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# How can California Best Promote Electric Vehicle Adoption? The Effect of Public Charging Station Availability on EV Adoption

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The Effect of Public Charging Station Availability on Electric Vehicle Adoption

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**Abstract**

To promote higher air quality and reduce greenhouse gas emissions, the Californian government is investing heavily in developing public charging infrastructure to meet its electric vehicle adoption goal of five million zero-emission vehicles on the road by 2030. This thesis investigates the effect of public charging infrastructure availability on electric vehicle adoption at the zip code level in California. The analysis considers other factors that may influence electric vehicle adoption such as education level, income, commute time, gas prices, and public transportation rate. The findings suggest that public charging infrastructure availability does significantly positively correlate with electric vehicle registrations. Linear regressions were run using data from the U.S Department of Energy Alternative Fuels Data Center, IHS Markit vehicle registration data, and the US Census Bureau. The findings support continued investment in public charging infrastructure as a means of promoting electric vehicle adoption.

**Introduction**

The Intergovernmental Panel on Climate Change(IPCC)'s fifth assessment report asserts with high confidence that human activities have caused approximately 1.0 degrees C of global warming above pre-industrial levels. At the current rate, the planet is expected to hit 1.5 degrees C between 2030 and 2052 (IPCC). Various outcomes such as sea level rise and increased intensity of storms and droughts will be exacerbated as the planet reaches the 1.5-degree C warming mark. The EPA asserts that approximately 28% of the U.S. Greenhouse Gas emissions are released by the transportation industry (EPA 2016). Ninety percent of the fuel used for transportation is petroleum-based (EPA 2016). The majority of the emissions associated with the transportation industry come from light-duty vehicles (EPA 2016). Sixty percent of the emissions are released from light-duty vehicles, 23% are released from medium- and heavy-duty trucks, and the airline industry accounts for nine percent of all releases (EPA 2016). When purchasing a light-duty vehicle, consumers have a menu of fuel types to choose from such as diesel, gasoline, hybrid, plug-in hybrid, and battery electric. Other than the various inputs required to build and maintain the car and the backend burning of fuel for the utility to produce electricity, electric vehicles produce no "tail pipe" emissions and are considered to be the more environmentally friendly automobile option in the marketplace (U.S. Department of Energy).

The state and federal government recognize that hybrid, plug-in hybrid, and battery electric vehicles emit far less greenhouse gases than other types of light duty vehicles, and therefore take action to promote their adoption to meet state and national emission reduction goals. In September 2018, Governor of California Jerry Brown signed a state goal of reaching

100 percent clean energy by 2045 which would require that every car in California be battery electric by 2040 (Zalubowski 2018). A shorter-term goal to meet the clean energy goal is reaching five million zero-emission vehicles on the road by 2030 (Zalubowski 2018). To meet these ambitious goals, Gov. Brown required that all auto manufacturers selling in the state must offer a zero emissions vehicle, and rolled out a $2.5 billion plan that includes increasing rebates and charging station availability (Zalubowski 2018). In 2017, Governor Brown signed AB 1082, which prioritizes the placement of electric vehicle charging stations in school facilities, general educational facilities, and school facilities in disadvantaged communities. In the same year, Governor Brown also signed AB 630, which provides incentives for people to replace existing high emitting cars with cleaner electric vehicles. The cash incentive would be $1,500 to $2,500 for low-income motor vehicle owners and no more than $1000 for all others. To meet the electric vehicle goals, the California Public Utilities commission approved the spending of $768 million on charging infrastructure for electric vehicles (CPUC 2018). Eighty percent of this spending, so roughly $600 million would be spent on development of public charging infrastructure. From 2010 to 2017, the state of California has spent over $449 million on rebates to promote electric vehicle adoption (Mitchell 2017). In 2017, AB 1184, which allocated nearly $3 billion towards rebates for electric vehicles, did not pass the state legislature (Mitchell 2017). The state of California has consistently used public funds to incentivize electric vehicles by installing public charging infrastructure and providing rebates to EV consumers. Which is more effective at convincing a consumer to go electric? To what extent does public charging infrastructure incentivize electric vehicle adoption given that Nissan Leaf and Chevy Volt drivers in the US charge their vehicles either at work or at home 96% of the time (Menser 2014)?

Understanding the extent to which public charging infrastructure availability influences electric vehicle adoption can help optimize the allocation of public funds. Ultimately, I hypothesize charging station availability will positively correlate with electric vehicle adoption because it will help to reduce range anxiety, the fear of not finding a place to charge when one's battery is low, experienced by EV drivers.

**Literature Review**

The options in today's automotive marketplace are overwhelming for the average consumer. Consumers must decide what make and model satisfies their wide array of desires—size, performance, safety, budget friendliness, mileage rating, environmental impact, aesthetic, color, etc. While trying to cater to as many of these desires as possible, the consumer must also decide what fuel type—whether gasoline-powered, hybrid, plug-in hybrid, or fully electric. When deliberating the purchase of an electric vehicle, consumers must juggle many considerations. In a 2016 consumer preference survey-based study, Zhang presents these considerations as three distinct perceptions related to the economic impact on the consumer, the environmental impact, and the risks associated with the EV purchase (Zhang 2016). Risk factors included the long charging time, short battery life, and the power loss of all electric vehicles over time. Since electric vehicles are still an emerging market, the long-term durability of the product, specifically related to the battery pack, is yet to be proven (Zhang 2016). The negatives aside, the primary benefit is the environmental perceptions of EV adoption that include the zero tailpipe emissions which would lead to cleaner city air quality, an EV purchase would be supporting the shift to cleaner transport to combat climate change, and in certain "greener" areas, social capital would be gained from the purchase (Zhang 2016). The economic perceptions include the subsidies associated with the purchase, and whether cheaper fueling prices would result in long-term payoff that would support claims of electric being cheaper than gas-powered vehicles in the long run (Palmer et al., 2017). Lastly, Zhang notes that to sustain EV adoption rates as governments phase out financial incentives for electric vehicles, the perceived environmental outcomes and risks associated with the purchase must be strengthened with improved effective marketing and technological advancement. Having a better understanding about what consumers are considering when purchasing a car and what the average consumer's current perception of electric cars is important for businesses and the public sector to tailor their strategies to boost EV adoption. In this literature review, I hope to explain the various underlying factors that shape a consumer's perception of an electric vehicle as a viable purchase option. Understanding the psychology of a car buyer can help inform strategies used by state governments, federal governments, and auto manufacturers to increase EV adoption to secure a greener future.

**Charging Station Availability**

The first factor I investigate is public charging station availability. I hypothesize that an increase in public charging stations will result in increased vehicle adoption because more charging stations reduce the risks associated with driving an electric vehicle. In a survey of a random sample of car buyers, EV battery range limitation was the most frequently noted perceived risk of purchasing an EV (Egbue 2012). More available public charging stations would reduce the likelihood of completely losing charge on the way to one's destination. In a study that examined electric vehicle adoption across 30 countries, Sierzula et al., 2012 regresses EV market share with the following explanatory variables: presence of incentive programs, environmental regulation index, fuel price, per capita income, the number of vehicles in a country per capita, household electricity prices, the year EVs were first sold in the country, the average electric vehicle price, and the number of charging stations corrected for population (Sierzula 2014). Out of all of these explanatory variables, charging infrastructure was most strongly correlated with a country's electric vehicle market share (Sierzula 2014). A 2018 study conducted at the state level suggests that the density of charging infrastructure significantly influences EV and Plug-in Hybrid Electric Vehicle (PHEV) purchase decisions (Narassimhan 2018). Narassimhan uses additional vehicle registrations as a proxy for vehicle purchases. For his independent variables, Narassimhan uses estimated averages at the state-level that can abstract more granular effects. His use of additional vehicle registrations as the dependent variable does not capture time delays in adoption. Consider this example—additional charging stations are installed in the vicinity of a consumer. Since the risks associated with purchasing an EV is reduced, the consumer decides to order an electric vehicle. Because of supply constraints and delivery time, the customer may not receive the vehicle to register until a few months to a year after the order was placed because of the installation of charging stations. This would result in an underestimate of the effect of charging stations on electric vehicle adoption in Narassimhan's model. Additionally, the use of state-level averages is problematic given that charging stations are very concentrated in certain geographical areas.

Not all charging stations are equal, and therefore the availability of each different type of charging station would influence the consumer's purchase decision differently. There are three different types of charging stations—level 1 chargers, level 2 chargers, and DC fast chargers (Lutsey 2016). These chargers can vary between public and private use. Level 1 chargers are those that plug into standard house outlets. Level 1 chargers will take roughly 18 hours for a full charge or roughly 9 hours for 40 miles of driving (Plug-in America, 2018). The next fastest charging option is Level 2, which provides roughly 70 miles of range per one hour of charging. Level 2 chargers are commonly installed at the household level for approximately $2000, or at the office or public facility level for approximately $10,000. Direct current (DC) fast chargers are the fastest type of charging available on the market, and are generally installed for public use (Plug-in America). DC fast charging stations provide 40 miles of range for every 10 minutes of charging (Plug-in America). While these charging stations are efficient, they are also very expensive. DC fast charging stations can cost up to $100,000 and require more power than the average American household (Plug-in America). Running different regression equations to discern the different effects of the various charging stations is important to recommend the optimal strategy for allocating limited public funds towards EV infrastructure development.

