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If You Build It, Will They Come?: Does Increasing the Number of EV Chargers Increase the Number of EVs?

Stephanie A. Coates

University of Houston, 4302 University Dr., E. Cullen Bldg., Rm. 124AB, Houston, TX 77204-2040, sacoates@uh.edu

Summary

Electric vehicles (EVs - in this paper defined as pure battery electric vehicles and plug-in hybrid vehicles) are viewed as an essential part of the strategy to decrease our carbon footprint and lower our impact on climate change. Their adoption is increasing; however, significant barriers remain. Range anxiety is most often cited as a reason for EV's lack of penetration in the market. This paper examines whether increasing the number of EV charging outlets to mitigate this concern would have a positive effect on EV adoption. Panel data is used from 50 states plus the District of Columbia to analyze the market share of EV sales annually from 2011 to 2017. According to a fixed-effect statistical modeling technique, the number of outlets is not statistically significant suggesting that money and resources could be better spent on other incentives to encourage EV usage.

Keywords: electric vehicle (EV), electric vehicle supply equipment (EVSE), incentive, modeling, policy

1 Factors Affecting EV Adoption

Although most people consider widespread adoption of electric vehicles (EVs) to be a major factor necessary to reduce greenhouse emissions and sales are on the rise, substantial barriers to adoption still exist. As of June 2019, the total marketshare of EVs in the U.S. is slightly higher than 1.0% of automobile sales [1]. Personal barriers facing consumers include lack of knowledge, inability to afford the comparatively higher initial cost, range anxiety and low risk tolerance. Additional external factors include electricity prices, gas prices and urban density. Education, income and concern for the environment are individual factors positively correlated with EV adoption. [2, 3].

Range anxiety is often cited as the first concern of potential EV adopters [4,5,6]. Some research shows that the pervasiveness of charging infrastructure, which operationalizes the variable of range anxiety, is a correlate with increased EV usage. For example, Wold and Olness (2016) found that an increase of one charging point per 1,000 people increases the share of specifically battery electric cars by 3.05%. Sierzchula et al (2014) found that "adding a charging station (per 100,000 residents) had a greater impact on predicting EV market share than did increasing financial incentives by $1,000" [7, 8, 9, 10]. However, most of the research on EV adoption has been

done in Europe where there is a higher marketshare of EVs, so there is some question of whether this conclusion holds true for the U.S.

2 What's the Best Approach to Increase EV Marketshare in the U.S.?

Because of the benefit of lower transportation emissions, as well as in the interest of national security, the United States government supports and is preparing to embrace the growing EV sector. According to the U.S. Department of Energy (DOE) (2018), "the U.S. supports plug-in electric vehicles (PEVs) as one component of a suite of solutions for the challenge of providing affordable, clean, secure transportation. Unlike conventional vehicles, which are powered primarily by petroleum-based fuels, PEVs are powered at least in part by electricity, which is generated from domestic, diverse, and secure energy sources" [11]. Given the powerful reasons to support EV adoption, it would be wise to determine the most effective approach to increase the use of EVs. To increase the number of EVs on the road, is incentivizing the construction of new charging outlets a good way or would incentivizing the purchase of electric vehicles be better? There are some who are banking on the former. In 2016, Volkswagen was sued for knowingly installing emissions "defeat devices" in their diesel cars. The cars were able to pass emissions inspections, but when in use on the road, they emitted up to 40 times the allowable amount of pollution. Part of the settlement agreement involved setting aside money to install EV charging stations to increase the number of electric miles driven to make up for the damage to the environment those vehicles did [12].

