Household vehicle portfolios and EV demand

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Introduction and research questions

The automotive industry and policymakers worldwide are placing massive bets on transportation electrification. Implications for the automobile industry, the success of climate change mitigation efforts, and for the overall economy are enormous. However, remarkably little is known about how consumer choose to adopt and utilize electric vehicles (EVs). This gap in knowledge is understandable given how rapidly the technology and policy landscapes have changed in recent years. Moreover, researching this topic is challenging. Understanding how households make vehicle choices requires researchers to observe data on vehicle purchases and intensity of use. The knowledge gap is concerning, since policies being considered are intended to do nothing short of transform our transportation and energy economies. Early results from our and others' research highlights the urgent need for further empirical research to better inform policy decisions.

In prior work (Burlig et al. (2021)), we demonstrate that, from 2014 to 2017, battery EVs (BEVs) and plug-in hybrid EVs (PHEVs) in northern California were, on average, driven approximately 6,700 and 1,700 miles on electricity per year – substantially less than the average internal combustion engine (ICE) vehicle average of 9,800 VMT per year.[1] Why are EVs driven so little, and what does this tell us about their envisioned role as substitutes for ICEs? There are several potential explanations, and each has its own natural implications for policy. In this project, we will focus on understanding one of them: the role of the EV as part of a household's vehicle portfolio.

The average American household owns close to two vehicles, with over 60 percent of US households owning multiple cars (Davis (2019) and the 2017 National Household Travel Survey (NHTS)). EVs are rarely the technology chosen by one-car households. According to the 2017 NHTS, only one in ten EVs is the only car the household owns; nearly half reside in two-car households, and nearly 20 percent in households with four or more cars (Davis (2019)). This is relevant because households readily substitute driving across their vehicles, as we have shown in previous work (Archsmith et al. (2020)). It is thus important to understand how portfolio considerations affect the private utility and external benefits of EVs.

We plan to answer three main research questions relating to household vehicle portfolios. First, are households purchasing EVs primarily as substitutes for their existing ICE

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1. This result mirrors Davis (2019), though stands in contrast to other survey-based estimates. We hypothesize that survey response bias may be a factor explaining the difference.

vehicles, or as additional cars? Second, what is the impact of EV ownership on VMT in ICEs? Third, how does the pre-existing composition of a household's portfolio impact eventual EV utilization? We also plan to examine how household portfolios interact with other determinants of EV demand, such as purchase and operating costs and charging network density. These questions have key implications for policy. For example, if household treat EVs as complements to (rather than substitutes for) ICEs, the net benefits of significant electrification will be lower than anticipated, and potentially negative. In that scenario, most of the costs will be borne by the public in the form of lower pollution abatement and higher fiscal burden of policies such as EV subsidies and public infrastructure investments.

Empirical approach

To answer these questions, we will assemble a novel dataset on vehicle portfolio choices and utilization in California, and employ a standard panel fixed effects research design for econometric identification. California is an ideal setting for research on EVs; the state is home to approximately 50 percent of American EVs and is one of the largest EV markets worldwide.

Data:

Our dataset has three primary components. First, we obtained the universe of California Department of Motor Vehicles (DMV) vehicle registration records for the period 2008 to 2019. This dataset contains all EV and ICEs registered in the state of California during this time period, and includes the registration address, registration date, make, model, year, and VIN stem, as well as a series of other vehicle characteristics. We also observe an anonymized unique vehicle identifier which allows us to track vehicles across time.

Second, we have access to the universe of testing records from the California Bureau of Automotive Repair's (BAR) Smog Check emissions testing program from 2008 to 2020. These data include an anonymized unique vehicle identifier, which is constructed through a hashing algorithm to be linkable with the DMV registration records described above; the date of the emissions test; the result of the emissions test; and the vehicle's odometer reading. Vehicles appear in the smog check data (i) when they are sold, so long as they are more than 4 years old; (ii) as a requirement of registration, every other year, so long as they are at least six years old; (iii) when they move to California from out-of-state.[2] We use these data to construct biannual measures of VMT for each ICE in a household's vehicle portfolio.