The 2018 State of the Charge Report by the Electric Vehicle Charging Association asserts that the EV charger market will increase at a rate of 50 percent per year until 2025. The industry is set to be valued at $45 billion in revenue by 2025. This growth is expected to drive down costs. As of 2018, there are approximately 57,000 public and private charging stations available in the nation. The State of the Charge Report also highlights several EV charging “innovators” that have a unique approach to electric vehicle charging. Volta, a company based in San Francisco, has developed an innovative charging model. Volta strategically places their charging stations in highly visible, heavily trafficked areas such as shopping centers and entertainment zones. The user of the charging station does not pay a dime for the hardware, installation, electricity, or maintenance cost because Volta partners with prominent national brands that use the space for marketing. EVgo is the largest provider of public DC fast charging and markets itself as providing charging that is eight times as fast as other charging stations. EVgo was also the company to help complete California's DRIVEtheARC, a corridor of fast charging stations that runs from Monterey to Lake Tahoe. The company EV Connect develops hardware agnostic cloud-based software that helps manage the charging stations. This software is in charge of running demand response, pricing, and interfacing with the EV itself. ChargePoint is widely considered to be the leader in the EV charging station market. ChargePoint has over 40,000 charging spots, manufacturers their own charging stations, allows other hardware to run on their network, develops its own cloud software and support. In 2017, ChargePoint started a line of DC fast charging stations and one year later it acquired GE's entire EV charging network. The Volkswagen emissions scandal was beneficial for the electric car industry. As part of their settlement with the federal government, Volkswagen agreed to invest $2 billion over the next 10 years in U.S. electric car infrastructure (Bomey 2018). CEO Mark McNabb of the Volkswagen funded Electrify America program notes that the first round investment of $500 million over 30 months will focus on installations in 17 metro areas, 6 of which are located in California (Bomey 2018). McNabb also asserts that it is important for electric vehicle charging stations to be "future-proofed" so that they can be upgraded as battery technology improves (Bomey 2018). Many electric auto manufacturers are upping their investment in public charging infrastructure—Tesla is tripling its fleet of fast chargers by the end of 2018.

Since the Electric Vehicle Charging Station market is growing at a fast rate, many different players want to get involved. Utilities, oil companies, and technology developers all want a piece of the EV charging station market. Currently, Green Tech Media Research predicts that there will be 1 million charging stations globally in 2020 that are available for public use and 5 million available for private use (Deign 2018). The public utilities commission pays a significant role in promoting EV charging station availability. As of August 2018, the three IOUs, PG&E, SCE, SDG&E, have set goals of installing 12,500 charging stations for multifamily, workplace, and public-use with a budget of $197 million (PUC 2018). The IOUs have also set targets of installing over 10% of these charging stations in disadvantaged communities (PUC 2018). Southern California Edison has developed a rate plan for EV chargers that takes into account time-of-use. Consumption in the late afternoon and evening is the highest, and the price ranges from 18 cents to 37 cents per kilowatt hour (Edmunds 2018). The rates of electricity for electric vehicle are less than that for the home and its other appliances. The cost for 50 miles of range can range from $1.50 to $6.30 depending on the hours that the car was charging for (Edmunds 2018). Ultimately, the Public Utilities Commission plays an integral role in helping the state meet their Electric Vehicle and transportation emissions reduction targets by promoting the adoption of EVs through infrastructure development. The effect of public charging station availability on electric vehicle adoption may be undermined by the fact that most people charge their electric vehicle at home or at the workplace—locations where one would park their car normally. Given that private, residential charging is more convenient and inexpensive than public charging, approximately 80% of EV drivers charge their vehicles at home (U.S Department of Energy).

**Environmental Consumerism**

I suspect that populations who are more environmentally conscious will want to purchase an EV. A cradle-to-grave life cycle assessment of a standard electric vehicle suggests that EVs have the potential to decrease GHG emissions compared to conventional vehicles and that highest environmental burden associated with EVs is the battery's toxicity (Tagliaferri 2016). While hybrid vehicles and electric vehicles are not perfect substitutes, the literature on environmentalism influencing hybrid and alternative fuel vehicle adoption is relevant since hybrid and EVs are environmentally friendlier options than conventional gas-powered vehicles (Tagliaferri 2016). In a 2007 paper investigating the effect of community environmentalism on hybrid vehicle adoption, Mathew Kahn asserts that a community's hybrid adoption is positively correlated with the level of the community's environmentalism (Kahn 2007). In this study, Kahn uses a community's share of Green Party registered voters as a proxy for community environmentalism. He defends this proxy by noting the correlation between concentration of green party registered voters and likelihood of voting for California's environmental-focused propositions. Lastly, Khan's findings suggest that community environmentalism not only effects EV adoption, but also public transportation adoption. Kahn uses 2000 census data to determine the proportion of Green Party registered voters, 2001 National Household Transportation Survey data to study California household driving patterns, and a count of registered green vehicles in Los Angeles in 2005 from a census tract to use as the key independent variable. Another study by Jansson et al. builds on Kahn's work. Jansson investigates the "neighborhood effect" that influences people to purchase alternative fuel vehicles. Jansson hypothesizes that neighbors, family, and coworkers all influence alternative fuel vehicle adoption because of the social pressure placed on a consumer by those around her. This study includes all alternative fuel vehicles including electric, hydrogen, and biofuels. Jansson uses a logistic regression to understand the relationship between alternative fuel vehicle ownership and the independent variables being neighbor domain, family domain, and coworker domain. Ultimately, neighbor domain seemed to have the largest influence on alternative fuel vehicle adoption compared to family and coworker pressures (Jansson 2017). This study has its limitations—other than controlling for green party voting, there is no way to rule-out that people have self-selected into the neighborhood domain which suggests that similar people choose neighborhoods with similar attributes and would therefore buy similar cars. Ultimately, it is unclear whether neighbors influence one another to purchase an EV, or there are unobserved attributes that correlate with neighbors. Including a metric of community environmentalism at the zip code level for California in my model will help contribute build upon Kahn and Jansson's work regarding environmentalism and social influence on consumer purchase decisions.

**Financial Burden of EV Adoption**

When deciding to purchase a new vehicle, consumers must consider the costs associated with the various car options. Both Federal and State governments still offer subsidies for EVs and PEVs because most alternative fuel vehicles are still not cost competitive with conventional gas-powered vehicles. A study that analyzed the 5-year ownership costs for conventional, hybrid, and electric vehicles across 14 U.S cities asserts that even in optimistic scenarios where the price of electricity falls, it is not feasible for electric vehicles to be cost competitive without subsidies (Breetz 2018). This study looked specifically at the ownership cost differences between the Nissan Leaf, Toyota Prius, and the Toyota Corolla. Ultimately, Breetz's study suggests that subsidies will continue to be necessary to keep EVs cost competitive for the foreseeable future, unless there is a technological breakthrough that reduces the cost of the battery. Despite this assertion, it must be noted that the study only conducted a five year cost ownership, and most people own their car for 6 years and the average life-span of a car is 11 years (Autotrader) (Demuro 2015). This suggests that there may be unknown long-term cost benefits associated with adoption depending on the durability and average lifespan of electric cars. (Palmer et al., 2017) compared the cost of ownership of conventional, hybrid, plug-in hybrid, and battery electric vehicles in the UK, USA (California and Texas), and Japan. The results suggested that the total cost of ownership was the least for battery electric vehicles across all three observed markets (Palmer et al., 2017). Additionally, the average maintenance cost for electric vehicles was much cheaper (Palmer et al., 2017). This is likely because there is less wear on the brakes and fewer moving parts. (Palmer et al., 2017) did take into consideration the myriad subsidies and financial incentives offered by governments.

The federal government incentivizes EV purchases via a $7500 tax credit given to consumers buying EVs from specific auto manufacturers (Breetz 2018). After the auto manufacturer sells 200,000 BEVs, this tax credit is phased out. The federal tax credit will begin to be phased out for Tesla Motors at the end of 2018—the tax credit will be reduced to $3750 for six months, and then reduced to $1875 for the following six months (Tesla 2018). This tax credit system was likely implemented to promote different car manufacturers' development of EV manufacturing to maintain a competitive marketplace. California offers a $2,500 rebate based on income eligibility after the purchase of an EV (Tesla 2018). To combat criticism that the rebate is a regressive subsidy that disproportionately benefits higher-income populations who can already afford to purchase an EV, the rebate is only provided to single filers whose income is under $150,000, head-of-households earning under $204,000, or joint filers under $300,000 (DMV 2018). Additionally, there are zip codes, such as Atherton, California, where there would likely be a high concentration of electric vehicles given that it is located in the heart of Silicon Valley, but likely no one living in this zip code would qualify for the rebate because Atherton is the most expensive zip code in California (Investopedia 2018). Therefore, the income of a given zip code affects the relevance of the state rebate. In my model, I will include income by zip code and percentage of people in each income bracket. In a study that reviewed the latest figures of the tax credits for electric car purchases, (Winegarden 2018) found that 79% of the credits were claimed by households with annual incomes greater than $100,000 per year, and households with making more than $50,000 per year claimed 99% of the tax credits (Winegarden 2018). The average annual income of an automotive buyer in the U.S. is $90,615 (Zip Recruiter 2018). I am interested to know the effect that income has on electric vehicle adoption because higher income zip codes are more likely to be able to afford EVs, but the lower income zip codes are more eligible for the state rebate. I hypothesize that higher income will positively correlate with EV adoption, because the EV market is still in its infancy and higher income consumers are more likely to be early adopters (Pew Research Center 2014).

