HVO among BEV purchasers was already much higher than that of ICEV purchasers even before the new car was purchased. As noted by de Haan et al. (2006), who investigated purchase rebound effects among hybrid cars in Switzerland, a more appropriate question is whether the new car was bought in addition to other vehicles in the household, or replaced a pre-existing...
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