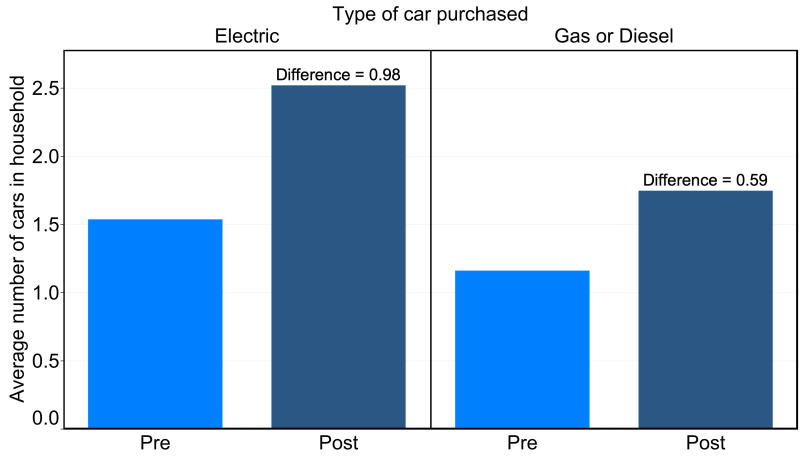
Finally, we are obtaining household-level data on hourly electricity consumption from 10% of the households served by California's investor-owned electric utilities (IOUs): Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric (SDG&E). These data include hourly kWh, electricity tariff, a solar panel interconnection date where applicable, and household address, which we use to link with the DMV registration data. The sample consists of billions of hourly electricity consumption observations, and was selected to maximize the number of EVs in the dataset, with a sampling frame that over-weights households in Census Block Groups with particularly high EV penetration. In Burlig et al. (2021), we used PG&E data from 2014 to 2017. We are currently extending this sample to include data from all three IOUs from 2014 through 2019. These data enable

2. Certain vehicles, including all electric-only cars (BEVs), are exempt from the Smog Check program. PHEVs, which have both electric and ICE drivetrains, are not exempt.

us to quantify the amount of at-home EV charging, which we use to construct an estimate of eVMT (see Burlig et al. (2021) for details).

Research design:
Our first research question asks whether EVs are being purchased as substitutes for a household's ICE vehicles. To answer this question, we will use the DMV registration data to estimate the impact of an EV purchase on the total number of vehicles in a household. We will use a standard event study framework to estimate the change in the number of vehicles before and after the arrival of an EV. We will compare this estimate to the impact of an ICE vehicle purchase. Figure 1 shows preliminary evidence using simple differences in means.

Figure 1: Number of cars per household before and after EV and ICE purchases

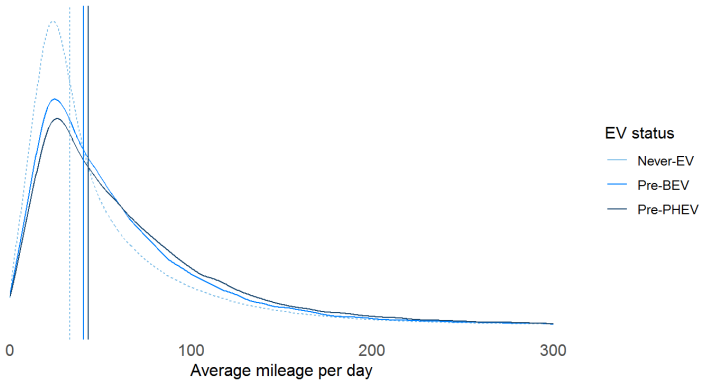


These summary statistics suggest that EVs are much more likely to be additional cars than ICEs, which replace an existing vehicle 41 percent of the time. However, we also see that EV-purchasing households have more vehicles on average before their new purchase, highlighting the importance of controlling for unobserved differences using our proposed research design.

Our second research question asks how EV ownership impacts VMT of a household's ICE fleet. To answer this question, we use the EV purchase data from the DMV data to determine the timing of an EV's arrival, and use the BAR data to compute VMT for each existing ICE car in the same household. We again plan to use an event study design surrounding the EV's arrival to estimate the impact of EV ownership on ICE VMT. Figure 2 plots preliminary summary statistics from these data.