Investor Owned Utilities also offer rebates for drivers of plug-in electric vehicles. PG&E offers a $500 Clean Fuel Rebate that the utility asserts is equivalent to nearly one year's worth of electricity to fuel an electric vehicle (PG&E 2018). San Diego Gas & Electric offers an Electric Vehicle Climate Credit worth $50-$200 depending on the number of applicants in a given year (SDGE 2018). Southern California Edison provides a $450 Clean Fuel Rebate to drivers of new or used electric vehicles (SCE 2018). Smart meters help consumers decide when to charge their electric vehicle by noting when it is off-peak demand and what the price of the electricity is at a given time based on demand. Utilities could promote the adoption of electric vehicles by investing in smart meter infrastructure that helps ease the financial burden of charging an electric vehicle (Holbrook 2018). In a survey conducted by businessgreen.com of UK residents, one third of respondents noted that they would be more interested in purchasing an electric vehicle if they had a smart meter, and one third of drivers noted that they would be more likely to purchase an electric vehicle if when plugged-in at home, the EV would charge automatically when energy is cheapest (Holbrook 2018).

**HOV Lane Access**

In addition to a rebate, California offers HOV lane access to all electric vehicles and plug-in hybrids (DMV 2018). (Nicholas 2014) conducted a survey of plug-in vehicle buyers—57 percent of Plug-In Prius, 34 percent of Chevy Volts, and 38 percent of Nissan Leaf drivers identified HOV lane access as the primary motivator of purchasing their plug-in vehicle. Since the electric vehicle policy in California applies uniformly across the state, I will assume that all zip codes are affected equally by the policy. This assumption is not completely valid given that there are some zip-codes in very low trafficked areas that would not benefit at all from the HOV lane access incentive. The HOV lane access incentive would benefit EV drivers in larger metropolitan areas with more traffic disproportionately more than those living in less metropolitan areas with less traffic. (Nicholas 2014) notes that the distance one travels in a day has a significant effect on whether the HOV lane access is a primary influencer of adoption—Volt driver that did not select HOV lane access as a primary motivator tended to drive 10 fewer miles per day than those who did select HOV lane access as a primary motivator. HOV lane access offers an explanation as to why electric vehicle adoption tends to be higher in metropolitan areas. The importance of the HOV lane incentive is strongly correlated with HOV usage—80% of buyers who selected HOV lane access as the most important influencer of EV adoption used HOV lanes during their daily commutes (Nicholas 2014). While no explanatory theory was presented, the model of the car has a significant impact on finding the HOV lane access sticker motivating—Nissan Leaf drivers found the HOV sticker far less incentivizing than Volt and Prius drivers (Nicholas 2014). Another study examines the impact of HOV lane access on EV registrations at the census tract level in California controlling for HOV lane density (Sheldon 2016). Sheldon further asserts that with a 95 percent confidence interval, roughly one quarter of California PEV registrations during 2010-2013 were a result of the HOV lane sticker offering.

**Demographics (i.e. income, education level, etc.)**

There are many other general demographic effects that would have an effect on electric vehicle adoption. Specifically, an individual's level of education would have an effect on electric vehicle adoption. Intuitively, the more educated an individual, the more likely they are to understand the possible long-term cost benefits of purchasing an EV, appreciate the environmental benefits of purchasing an EV, and live in communities that would ascribe social capital to those driving an EV. Despite this intuition, a 2012 study analyzing 30 countries found that charging station availability and presence of financial incentives, not education level or income, had a significant effect on electric vehicle adoption (Sierzchula et al. 2012). Despite these findings, a consumer survey found that there was a significant relationship between education level and general interest in alternative fuel vehicles (Egbue 2012). I intend to investigate this relationship by including metrics that capture income and education level at the zip code level in California. Ultimately, if these factors were to significantly influence the adoption of EV, public funds could be redirected towards education to secure long-term sustained adoption of EVs.

**Fuel Prices**

The price of electricity and the price of conventional gasoline will play a role in a consumer's decision to purchase an electric vehicle. In a 2012 study that used weighted average national gasoline and diesel fuel prices across 30 countries, the effect of gasoline and diesel prices on electric vehicle market share was insignificant (Sierzchula et al. 2012). The effect of electricity prices was also insignificant. In a 2008 cross sectional study that tested the relationship between gasoline prices and presence of incentive policies across all 50 states, gas prices had a significant effect on hybrid-electric market share at the one percent level (Diamond 2008). This relationship continued to have a statistical effect when the regression was narrowed to focus on adoption of Honda Civic hybrids and Ford Escape hybrids (Diamond 2008). Ultimately, Diamond's study looked at the effect of vehicle miles travelled per capita, combined value of all federal and statewide tax incentives and rebates, dummy variable for presence of HOV lane access, and state per capita income all of which had a less significant effect on hybrid adoption than gasoline prices (Diamond 2008). The literature suggests that high fuel prices force consumers to consider purchasing alternative fuel vehicles. Most of the literature on the effect of fuel prices on HEV and EV adoption has been conducted at the state-level or country-level. This makes sense considering that fuel prices would vary to a greater degree at the state or country level and therefore the effect on electric vehicle adoption may be more pronounced. A 2012 time-series study investigating the impact of federal incentives on the adoption of hybrid electric vehicles and adoption of ICEs used fuel prices as a control variable (Jenn et al., 2013). Interestingly, Jenn found that gas prices had no significant effect on ICE consumption, but an increase in gas prices did result in a significant increase of the hybrid vehicles purchased in the subsequent months (Jenn et al., 2013). I found no literature investigating the relationship between fuel prices and electric vehicle adoption at scale smaller than the state-level. Realistically, consumers would attempt to predict gas prices in the future, and use these expectations when making their vehicle fuel-type consumption decision. I found no research that investigated the effect of expectations of gas prices on electric vehicle adoption.

**Existing Commuting Behavior**

The existing commuting behavior of a given population would influence adoption of electric vehicles. The first aspect of commuting behavior I will examine is commuting distance. Intuitively, consumers who have longer commutes are more prone to experiencing range anxiety and would therefore be averse to purchasing an electric vehicle. Additionally, that those with longer commutes, in the case of a low fuel scenario, would be less willing to spend time waiting for their car to charge at a public charging station because most charging stations take longer to charge than the average fuel-up at a gas station. This desire for flexibility suggests that consumers that would fit the profile for purchasing an electric vehicle, but are prone to range anxiety, will choose the plug-in hybrid alternative. Ultimately, consumers value their time and certainty that they will reach their destination efficiently. The median range on an electric vehicle in 2017 was 114 miles (US Department of Energy, Electrek). In the United States, the average distance traveled to and from work in a given workday is approximately 32 miles (Harris). Interestingly, the average commute time to work among California zip codes is 28 minutes (US Census, 2016). Therefore, range anxiety should not be an issue if the average driver is routinely plugging in their car at the end of the work day. There still may be a psychological effect at play that is driving consumers with longer commutes away from purchasing an electric vehicle. A 2015 study examines the psychological effect of range anxiety. To better understand range anxiety that EV drivers experience, (Rauh 2015) compared the range anxiety of 12 experienced EV drivers and 12 first time EV drivers and noted that the range anxiety was dramatically reduced amongst the experienced drivers. As commuting and recharging habits form over time, people become more comfortable with driving longer distances knowing where go-to charging stations are and remembering to plug-in their car at the end of the work day. (Rauh 2015) calls for more research that would employ eye-tracking technology to see where drivers are glancing on their displays—those with more range anxiety would likely glance more towards their battery charge display. People who live and drive in colder climates suffer from added range anxiety because EVs do have lower ranges in cold weather (Marx 2017). Those who live in areas with a longer, colder winter would be less likely to adopt an electric vehicle. Norway serves as an excellent example of a country where the winter is long and cold, yet electric vehicles are working well to meet the transportation needs of the public. Ultimately, the presence of range anxiety amongst inexperienced drivers and the lack thereof amongst experienced driver suggests that the range anxiety and fear that prospective EV consumers are thinking about are not necessarily rational. A longer commute would likely exacerbate this range anxiety and dissuade EV adoption. I found no literature that examines the relationship between commuting distance and electric vehicle adoption. Therefore, I believe that my analysis would contribute significantly to literature on effects that influence EV adoption.

The second commuting behavior I would like to examine is public transportation availability. Intuitively, areas with good public transportation would likely see less EV adoption because those who would consider purchasing an electric vehicle for environmental reasons would likely choose the least environmentally damaging option of taking public transportation. The relationship between public transport availability and electric vehicle adoption would likely be obscured since wealth is concentrated in metropolitan areas with good public transportation, and higher income people are more likely to be able to afford EVs (Winegarden 2018).

(Langbroek et al., 2018) reviewed how people's travel patterns change after adopting an electric vehicle. The study analyzed travel diary entries of Stockholm EV drivers to discern the ways in which drivers adjusted for the shorter ranges associated with electric vehicles. People can adjust their trips to compensate for limited range by driving slower, rescheduling trips to fit in charging times, or cancelling or changing the destination of the trips. The study found that in 71 percent of cases, respondents did not change any part of their travel patterns. For the remaining 29%, mixed effects were observed—some of the participants experienced range anxiety and cancelled their trips while others with adequate range started taking additional trips choosing to use their electric vehicle over other forms of transportation such as public transportation. Trip cancellation was correlated with the purpose of the trip. For example, trips meant for non-mandatory purposes such as shopping were frequently cancelled.

