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Do electric vehicles need subsidies? Ownership costs for conventional, hybrid, and electric vehicles in 14 U.S. cities

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ABSTRACT

Battery electric vehicles (BEVs) are an important pathway for decarbonizing transportation and reducing petroleum dependence. Although one barrier to adoption is the higher purchase price, advocates suggest that fuel and maintenance savings can make BEVs economical over time. To assess this empirically, this paper analyzes the five-year Total Cost of Ownership (TCO) for conventional, hybrid, and electric vehicles in 14 U.S. cities from 2011 to 2015. Results show spatial variation due to differences in state and local policies, fuel prices, insurance and maintenance costs, depreciation rates, and vehicle miles traveled. Yet in nearly all cities, the BEV's higher purchase price and rapid depreciation outweighed its fuel savings. Extensive sensitivity analyses highlight the impact of key parameters and show that both federal and state incentives were necessary for BEVs to be cost competitive. Future BEV cost competitiveness may improve if innovation and scaling lead to significantly reduced BEV purchase prices, but our analysis suggests that it will be challenging for BEVs to achieve unsubsidized cost competitiveness except in the most optimistic scenarios.

1. Introduction

U.S. battery electric vehicles (BEVs) sales have more than doubled in the past five years, from 48,000 new vehicles sold in 2013–106,000 in 2017.[1] Early adopters choose BEVs for a variety of reasons, including protecting the environment, reducing oil dependency, and saving on fuel costs (Center for Sustainable Energy, 2013; Rezvani et al., 2015). Policy incentives, particularly the $7500 federal tax credit and numerous state and local incentives, also play a large role in stimulating BEV adoption (Gallagher and Muehlegger, 2011; Jenn et al., 2013). But even with these subsidies, many potential BEV adopters remain deterred by the “sticker shock” of higher purchase prices (Deloitte, 2011; Liao et al., 2017). Currently, the Manufacturer's Suggested Retail Price (MSRP) for BEVs tends to be $8,000-$16,000 higher than comparable conventional vehicles.

BEV advocates emphasize that high capital costs can be offset by low operating costs. Since consumers tend to underestimate long-term savings (Allcott and Wozny, 2014; Krause et al., 2013; Greene, 2010), consumer education is often seen as a low-cost tool for encouraging BEV adoption. Fuel cost savings, in particular, are emphasized by educational websites and cost calculators from governments, utilities, environmental groups, automakers, and universities.[2] More comprehensive cost estimates from Total Cost of Ownership (TCO) modeling are also entering public discourse and education, including the U.S. Department of Energy's online Vehicle Cost Calculator.[3] Some policy scholars further suggest that standardized vehicle TCO labels may help alleviate the perception of high BEV costs and “nudge” consumers towards BEVs (Wu et al., 2016; Dumortier et al., 2015; Siddiki et al., 2015).

This paper addresses two critical questions related to BEV ownership costs: Now that we have several years of empirical data on BEV costs, including resale values, does it appear that drivers in major US

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[1] InsideEVs.com estimates for 2013 (https://insideevs.com/december-2013-plug-in-electric-vehicle-sales-report-card/) and 2017 (https://insideevs.com/december-2017-plugin-electric-vehicle-sales-report-card/).

[2] Examples include the U.S. Department of Energy's website on “Saving on fuel and vehicle costs” (https://energy.gov/eere/electricvehicles/saving-fuel-and-vehicle-costs), Nisssan's “Leaf Savings Calculator” (https://www.nissanusa.com/leaf-electric-car/savings-calculator), the “EV Explorer” tool developed by the University of California, Davis (http://gis.its.ucdavis.edu/evexplorer/), Pacific Gas & Electric's (PG&E) Plug-In Electric Vehicle Calculator (https://www.pge.com/en/pevcalculator/PEV/index.page), Southern California Edison's Plug-In Car Rate Assistant (https://www.sce.com/nrc/pev/index.html), and the Sierra Club's “Electric Vehicles: Myths vs. Reality” site (https://content.sierraclub.org/evguide/myths-vs-reality).

[3] Available at: https://www.afdc.energy.gov/calc/.

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cities actually saved money with BEVs compared to hybrid electric vehicles (HEVs) or conventional internal combustion engine vehicles (ICEVs)? How much did BEV cost competitiveness depend on government subsidies?

We answer these questions with an empirical comparison of five-year TCO for three representative vehicles – Nissan Leaf (BEV), Toyota Prius (HEV), and Toyota Corolla (ICEV) – across 14 major US cities. To estimate ownership costs as realistically as possible, we use a five-year ownership period (Fiscal Years 2011–2015) and city-specific data on vehicle mileage, fuel prices, insurance costs, maintenance and repair costs, resale values, and taxes, fees, and subsidies. We examine spatial variation in ownership costs and highlight the relative importance of various cost components (e.g., net capital costs, fuel and operating costs, and policy-related costs and subsidies). We also conduct extensive sensitivity analyses that explore the impact of fuel prices, discount rates, depreciation rates, length of ownership, and driving distances – and explore what it would take for the Leaf to achieve cost-competitiveness without federal and state subsidies.

We find that although ownership costs varied considerably across cities, the Leaf cost substantially more than the Corolla in all cities and more than the Prius in all but one city. A principal reason is that the Leaf depreciated faster than the gasoline vehicles, losing more in resale value than it gained in fuel savings in the first five years. In addition, the Leaf's higher purchase price resulted in higher sales tax, ad valorem taxes, and insurance costs. Sensitivity analyses demonstrate that an owner *may* save money with the Leaf compared with the Corolla or Prius, especially if they have access to free or reduced-rate charging. Government incentive programs were still necessary, however, for the Leaf to achieve cost competitiveness.

