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Impact of public electric vehicle charging infrastructure

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ABSTRACT

This work uses market analysis and simulation to explore the potential of public charging infrastructure to spur US battery electric vehicle (BEV) sales, increase national electrified mileage, and lower greenhouse gas (GHG) emissions. By employing both scenario and parametric analysis for policy driven injection of public charging stations we find the following: (1) For large deployments of public chargers, DC fast chargers are more effective than level 2 chargers at increasing BEV sales, increasing electrified mileage, and lowering GHG emissions, even if only one DC fast charging station can be built for every ten level 2 charging stations. (2) A national initiative to build DC fast charging infrastructure will see diminishing returns on investment at approximately 30,000 stations. (3) Some infrastructure deployment costs can be defrayed by passing them back to electric vehicle consumers, but once those costs to the consumer reach the equivalent of approximately 12¢/kWh for all miles driven, almost all gains to BEV sales and GHG emissions reductions from infrastructure construction are lost.

1. Introduction

How many chargers is enough? Current research and media (Singer, 2016; Mooney, 2016; Davies, 2014; Read, 2013) suggest that the prevalence of charging stations is an important factor for consumers' acceptance of electric vehicles (EVs) and that there are currently not enough charging stations in the US to soothe the range concerns of the average car buyer.

Government, utilities, and industry have been hearing this call for more public charging and, spurred by the current market potential of electric vehicles and their potential positive impacts on greenhouse gas (GHG) emissions, have been building, and proposing to build, more public charging infrastructure. Between January 1, 2011 and December 31, 2013, the US Department of Energy built over 17,000 charging stations across the US through the EV Project and the ChargePoint America project (Francfort et al., 2015). Idaho National Laboratory used data from this network of chargers and participating electric vehicles to study electric vehicle use and charging. In July 2016, President Obama announced a new plan to help transition the nation to EVs. The President's plan involves promoting "electric vehicle adoption by increasing access to charging infrastructure", as well as investing in the vehicles and manufacturing (Office of the Press Secretary, 2016). States, cities, and utilities are investing as well. In particular, California is using infrastructure as one of many tools to meet an objective of 1.5 million zero-emission vehicles on the road by 2025: the California Public Utilities Commission approved Southern California Edison to begin a pilot project wherein the utility will support installation of 1500 EV charging stations (Southern California Edison, 2016); San Diego Gas & Electric is similarly approved to install 3500 chargers at 350 locations in its coverage region (SDG & E, 2016); and PG & E is working on an infrastructure deal (John, 2016). Within the greater Kansas City metropolitan area, Kansas City Power & Light built 1000 EV charging stations in advance of demand, creating a small "EV mecca" in Missouri and Kansas (Wernle, 2015; Shelton, 2015). Moreover, automakers are building charging stations as well, both as part of these aforementioned efforts and as part of their own marketing strategies (Sparks,

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2015; Boeriu, 2014; NissanNews.com, 2015).

Of course, the construction of all of this infrastructure leads naturally into the question of exactly what everyone is hoping to accomplish by constructing it. Ostensibly EV charging infrastructure will spur EV market growth, but by how much, and to the detriment of sales of which other vehicle types? And at what point is saturation reached? More important for government initiatives are the impacts on GHG emissions. Research indicates that EVs are cleaner than their conventional counterparts in most regions of the US, even including manufacturing emissions, and will continue to get cleaner as electric grids evolve (Nealer et al., 2015). However, the strength of the correlation between the installation of EV charging infrastructure and GHG emissions reductions, especially if other alternative energy vehicle technologies are displaced, deserves study. Next follows the question of cost. Many charging networks are not free, and utilities constructing infrastructure must eventually recoup losses (Berman, 2014; Shelton, 2015). If EV infrastructure must bring with it increases in electricity prices due to station construction costs or required improvements to the electricity grid in order to handle increased loads, how will EV sales respond? Under what combinations of infrastructure deployment and electricity prices will GHG emissions still improve? Last is the question of prioritization. If it becomes prudent to focus EV infrastructure construction efforts on a limited number of states rather than divide efforts nationally, might infrastructure have more impact in some states than others?