**The rise of residential solar**

Growing concerns over the impact of climate change, declining cost of solar photovoltaic technology, favorable subsidies by utilities, and improvements in storage technology have fueled the growth of solar and the transition to renewable energy. As storage improves and utilities transition away from strong subsidies offered to residential solar customers via the net energy-metering program, more residential customers will be incentivized to purchase storage and shift away from the utility-owned grid. Incentives for solar energy expansion include not only environmental benefits, but also economic benefits from many existing policies and subsidies. Net energy metering, the process by which residential and commercial solar energy producers can sell excess energy produced from their solar arrays back to the grid at the retail rate, is the most notable subsidy. While other financial incentives exist for renewable energy, such as federal tax credits and Renewable Energy Credits (RECs), net metering is more financially attractive and has been the primary driver of residential solar growth in the U.S. Utilities commonly place “caps,” defined as the limit of the amount of renewable energy as a percentage of total energy demanded, on the existing net metering program. Once the cap is reached, utilities reevaluate the program. Utilities in California placed caps for their first net energy-metering program (NEM) at 5% of the total energy demanded (Matasci 2017). Unfortunately, as the popularity of residential and commercial rooftop solar increases, the burden on utilities to purchase excess solar energy at the retail rate is becoming burdensome and many view the act of net metering as an unnecessary subsidy. California has recently made the transition from their net metering policy from Net Energy Metering (NEM) to NEM 2.0 as many utilities in the state are starting to reach their 5 percent cap. The three main investor-owned utilities in the state—Southern California Edison, San Diego Gas and Electric, and Pacific Gas and Electric--agreed to cap their net metering programs at 5 percent of the total peak electricity demand. Once this cap is reached, NEM 2.0 will begin (Matasci 2017). PG&E and SDG&E have both already hit their 5 percent cap and SCE is expected to reach its cap by the summer of 2017 (Matasci 2017). Under NEM 2.0, homeowners will still be able to receive per kWh credits for their solar electricity that are equal to the value of a kWh of utility electricity, but solar homeowners are subject to new fees to compensate for the net metering price remaining at the retail rate (Matasci 2017). These fees include time-of-use rates and interconnection fees. Ultimately, NEM 2.0 is still a financially attractive package to install rooftop photovoltaics in California. While only slightly less economically beneficial for residential solar homeowners, the transition represents the shift away from traditional net-metering at the retail rate as more people view net metering as an overvalued subsidy.

The transition from traditional retail rate net metering contributes to a rapidly growing storage market. In 2015, a record 211 megawatts of storage capacity were installed in the United States, more than three times as much as in 2014 (65 megawatts installed) (D'Aprile 2017). McKinsey & Company also estimates that from 2015 to 2020 the market will increase six times and reach a size of $2.5 billion, reaching an estimated 1,000 gigawatts in the next 20 years (D'Aprile 2017). The cost of storage is decreasing dramatically as well. By 2020, storage is estimated to drop to $200 per kilowatt-hour, down from $400 in 2016 (D'Aprile 2017). Demand charges and time-of-use rates will contribute the growth of storage for solar customers. Demand charges are based on a customer's peak consumption where he or she is billed for the highest average fifteen-minute flow of electricity during the billing period (D'Aprile 2017). Using storage can reduce this charge because households can switch to drawing energy from the battery during peak load hours to reduce the value of the peak. As technology progresses, batteries and electric vehicle charging will become more integrated to work with utility policy and respond to changing rates. Some batteries have automatic demand response where the battery charges the house according to electricity rates to optimize whether the energy should be drawn from the grid or battery. Electric vehicles will benefit from the micro grid environment because the cost of charging EVs will decrease if the consumer can charge from energy stored in battery during peak hours when utility rates are higher.

More households are creating "mircogrid" environments, where the solar panels charge a battery pack that can power the home's appliances and an electric vehicle. This ensures that the electricity powering the electric vehicle is coming from a renewable fuel source and allows the resident to be less reliant on the grid. While people have attempted to create these solar powered microgrids, a grid connection is still necessary to ensure reliable electricity. (Chowdhury et al., 2018) asserts that approximately 20% of the energy produced from a residential solar home is needed for the charging of an EV. More research is being conducted to figure out how to use the electric vehicle as a battery source to power the house when the sun is not shining and the battery packs inside the building have run out (Torres-Moreno et al., 2018). Needing to take electricity from the grid would be a worse-case-scenario for those who have invested in a microgrid. As battery technology improves, and residential solar becomes cheaper and more efficient, the feasibility of small microgrids will increase. Will the prevalence of rising residential solar with battery storage promote electric vehicle adoption? I hypothesize that households with solar microgrids would positively correlate with electric vehicle adoption given that those consumers are driven to consume goods for environmental reasons, be of a higher-income bracket, and likely be early adopters of new technologies in general. The rise of rooftop solar also likely contributes to the network effects that would promote electric vehicle adoption. As consumers notice that their community is starting to value clean energy and sustainable practices, they may be more likely to adopt more sustainable practices such as choosing an EV over a gas-powered vehicle. Additionally, electric vehicle drivers with home solar may be able to save money by charging from energy stored in their household battery during peak hours when utilities charge higher rates (Zientara 2016). While the rise of residential solar may influence EV adoption, I will not include a dependent variable in my model that controls for this effect.

**Norway: Success story of electric vehicle adoption**

Norway is a prime example of a country where electric vehicles are popular and adoption rates are high. Norway's electric vehicle successes are often written off because of the small market size. By understanding what the Norwegian government is doing to promote EV adoption and the socioeconomic factors at play that dictate consumer’s perception of electric vehicles, we can identify what influencers of adoption can translate to the US and Californian markets. In the month of September 2018, 10,620 new vehicles were registered in Norway (Lambert 2018). Forty-five percent of those registered vehicles were battery electric and twenty percent were plug-in hybrid. Norway aims to be all-electric by 2025 and many industry experts believe that this goal will be met with high confidence (Lambert 2018). The Norwegian Institute of Transport Economics asserts that a tipping point was reached in Norway in 2014. In 2014, the rate of adoption of internal combustion engine vehicles switched from positive to negative in favor of EVs (Gray 2018). As of 2017, according to the International Energy Agency (IEA), Norway has the highest market share of electric vehicles in the world at approximately 39.2 percent (The Local 2018). At the end of 2016, Norway also had the highest concentration of plug-in vehicles at 21.5 registered vehicles per 1,000 people, while California only has 5.8 plug-in vehicles per 1,000 people (Marx 2017).

Norway's strong sense of environmentalism could also be a reason behind the boom in electric vehicles. Interestingly, Norway's economy and the historical development of the country revolves around petroleum production. The petroleum sector accounts for ten percent of jobs, twelve percent of GDP, thirteen percent of the nation's revenues, and 37 percent of the country's exports (CIA 2018). Norway is rich in other natural resources such as gas, fish, forests, and minerals. An estimated 50% of the oil reserves in the country have already been depleted, and Norway anticipates that to secure their long term future, they must look to develop other industries. To aid this transition, Norway has created a Sovereign Wealth Fund that is built upon initial capital from oil revenues. At the end of 2017, the fund was valued at over $1 trillion (CIA 2018). While the Sovereign Wealth Fund is funded by revenues from harmful fossil fuels, the investors behind the fund abide by strict ethical guidelines that dictate where the money can be invested. Specifically, the investors don't invest in companies that engage in "unethical behavior" such as the production of tobacco or weapons, engagement in human rights, labor, or environmental abuses (Hines 2018). The fund's commitment to environmentalism reflects the entire country's commitment in environmental values.

Norway has taken significant steps to avoid the localized effects of petroleum production. In Norway, the use of internal combustion engine vehicles is discouraged by the high price of gasoline. As of April 2018, Norway has the highest gas prices in the world at roughly $7.82 per gallon, while the price in the U.S. is $2.99 per gallon (Global Petroleum Prices 2018). The high price of gasoline in Norway is driven by high taxation. The government applies a 27% tax on corporate income and a 51% resource extraction tax which results in a 78% total tax rate on petroleum corporations (Michel 2014). The tax is passed on to the consumer in the form of high gasoline prices. The government's high taxation of fossil fuels demonstrates its commitment to environmental values by avoiding the localized effects of petroleum production and consumption. This mentality of environmentalism is rare for countries where petroleum production is a leading industry. Saudi Arabia, Iran, and Venezuela have the lowest prices for gasoline at $2.06, $1.08, and $.03 as of April 2018, respectively (Global Petroleum Prices 2018). Other oil producing countries choose to subsidize gasoline to support their leading industry, while Norway recognizes pursues high taxation to avoid the localized effects and create sustainable infrastructure domestically. While a strong sense of environmentalism at the national level may promote Norwegian EV adoption, there is no literature that explicitly links the values of a nation's government and the consumer behaviors of the nation's people.