3 Hypothesis and Empirical Model

To answer part of the above question, this paper looks at how the number of outlets within a state impacts the marketshare of electric vehicle sales within that state. The literature on EV adoption focuses primarily on countries other than the United States and mostly examines personal barriers to EV usage. Since money from the VW settlement will be spent on charging infrastructure in order to influence EV sales, it is important to find out if this is a viable policy solution. My hypothesis is that as the number of electric vehicle charging outlets increase, the marketshare of electric vehicles is positively correlated. To test this hypothesis, I use panel data from all 50 states examining the marketshare of annual sales of electric vehicles and the number of EV charging outlets, as reported by the Oak Ridge National Lab in their annual Transportation Energy Data report. The model is as follows:

$$\begin{aligned} ElectricVehicleMarketshareofSales_{ti} & \\ &= \beta_0 + \beta_1 ChargingOutlets_{ti} + \beta_2 GasPrices_{ti} + \beta_3 ElectricityPrices_{ti} \\ &+ \beta_4 FuelIncentives_{ti} + \beta_5 CostofEVBattery_t + \beta_6 CafeStandard_t + \\ &+ \beta_8 GDPperCapita_{ti} + \beta_9 PopulationDensity_{ti} + \varepsilon_t \end{aligned} \quad (1)$$

The time variable (t) is measured in yearly intervals from 2011 to 2018 (through August 2018). The classes (i) include each of the 50 states and the District of Columbia.

Table 1: Summary Statistics

VARIABLE NAME	Obs	Mean	Std Dev	Min	Max
Electric Vehicle Marketshare of Sales (%) Source: Alliance of Automobile Manufacturers (2018)	306	0.64	0.77	0.03	7
Charging Outlets for EVs (# per sq mi) Source: Oak Ridge National Laboratory (2018)	408	0.06	0.39	0	4.48
Gas Price ($ per gallon) Source: eia Weekly Retail Gasoline and Diesel Prices (2018)	408	3.03	0.57	2.02	3.91
Electricity Price ($ per kilowatt hour) Source: eia Electric Power Monthly (2018)	357	0.11	0.04	0.06	0.34
Fuel Incentives (#) Source: Oak Ridge National Laboratory (2018)	408	7.10	7.28	0	66
Battery Cost for EV ($) Source: Bloomberg New Energy Finance (2017)	408	448	214.20	190	800
Café Standard (# of mpg) Source: Environmental Protection Agency (2018)	408	27.18	1.77	24.40	29.60
GDP per Capita ($ per person) Source: Bureau of Economic Analysis (2018)	357	55,122.25	20,942.43	32,367.14	195,639
Population Density (# of people per sq mi) Source: U.S. Census (2018)	408	336.09	1,258.71	0	10,154.70

GasPrices is a continuous variable measured in dollars per gallon. ElectricityPrices is a continuous variable measured in dollars per kilowatt hour. FuelIncentives is the number of incentives regarding electric vehicles offered by each state. CostofEVBattery is the average cost to manufacture battery packs in the production of electric vehicles. CafeStandard is the federally mandated fuel economy standard for newly manufactured vehicles. GDPperCapita is the GDP of each state divided by its population. PopulationDensity is the state's population divided by square mileage.

I would expect ChargingOutlets, GasPrices, FuelIncentives, CafeStandard, GDPperCapita and PopulationDensity to be positively correlated with ElectricVehicleMarketshare. In other words, as each of these variables increase, marketshare should also increase. ElectricyPrices and CostofEVBattery should be negatively correlated with marketshare.

To analyze this panel data, pooled ordinary least squares (OLS) fixed-effect and random-effect techniques were used. The dataset consists of 306 panel data observations. Because the units of many of the variables differ, logarithms are taken (indicated with an "L" preceding the variable in Table 2). There are most likely some characteristics within each state that impact predictors of EV adoption, so I expect the fixed-effect model will be the most appropriate model and diagnostic tests suggest the same.