2. Literature review

This section briefly reviews the TCO literature to contextualize our contribution. For full technical reviews of TCO modeling, see Roosen et al. (2015) and Contestabile et al. (2011).

TCO analyses aim to estimate all costs associated with owning an asset over its lifetime. When applied to vehicles, these studies often compare the costs of conventional and alternative fuel vehicles. Although this sounds straightforward, the variation in parameters and assumptions across vehicle TCO studies means that “results are often misleading” (Roosen et al., 2015) and “difficult to compare” (Wu et al., 2015), with “little consensus on the TCO value or payback period” (Al-Alawi and Bradley, 2013). For example: most studies assume an ownership period of the entire vehicle lifetime, variously interpreted as 10, 12, 15, or 20 years, while others consider a shorter ownership period of 3–7 years; some studies only include vehicle purchase and fuel costs, while others include many additional operating and maintenance costs; many studies assume no residual value, others assume fixed depreciation schedules across all vehicle types, while a few look at market-based residual value. In fact, Roosen et al. (2015) found that only two out of 44 studies included all the relevant private costs of vehicle and battery purchases, fuel, charging infrastructure, maintenance, insurance, taxes, and credits from resale or residual value.

This paper addresses three aspects of consumer vehicle costs that are understudied in the TCO literature. First, there is a startling lack of attention to spatial variation, especially at sub-national scales. The vast majority of TCO studies use parameter values that are meant to be representative for an entire country. Although a handful of studies consider smaller spatial scales – such as one state (Parks et al., 2007), two states (Palmer et al., 2018), or one city (Peterson et al., 2011; Hao et al., 2015) – none examine variation at the city scale. Our spatial comparison, based on city-specific empirical data, is a significant contribution.

Second, many TCO studies for the US have an incomplete representation of policy-related costs, perhaps because many taxes and fees are implemented by state and local governments. For example, the majority of US vehicle TCO studies do not include vehicle sales tax (e.g., Delucchi and Lipman, 2001; Lipman and Delucchi, 2006; Elgowainy et al., 2013; Tseng et al., 2013; Miotti et al., 2016; Palmer et al., 2018), which we show to be an important contributor to the higher net capital cost of BEVs. Many of these studies also exclude annual registration fees and ad valorem taxes, which can be also higher for BEVs due to higher vehicle weight and purchase price. In contrast, recent European TCO studies often include more detailed, country-specific vehicle taxes (Bubeck et al., 2016; Hagman et al., 2016; Lemathe and Suares, 2017; Lévay et al., 2017). In this study, we consider a comprehensive set of federal, state, and local policy-related costs and incentives, including tax credits and exemptions, purchase rebates, vehicle sales and excise taxes, title fees, registration fees, ad valorem taxes, use fees, emissions inspection or smog abatement fees, and EV taxes and fees.

Third, this study contributes to the growing subset of the TCO literature that estimates costs over a short-term ownership period with attention to resale value. Earlier TCO models tended to estimate costs over 10- to 20-years with no vehicle resale (see review in Roosen et al., 2015; more recent examples include Miotti et al., 2016; Bubeck et al., 2016). However, since most buyers of new cars trade or resell their cars after five to eight years, resale values are an important determinant of net ownership costs. An increasing number of both US and European studies therefore consider ownership periods of three to six years (Gilmore and Lave, 2013; Al-Alawi and Bradley, 2013; Elgowainy et al., 2013; Lévay et al., 2017; Palmer et al., 2018; Hagman et al., 2018; Harvey, 2018). Although this provides a more ‘realistic’ estimate of ownership costs for new vehicles, it raises a new challenge: estimating depreciation rates for new vehicle types. Many studies assume a standard depreciation rate for all vehicles (e.g., Elgowainy et al., 2013; Hagman et al., 2018) or model depreciation as a function of miles driven (e.g., Wu et al., 2015), sometimes including battery salvage value (Letmathe and Suares, 2017). Neither approach considers how used vehicle markets may produce differential depreciation rates for BEV, PHEV, and ICEVs. A few studies use actual auction price data (e.g., Gilmore and Lave, 2013; Allcott and Wozny, 2014). Since this likely underestimates what owners can negotiate in a private sale, however, we use automotive websites to estimate a realistic, city-specific, five-year resale value.

3. Methodology and data

This section specifies the case selection criteria, cost equations, and key data sources. Because we aim to approximate real-world ownership costs across US cities, our assumptions diverge from most existing TCO studies with a shorter ownership period and city-specific data for operating and maintenance costs, policy-related costs, vehicle miles traveled, and resale values.

3.1. Case selection

3.1.1. Vehicles

This analysis compares the most popular ICEV, HEV, and BEV according to U.S. sales: Toyota Corolla, Toyota Prius, and Nissan Leaf.[4] We use the 2011 model year since that is when the Leaf was first available, providing a full five years of data. When estimating new and used values, we specified mid-trim models with comparable features (Corolla LE, Prius II, Leaf SV).

3.1.2. Ownership period

The five-year ownership period in this study comprises fiscal years

[4] Palmer et al. (2018) selects the same representative HEV, BEV, and ICEV vehicles. Gilmore and Lave (2013) instead selected the Toyota Camry instead of the Corolla to compare with the Prius, since the Corolla is classified as compact while the Camry is classified as mid-size (as are the Prius and Leaf). However, the size and performance of the Corolla, Prius, and Leaf are quite similar, while the Camry has a larger body, larger engine, and higher horsepower.