To create sustainable infrastructure and promote environmentally friendly behavior domestically, Norway is taking steps to becoming a fully electrified society powered by renewable sources. As of 2017, 96% of Norway's electricity needs has met by renewable hydropower (Morgan 2017). Two percent comes from other renewable sources and the remaining 2% comes from natural gas. Norway routinely produces more electricity than needed, and therefore exports energy to Denmark and Sweden through the Nordic interconnection (Morgan 2017). This commitment to electricity powered by renewables reflects the countries commitment to environmental values. The massive amounts of hydropower renewable energy at Norway's disposal makes the transition to electrified transport smoother. The electricity sourced from renewable energy also helps avoid the criticism that many electric vehicle consumers in the United States face which is that while EVs have zero tail pipe emissions, the electricity that is pulled from the grid is frequently generated from non-renewable sources such a coal and natural gas.

Electrifying all types of transport beyond passenger cars is another strategy used by Norway to promote a sustainable, electrified future. The organization that runs Norway's airports, Avinore, has set the goal of having all 1.5-hour short haul flights to neighboring Sweden and Denmark to be electric by 2040 (Marx 2017). Norway has also pioneered the first electric ferry. As of 2017, there were two electric ferries in operation with a backlog of 53 orders (Marx 2017). Norway's power grid is robust enough to handle rapid electrification of transport. As the demand for electric vehicles rise, Sonja Monica Berlijin, a board member of the Norwegian energy operation company Statnett asserts, "The power grid will probably cope, because even though the number of electric cars increase, electricity consumption is increasing at a slower rate. Even when all cars run on electricity, it will only increase electricity consumption in Norway by about 6 percent and if charging is done intelligently, the load at peak will only rise a few percent. It's actually the worst on Thursday, so please don't charge your EVs on Thursday nights" (Berggreen 2018). This statement suggests that the electricity grid in Norway is prepared for the rise in electric vehicles and can meet the demand for electricity efficiently.

The literature suggests that the Norwegian government does not view public charging station availability as a key factor when promoting electric vehicle adoption. In a 2017 household survey, 97 percent of Norwegian EV owners noted that they charge their vehicle at home daily or weekly (Lorentzen et al., 2017). Eighty-nine percent of Norwegian EV owners noted that they use public charging stations monthly or never, which would explain why the Norwegian government has not prioritized public charging station availability to promote EV adoption (Lorentzen et al., 2017). Lorentzen notes that "there is a substantial number of early users that will buy BEVs even without a comprehensive fast charging network. In for instance, neighboring Denmark, there is quite a well-developed charging infrastructure network, but the BEV sale is sluggish, and even more so after a weakening of the tax incentives when buying a car" (Lorentzen et al., 2017). Ultimately, (Lorentzen et al., 2017) notes that as populations are increasingly moving to cities where housing is in high-demand, and people are increasingly living in apartment buildings, these buildings must be "charging ready," suggesting that owners must have the ability to retrofit parking spots with charging stations. Additionally, for Norway, the availability of fast charging stations does significantly correlate with the BEVs registered to a given city (Lorentzen et al., 2017). The cost of developing public charging infrastructure is high, and (Gray 2018) asserts that building out charging infrastructure for the demand on peak travel days may not be economic.

Ultimately, when all of the purchase incentives and high price of gasoline are taken into account, EVs in Norway are priced competitively with internal combustion engine vehicles (Figenbaum 2016). People in Norway who drive plug-in vehicles do not have to pay import taxes for the vehicle, are exempt from tolls, have a reduced road tax, and have access to free parking (Marx 2017). The boom of electric vehicles is driven by a cocktail of taxes, subsidies, and policies. In 1990, Norway exempted electric vehicles from a vehicle registration tax that ranged from 3000-9000 euros per vehicle. In 2001, a 25% value-added tax was lifted for electric vehicles that could have cost nearly 5000 euros (Figenbaum 2016). In 1997, toll roads became free for all electric vehicles in the greater Oslo area that saved electric vehicle drivers 600-1000 euros annually (Figenbaum 2016). In 1999, the government allowed electric vehicle drivers free parking in metropolitan areas (Figenbaum 2016). From 2009-2011, the government dedicated funds to building out fast charging stations to reduce range anxiety (Figenbaum 2016). These policies in addition to heavy taxes on petroleum have influenced electric vehicle adoption.

(Figenbaum 2016) examines policy documentation, historical literature, statistics, and surveys owners of BEVs to understand why EV adoption has been so successful in Norway. (Figenbaum 2016) tests four hypotheses explaining the success of EVs. The niche hypothesis asserts that the rapid development of BEVs in Norway is due to well-functioning niches for BEVs to expand. The regime hypothesis suggests that the development of BEVs in Norway is due to a weak ICE regime in Norway. The governance hypothesis suggests that the success of BEVs in Norway is due to the economic incentives and policy directions at different scales. The opportunity hypothesis asserts that the development of BEVs in Norway is the result of “windows of opportunity” opening up, and niche actors taking advantage of these opportunities. Ultimately, all of the hypotheses were strengthened and weakened in certain ways. The niche hypothesis was strengthened because of the economic incentives such as tax reductions have leveled the playing field between ICEVs and BEVs cost. The regime hypothesis was strengthened by evidence that Norway does not have any ICEV production and the government recognizes that employment can be boosted through investment of domestic BEVs rather than importing ICEVs. The United States, unlike Norway, has large ICEV manufacturers that would have a vested interest in suppressing the adoption of BEVs. Many niche events both internationally and locally helped propel the EV market in Norway. These events include: the development of the Li-Ion battery, strict regulations on CO2 emissions by the EU, California's Zero-Emissions Vehicle mandate that every car manufacturer selling in California must have a zero emission option forcing the development of more EV options, and new entrants such as Tesla (Figenbaum 2016). Ultimately, (Figenbaum 2016) asserts that Norway's electric vehicle success can be credited to the undermining of the existing internal combustion engine vehicle (ICEV) regime through heavy taxation and rise of environmentalist values.

Norway serves as a strong case study about electrification of transport done well. Electric vehicles have been normalized in the culture through policies and the weakness of the existing ICEV regime. The U.S. has pockets of communities that mirror the environmentalist values of the Norwegian people—for example, the population of San Francisco Bay Area tends to have strong environmentalist leanings and their rates of electric vehicle adoption (IHS Markit 2016). The United States differs from Norway in that the ICEV regime is strong and environmentalism is highly polarizing—this explains why electric vehicle adoption in the U.S. is slower than that of Norway. Ultimately, the ample supply of renewable electricity and strong financial incentives, not public charging infrastructure availability, have driven electric vehicle in Norway.

**Historical Transitions in Transport**

Norway is a strong example of a modern day transportation revolution that offers insight into what motivates consumers to adopt electric vehicles. The electrification of transport is a significant transition from transport fueled by gasoline or diesel. Understanding past historical transitions in transportation can help explain many of the hesitancies and anxieties felt during modern-day the electric car revolution. The transportation transitions I will be examining are the transition from the horse-drawn carriage to the streetcar in Boston, Massachusetts, and the transition from bicycles to automobiles in Denver, Colorado. I will then examine the modern transition from gas-powered vehicles to electric vehicles happening today.

In the mid to late 1800s, carriages only moved a small proportion of a city's population because of the expense (Warner Jr. 1962). Most people walked from one location to another, and therefore cities were often segregated into smaller communities based on distance. These sub communities within the city would be approximately three miles from one end to the other with a walking time of one hour (Warner Jr. 1962). The lack of availability of transportation technology had a profound impact on the development of the city and its sprawl. People's productivity was limited by the distance that they could walk over a limited period of time. The "omni bus," introduced in 1826, and the steam railcar, introduced in 1835, offered an alternative to walking. These new technologies were slow and expensive. The expense dissuaded the lower classes from using the technology, and the slowness dissuaded nearly everyone else. Despite solving the problem of walking everywhere, people were initially averse to railcars. The high cost and range anxiety felt by consumers considering EV adoptions mirrors the hesitation towards the omnibus and steam railcar. Interestingly, in 1889, the first electric streetcar replaced the horse drawn streetcar in the Boston area (Warner Jr. 1962). The electrification of streetcars in 1890 brought the noise of grinding steel and the buzz of live wires to the streets (Warner Jr. 1962). This public disturbance caused people to be resistant to the switch to electric-powered transportation. Horse-drawn streetcars had their own drawbacks—horses are difficult to manage and their manure stinks. The transition from one technology to another comes with many tradeoffs.  Like the modern day electric car, early adopters of streetcars as a mode of transport tended to be of a higher economic class (Warner Jr. 1962). A technology transition reaches a tipping point when the financial business case for the product's adoption can be made to consumers. In the case of the introduction and electrification of the streetcar, the technology transition was dictated by economics of the purchase. Additionally, the notion that the upper class secured access to the new technology first is integral to technology transitions. The quote by writer William Gibson rings true in the case of electrification of streetcars and electric vehicles in the modern age, "the future is already here—it's just not evenly distributed" (The Economist 2003).