Previous works have analyzed the role of out-of-home vehicle charging in various ways. Typical analyses examine the local impacts of charging infrastructure (Andrews et al., 2013; Xi et al., 2013; Zhang et al., 2013; Pan et al., 2017), focusing on optimizing the number of trips that can be completed in a specific metro region assuming the trips are performed by BEVs of various ranges. González et al. (2014) additionally co-optimizes to reduce charging fees given time-of-use rates. While a range buffer is often added to the nominal BEV range to allow for driver range anxiety, the concept of consumer choice is absent from these analyses; drivers are assigned to BEVs, BEVs are assumed to be plugged in at charging locations when chargers are available (if charger congestion is considered in the analysis), and the analyses are designed to show the feasibility or infeasibility of EV ranges and charging power given the implemented networks. In all of the above analyses only level 1 and 2 public charging is considered, neglecting DC fast, and for all analyses save that presented in Pan et al. (2017), at home charging is assumed for all BEV owners. (Pan et al., 2017 considers the opposite extreme of no at-home charging for any vehicles.) A somewhat similar approach from Liu and Lin (2016) models charging availability as a percentage of public parking places installed with chargers that is translated into charging opportunity, defined as the probability that one PEV driver encounters a charger when parking the car. However, Liu and Lin (2016) go a significant step further; in addition to determining the feasibility and infeasibility of trips, this charging opportunity metric feeds into the MA3T consumer choice model for the national light duty vehicle stock (Liu and Lin, 2017). Sutherland (2016) takes a slightly different approach to weighing infrastructure value for a population; rather than creating local charging networks and declaring them feasible or infeasible, this study uses trip data to quantify the value of different levels of EV charging in terms of utility factors for different range EVs. For PHEVs the utility factor is measured as the percentage of miles driven on electricity. For BEVs, the utility factor is measured as the percentage of miles covered by the BEV, assuming that the driver will substitute the BEV with a conventional vehicle if the trip length exceeds the range of the vehicle plus the range enabled by out-of-home charging. This work is laudable in many ways, as it captures potential impact of charging for PHEVs and BEVs in homes with and without charging and potentially with substitute vehicles for BEVs for long trip days. However, it stops at utility factors, and does not extend to determining how those factors influence consumer purchasing and driving behavior as is done in the MA3T model.

In this work we seek to address the above questions concerning national scale implementation and impacts of EV charging through parametric analysis of the vehicle and fuel markets. We use the ParaChoice model, a market analysis simulation tool for the light duty vehicle (LDV) stock that is specifically designed for parametric analysis. The ParaChoice model simulates vehicle stock, sales, fuel use, and emissions from 2015 through 2050 given a wide variety of adjustable input parameters. In this analysis, we parametrically vary the number of level 2 or DC fast EV charging stations available to the consumer starting in 2017, simulating both national and state level policy-driven efforts to jumpstart infrastructure growth. We also parametrically vary the electricity prices in regions where EV infrastructure is constructed in order to test consumer tolerance to increases in electricity prices which may be necessary to support charging infrastructure initiatives. In a penalty model similar in spirit to the utility factors used in Sutherland (2016), EVs become more desirable to the consumer as their effective driving days and electrified mileage are enabled by public charging. However, reflecting the options available to consumers, BEVs and PHEVs must compete against conventional and other alternative powertrain vehicles on the market, and EVs are penalized for their high initial purchase price, time spent charging outside of the home, and other factors relevant to consumer choice.

A description of the ParaChoice model is given in Section 2, detailing the parameters varied and how those parameters might be expected to affect consumer choice and the simulation outcome. The model inputs for the specific scenarios and trade spaces explored in the analyses are outlined in Section 3. In Section 4.2, we analyze LDV sales by powertrain, mileage by fuel type, and fleet average GHG emissions per mile for four scenarios: (1) a baseline scenario, detailed results for which are presented in Section 4.1, (2) a scenario where 500,000 level 2 chargers are deployed nationally, (3) a scenario where 50,000 DC fast chargers are deployed nationally, and (4) a scenario where 50,000 DC fast chargers are deployed nationally and a 10¢/kWh electricity surcharge is imposed to offset the cost of the deployment. We broadly find that the level 2 charging infrastructure has limited impact on battery electric vehicle (BEV)[1] sales and GHG emissions, the more sparsely implemented DC fast charging infrastructure has the most impact on all metrics, and that the 10¢/kWh surcharge negates many of the BEV sales and GHG emissions gains from the DC charging

[1] In this work, we refer to pure battery electric vehicles with no gasohol engine as BEVs and plug-in hybrids as PHEVs. When referring to all vehicles with batteries, independent of the presence of a gasohol engine, we use the all inclusive, EV.