This figure shows that, prior to the purchase of an EV, households that eventually buy an EV drive more on average than households that do not buy an EV during our sample, suggesting that the results in Burlig et al. (2021) are not driven by selection into EVs by low-VMT households. As part of our proposed research, we will extend these results to estimate treatment effects of EV ownership on ICE VMT. To the extent that EV ownership

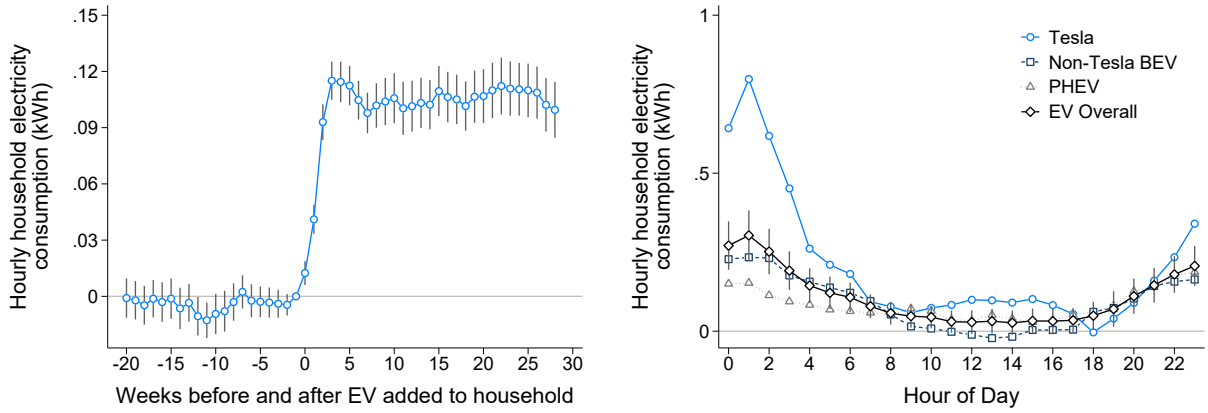
Figure 2: ICE VMT by EV purchase status



impacts ICE VMT, we will also be able to estimate heterogeneous treatment effects by ICE vehicle characteristics such as energy efficiency, vehicle class (sedan, trucks, etc), and size.

Our third research question asks how a household's pre-existing ICE vehicles impact EV utilization. To answer this question, we will follow the event study approach outlined in Burlig et al. (2021) in using IOU data to estimate the treatment effect of EV ownership on household electricity consumption. Figure 3 reproduces the main results of our earlier paper.

Figure 3: Impacts of EV adoption on household electricity use



We previously found that EV ownership increases household electricity consumption in PG&E's service territory by 2.9 kWh per day, or approximately 18% of mean usage. However, these estimates were less than half the size of policymakers' predictions, which rely on a selected sample of 500 households with dedicated EV meters. We also found evidence of substantial heterogeneity by EV type, with Teslas consuming much more electricity than non-Tesla BEVs and PHEVs. We will extend this approach to measure portfolio impacts by estimating heterogeneous effects by the size and composition of households' vehicle portfolios.

Finally, we will be able to utilize our data that provide detailed information on vehicle type and location to test how household portfolios interact with other determinants of EV demand, such as vehicle attributes, local energy costs, and charging network availability.

Research team

The research team consists of PIs Fiona Burlig, James Bushnell, and David Rapson.

Fiona Burlig is an Assistant Professor at the Harris School of Public Policy and Energy Policy Institute (EPIC) at the University of Chicago and a Faculty Research Fellow at the NBER. Prior to joining the Harris School, Prof. Burlig was a Postdoctoral Scholar in the Department of Economics at the University of Chicago. She received her PhD in Agricultural and Resource Economics in 2017 from UC Berkeley, where she was an NSF Graduate Research Fellow and a graduate student researcher at the Energy Institute at Haas. Prof. Burlig's research combines large-scale administrative data with natural and randomized experiments to understand the causal impacts of energy and environmental policy on welfare.

James Bushnell is a Professor of Economics and co-director of the Davis Energy Economics Program (DEEP) at UC Davis, and a Research Associate at the NBER. He has published extensively in the field of energy and environmental economics. Prof. Bushnell has been actively involved in energy and environmental policy for over three decades. Since 2002, he has served as a member of the Market Surveillance Committee (MSC) of the California Independent System Operator (CAISO). He has also advised the California Air Resources Board in several capacities, including as a member of the Emissions Market Assessment Committee from 2012 to 2014. He earned a PhD in Operations Research from UC Berkeley in 1993.

David Rapson is a Professor in the Economics Department and co-director of the Davis Energy Economics Program (DEEP) at UC Davis. His research focuses on how firms and consumers make decisions about energy use and what that implies for optimal energy and environmental policy. He earned his PhD in Economics at Boston University in 2008, and his research appears in journals that include the American Economic Review, RAND, Science and Nature. He has advised California policy-makers and electric utility companies in various capacities over the last decade.

Conflict of interest statement

The authors declare that we have no relevant or material financial interests that relate to the research described in this proposal.

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