The city of Denver experienced a similar transportation revolution at the start of the 20$^{th}$ century. This revolution dealt with the transition from bicycles to automobiles. In the late 1800s and early 1900s, bicycles were a popular form of private transportation for Denver residents. More than 25,000 of the city's 133,859 residents were members of the Denver Wheelmen, a bicyclist organization, (Gutfreud 2004). When the automobile arrived in Denver in

1899, the vehicle and its owners were met with fear and skepticism. Despite this initial hesitancy, the automobile took off in Denver in large part because of the government's role to intentionally incorporate the automobile through infrastructure development. City officials immediately passed registration laws and speed limit laws of 8 mph (Gutfreud 2004). While there was initial hesitation, the Colorado Automobile Club teamed together with the Denver Wheelmen to push for road development in the Denver area. The Denver city government started by building large camps for motorists with "free services for camping motorists, including running water, mail delivery, and adjoining golf course, and daily concert performance by the municipal band" (Gutfreud 2004). These parks made sense given that most automobile drivers were passing through the country and Denver wanted to become a more prominent stopping point. As the federal government promoted the interstate highways system under the Federal-aid highway program established in 1921—in particular through increases in gasoline taxation, the adoption of the automobile skyrocketed. By 1925, more than a quarter million automobiles were registered in Colorado (Gutfreud 2004). City planners chose to forgo other alternative forms of transport in favor of the automobile: "a major planning publication from 1932 called for removing trolley tracks from some of the major routes, because streetcars got in the way of automobiles" (Gutfreud 2004). The publication also noted that mass transit should only be provided for "citizens who do not have automobiles of their own, or visitors to the city" (Gutfreud 2004). Interestingly, the rise of automobiles over public transportation in Denver highlights the role that governments can play in a technological transition. For a technology to thrive, the necessary infrastructure must be put in place by either the government or private corporations to support the technology. In the case of the automobile, the government took the lead in developing roads that had a significant positive effect on the adoption of automobiles. In the case of public charging infrastructure for EVs, private companies and governments have led the infrastructure development. While public investment in infrastructure played a role in influencing automobile adoption, the automobile did have huge advantages over horses and bicycles in regards to maintenance, speed of travel, and distance travelled. The electric vehicle does not have these same advantages over gas-powered vehicles, and therefore the role that the state and federal government needs to play in the transition to electric vehicles would be different. In the transition to electric vehicles from gas-powered vehicles, the government needs to help convince the consumer that electric vehicles are a better alternative by educating the consumer about potential cost savings through rebates or environmental benefits as well as putting in place necessary infrastructure such as public charging stations to allow the travelling of far distances. In the transition from the horse and bicycle to the gas-powered vehicle, the government's role in building infrastructure such as roads necessary for use the automobile was more critical, while their role in convincing the consumers of the benefits of switching to the gas-powered vehicle was less critical.

In the United States, the first drive-in fuel station opened in 1913 (Eschner 2017). People could fill their own gas from roadside filling stations starting in 1905. Before 1905, people needed to buy their gasoline in cans from pharmacies (Eschner 2017). The drive-in fuel stations were different from those of today. Past gasoline stations had attendants to handle the fueling for the driver, and offered "free air, water, crankcase, and tire service" (Eschner 2017). The nature of the fueling station dictated motorists' behavior. In the past, people would go to the fueling station to have a pleasant experience and pass time. In modern times, people value efficiency and hope to spend as little time as possible at the fueling station. The same applies to EV charging stations—people would ideally like to spend as little time as possible charging their EV. Given that the technology and costs of charging stations do not support ubiquitous fast charging, placing level 2 charging stations in environments where the EV driver could do other things such as access internet, grab coffee, or shop maybe advantageous to promote charging station use.

The idea for the electric vehicle was the product of innovators in Hungary, the Netherlands, and the United States conceiving the idea of a battery-powered vehicle in the early 1800s (Matulka 2014). In the second half of the 1800s, Englishman Robert Anderson developed the first electric carriage (Matulka 2014). In 1890, American chemist William Morrison built the first electric car that held up to 6 people and could reach speeds of 18 mph (Matulka 2014). Interestingly, there was a boom in electric vehicles around 1900—electric vehicles made up one third of vehicles on the road (Matulka 2014). Electric vehicles were preferred to gasoline-powered vehicles for many of the same reasons they are preferred today. Electric vehicles don't emit pollutants, are quiet, and did not require a hand-crank like gasoline powered vehicles used to. Due to the popularity of the electric car, many automakers and inventors such as Ferdinand Porsche, Thomas Edison, and Henry Ford worked to build better batteries and develop hybrid technology (Matulka 2014). In 1908, Henry Ford mass produced and popularized the Model T, which was half as expensive as the average electric car and did not require a hand-crank (Matulka 2014). With the boom of the crude oil in Texas in the 1920s, more gasoline stations began popping up around the country (Matulka 2014). These gas stations allowed Americans to travel farther distances than EVs allowed for. The competitive cost of the Model T, lack of hand crank, and the boom of gas stations across the United States, led to the gas-powered vehicles domination over electric vehicles which continued for the rest of the 20th century.

The 1990s were considered to be the most intensive period of electric vehicle and hybrid electric research and development (Hoyer 2008). In 2000, a key turning point in the electric vehicle's resurgence occurred with the introduction of the Toyota Prius—the world's first mass produced hybrid-electric vehicle. In 2006, Tesla Motors was founded by Elon Musk and started producing luxury sports cars with a range of 200 miles (Matulka 2014). The US Department of Energy played a significant role in promoting EV adoption. The nickel metal hybrid battery used in the Prius was supported by US Energy Department's research and Tesla's first manufacturing facility was funded by a $465-million-dollar loan from the US Department of Energy which was paid back 9 years early (Matulka 2014). In 2010, the Chevy Volt and Nissan Leaf were released and many other auto manufacturers started to develop electric vehicles. The Tesla Model S was released in 2012 (Matulka 2014). Today there are approximately 20 electric vehicles and 40 hybrid models in the market (Matulka 2014).

The greatest rise in electric vehicle adoption occurred in the seven years from 2010 to 2017 have seen the greatest rise in electric vehicles. The global stock of electric vehicles passed three million in 2017 and global sales increased 54 percent (IEA 2018). The International Energy Industry forecasts that the global stock will increase to 125 million by 2030 (IEA 2018). The global share of EVs was .1 percent in 2011 and grew to 1.3 percent in 2017 (Hertzke 2018). Between Europe, the United States, and China, China has the largest share of the global stock (IEA 2018). In the United States, the percentage of electric vehicles in the total car market is approximately 1 percent, this share is projected to increase to 14 percent by 2025 (IHS Global Insight 2018). People across the world are starting to adopt EVs at a higher rate once again.

**Description of Data**

The data for the availability of charging stations comes from the US Department of Energy Alternative Fuels Data Center. This data center has level 1, level 2, and DC fast charging station locations across the United States and Canada up until the present day, or September 2018. The data set contains the following information about each charging station: the zip code, the latitude and longitude of the station, the city, the station phone number, whether the station is public or private, how many hours a day the station is accessible, the station's ID number, and the date that the charging station opened. I will use the charging station latitude and longitude and the zip code tabulation area centroid coordinates provided by the National Bureau of Economic Research to calculate the number of zip codes in a 32-mile radius of the centroid. The average commute distance to and from work in a day is 32 miles (Harris).

The data for the motor vehicles segmented by fuel type registered to each zip code in California comes from the California Department of Motor Vehicles. This data is from January 1st 2018. The various fuel types presented in this data set are: battery electric, diesel, diesel hybrid, ethanol, fuel cell, gasoline, hybrid gas, plug-in hybrid, butane, compressed natural gas, methanol, methane, natural gas, and propane; and the total cars registered in a given zip code. My regressions will use the total car value and the plug-in hybrid and battery electric cars registered to calculate the percentage of EV and PHEV per zip code. This data will be used for the cross sectional regressions. Additionally, I received annual automobile registration data from 2012-2015 for the electric vehicles registered at the zip code level in California from IHS Markit. The Claremont College Library purchased this data in 2016. I will use this data for the panel regression.

I collected data on the percentage of green registered voters in each county as a proxy for community environmentalism. The percentages of green registered voters are taken from the California Secretary of State. The report of registration contains values from May 2018 at the county level. The data set contains the total number of people eligible for registration, the total number registered, number of those registered democratic, republican, American independent, and green. I will not include this data in my regressions because I am unsure which zip code tabulation areas correspond to which counties, but I urge future research that builds on my regressions to use this data and relate the zip code tabulation areas to their corresponding counties.

Through the American Fact Finder, which houses the US Census data and estimates, I found data on educational attainment for those over 18 years by age, sex, race, and Hispanic origin for 2016. This data set contains the mean high school graduation rate by California zip codes. I will use this as a measure of how educated the population in a given zip code is.

Through the American Fact Finder, I will use income bracket information in each Californian zip code tabulation area. This data set has median annual income and mean annual income for the average family, household, married-couple families, and nonfamily households, as well as the percentage estimate for the various income ranges from $10,000 to $200,000 and above. This income range data is useful given that the state rebate is not given to single filers whose income is above $150,000, head-of-households earning more than $204,000, or joint filers earning more than $300,000 annually (DMV 2018).

To capture the commuting duration in each Californian zip code, I will use survey results from the American Community Survey. While average commuting distance per zip code would have been the most useful, I will use average commute time as a proxy for commuting distance because the average commuting distance is not asked for in the American Community survey. I recognize that in metropolitan areas with high levels of traffic such as Los Angeles, commuting time is not a good proxy for commuting distance. I will use 2016 estimates for mean travel time to work. The data was downloaded via the American Fact Finder. The same data table also contained 2016 estimates for the percentage of workers in each zip code that travel to work via public transportation which will help inform electric vehicle adoption and charging station availability.