Table 2: Regression Models

	(1)	(2)	(3)
VARIABLES	Pooled OLS	Fixed-Effect	Random-Effect

LChargingOutlets	0.161***	-0.0220	0.0649
	(0.0281)	(0.0408)	(0.0335)
LGasPrice	1.006***	0.864***	0.890***
	(0.224)	(0.159)	(0.161)
LElectricityPrices	0.367***	-0.267	0.324*
	(0.0876)	(0.373)	(0.147)
FuelIncentives	0.0555***	0.0409***	0.0546***
	(0.00324)	(0.00781)	(0.00474)
LCostofEVBattery	-0.00826	-0.106	-0.0490
	(0.224)	(0.150)	(0.151)
CafeStandard	0.119	0.154*	0.129*
	(0.0923)	(0.0634)	(0.0639)
LGDPperCapita	0.314***	0.537	0.338*
	(0.0926)	(0.530)	(0.163)
LPopulationDensity	-0.231***	-0.471	-0.0982
	(0.0379)	(1.538)	(0.0504)
Constant	-4.788	-8.625	-6.174
	(4.036)	(8.751)	(3.269)
Observations	253	253	253
R-squared	0.756	0.436	
F-statistic	94.48	18.73	
p-value for F test	0	0	
Number of States		51	51
Wald chi-square statistic			324
p-value for Wald test			0

Standard errors in parentheses

*** p<0.001, ** p<0.01, * p<0.05

Hausman Test

b = consistent under Ho and Ha; obtained from xtreg

B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Ho = difference in coefficients not systematic

chi2(7) = (b-B)'[(V_b-V_B)^(-1)](b-B)
= 21.55

Prob>chi2 = 0.0030

Breusch and Pagan Lagrangian Multiplier Test for Random Effects

marketshare[statex,t] = Xb + u[statex] + e[statex,t]

Test: Var(u) = 0

chibar2(01) = 131.68

Prob > chibar2 = 0.0000

4 Results and Discussion

Interestingly, the variable for number of charging outlets per square mile is not significant. So even as states make efforts to improve their charging infrastructure, it does not seem to have a corresponding effect on increasing market share of electric vehicles in that state. Since most people with electric vehicles charge at home and most people commute a relatively short distance day-to-day, it could be the case that charging at home is enough for most people's needs and so more charging outlets does not inspire someone to purchase an electric vehicle. If this is true, it implies that in order to influence electric vehicle adoption, money may be better spent on more direct incentives to purchase the vehicles than on charging infrastructure. In fact, according to the fixed-effect model, the coefficient for the number of incentives a state offers is statistically significant and positively correlated with an increase in electric vehicle market share. Georgia is a state that might not come to mind as a leader in sustainability, but they have one of the highest market shares of EVs due to special incentives offered to electric vehicle drivers like access to premium parking and carpool lanes [13]. The fixed-effect model also shows that by encouraging auto makers to increase the miles per gallon of their cars, this has a positive effect on electric vehicle adoption. Finally, gas prices also have a statistically significant effect on electric vehicle market share. As gas prices increase, market share of electric vehicles increases by 0.86%.

5 Conclusion

I would conclude from this regression analysis that cost is still the most relevant factor influencing consumer demand for electric vehicles and range anxiety may not actually be as much of a concern, holding all other factors constant. This has some practical policy implications. In order to more quickly influence the adoption of electric vehicles, a necessity to limit effects from transportation on climate change, it may be better to offer incentives now to make electric vehicles more cost competitive with internal combustion vehicles. As there are more electric vehicles on the road, there will be more of a financial incentive for firms to install charging stations. More research could be done on metropolitan areas, where more electric vehicles are likely to be purchased, to see if this conclusion holds true. Research could be improved by coding and differentiating the types of incentives to see which type of incentive works best. It would also be ideal to identify instrumental variables to rule out the possibility of endogeneity bias.

In sum, according to the fixed-effect model, charging infrastructure seems to have less of an effect on electric vehicle adoption at this stage of the technology adaptation. It seems to be the case that the early adopters are likely to buy an electric vehicle regardless of the density of charging infrastructure and incentives to lower price may be a better way to encourage the early majority of adopters.

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Authors

Stephanie A. Coates is the department business administrator for UH Energy, an umbrella for efforts across the University of Houston system to position the university as a strategic partner to the energy industry by producing trained workforce, strategic and technical leadership, research and development for needed innovations and new technologies. She also works with Evolve Houston, an organization promoting the electrification of transporation in Greater Houston, of which UH is a founding member. Stephanie is pursuing dual master's degrees in Social Work and Public Policy focusing on environmental justice and policy, with an expected graduation date of December 2020.