The Zip Code Tabulation Area metric created by the U.S. Census Bureau does correspond with US postal service zip codes. There are roughly ~2500 zip codes in California and ~1700 zip code tabulation areas reported in Census Data (U.S Census Bureau 2018). Only populated areas are included in census data, which explains why the number of zip code tabulation areas is so much less that the number of zip codes in California. In this study, I will assume that zip code tabulation area and postal zip codes cover roughly the same area and are a sound proxy for one another.

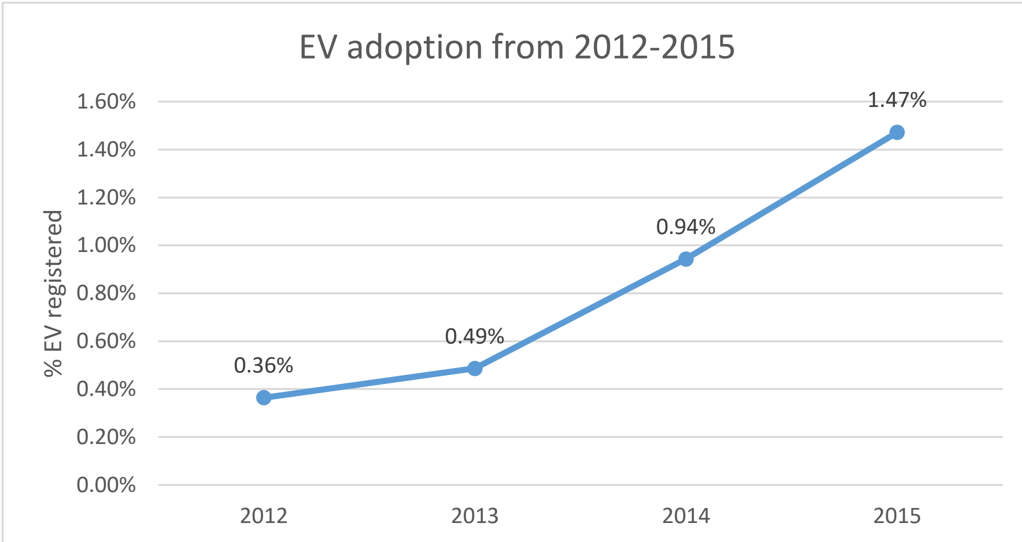


*Figure 1. Percentage of total vehicles registered that were EVs in each year from 2012 to 2015 using IHS Markit data*

This figure shows the percentage of EVs registered in each year from 2012 to 2015. The rate of EV registration increased 33 percent from 2012-2013, 93% from 2013 to 2014, and 56% from 2014 to 2015. Since the IHS Markit data was capped off at 2015, I use 2016 and 2015 CA EV sale volume values from the Alliance of Auto Manufacturers in the figure below.

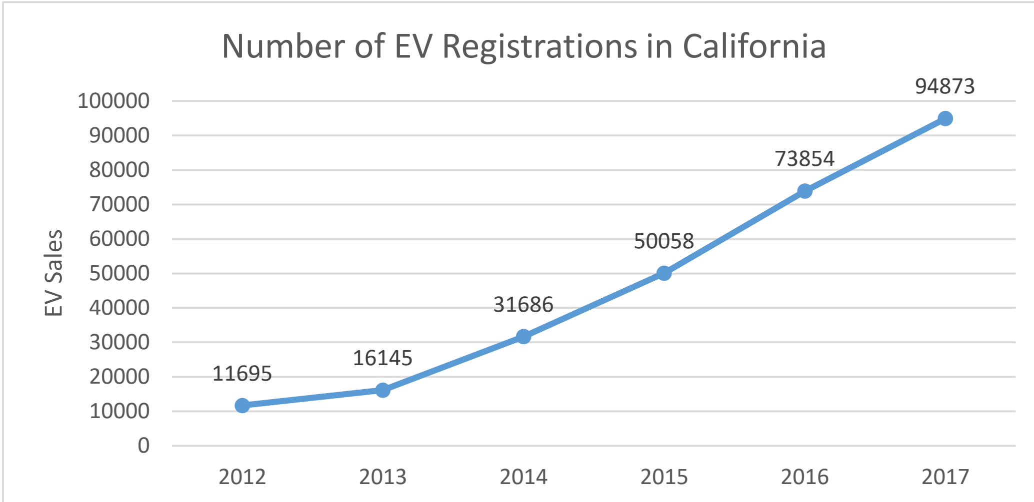


*Figure 2. The number of EVs registered in each year from 2012 to 2017 using IHS Markit data*

EV registrations in the state of California have increased significantly—the compound annual growth rate of EV registrations in California from 2012 to 2017 is 52%. According to EV Volumes, the number of EVs in California at the end 2017 was approximately 340,000 (Ayre 2017). This suggests that at the end of 2017, approximately 30% of the total electric vehicles in California were registered in that same year.

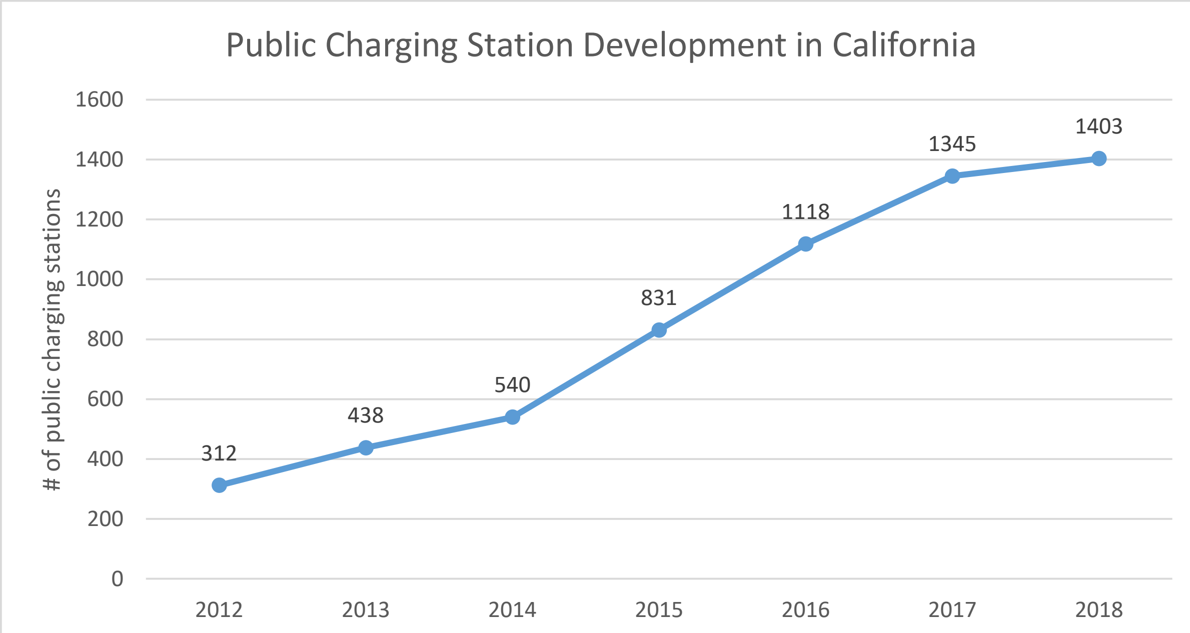


*Figure 3. The number of total public charging stations in California from 2012 to 2018 using data from the US Department of Energy*

The compound annual growth rate from 2012-2018 is 28.47%. The growth rate of public charging infrastructure from 2016-2017 was 20%. The growth rate from 2015-2016 is 35%. The growth rate from 2014-2015 is 54%. The growth rate from 2013-2014 is 23%. The growth rate from 2012-2013 is 40%. The average annual growth rate in the years from 2012-2018 is 34%. Based on the change in the 2012 to 2018 public charging station map below, charging station density has most prominently increased in the San Francisco Bay Area, the Los Angeles metropolitan area, and the San Diego Metropolitan Area. Charging station density has also increased along California's Highway 101 and Interstate 5—these are both major highways that transport people between the San Francisco Bay Area and LA metropolitan area. In rural areas, public charging stations is very sparse.

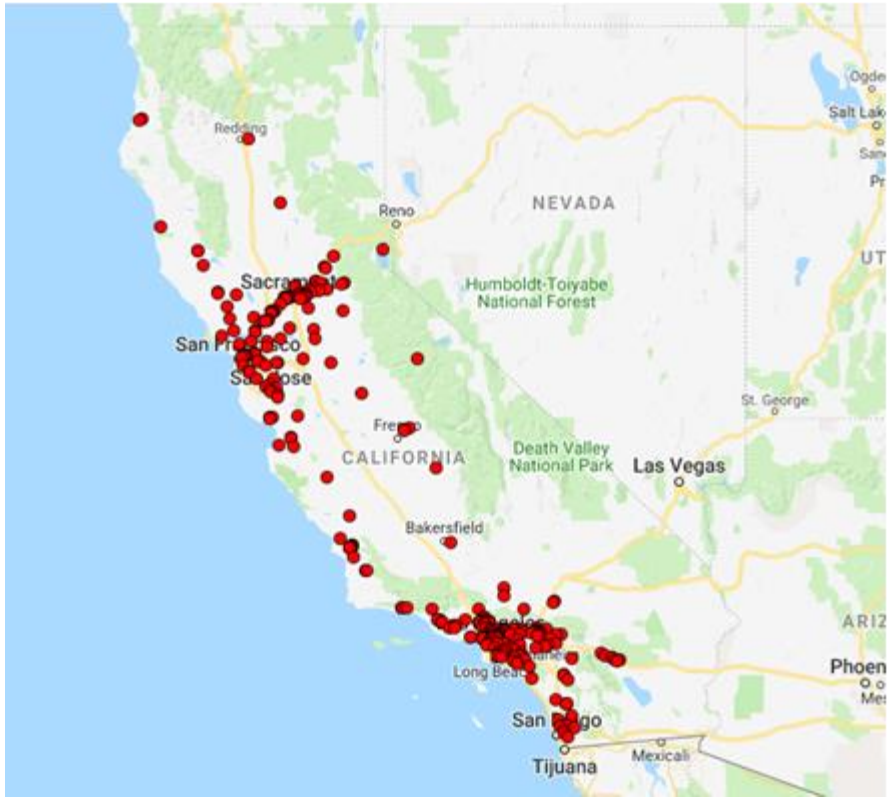


*Figure 4. Public charging stations in California in 2012*

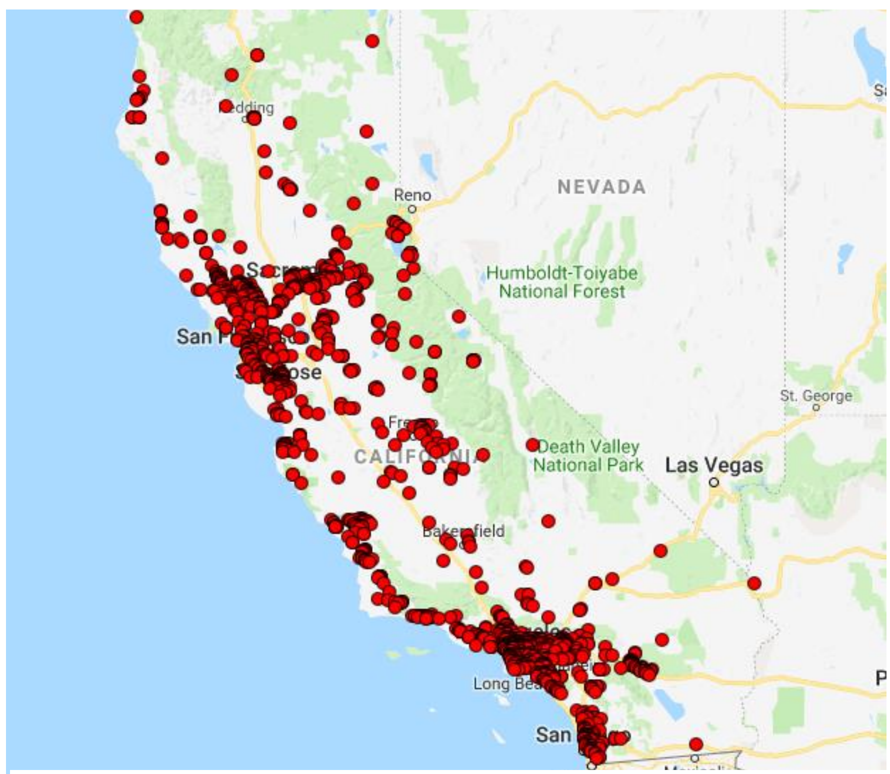


*Figure 5. Public charging stations in California in 2018*

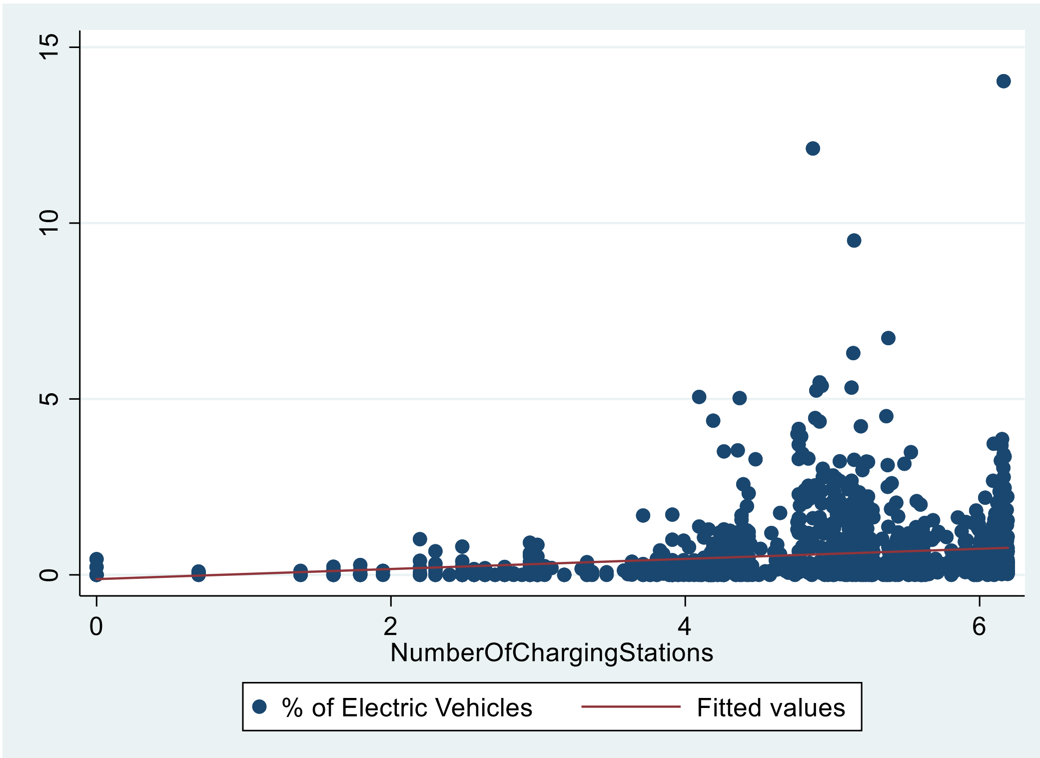


*Figure 6. Two-way scatter with number of charging stations and electric vehicle registration percentage*

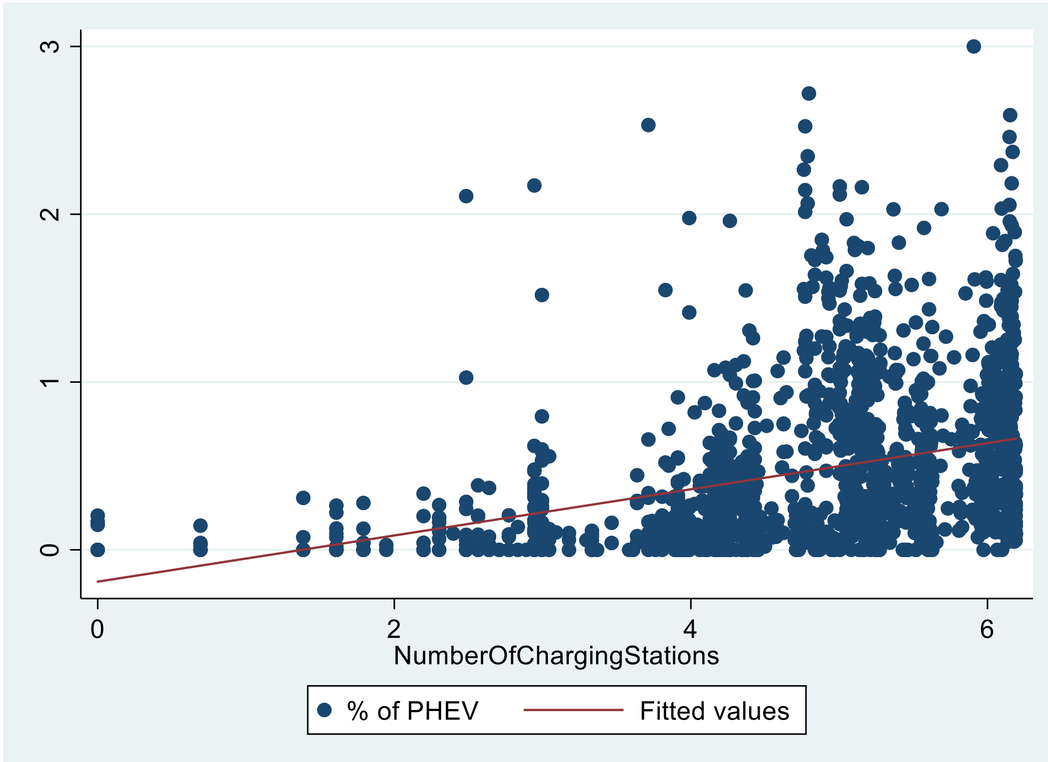


*Figure 7. Two-way scatter between number of charging stations and plug-in hybrid registration percentage*

The two-way scatter plot of the number of charging stations within a 32-mile radius of a zip code centroid and the percentage of EVs in a zip code in 2018 (Figure 6) shows a slight positive relationship which is in line with the hypothesis. The two-way scatter plot of the number of charging stations and percentage of plug-in hybrid sales (Figure 7) also shows a positive relationship. The skew of the scatter plots supports the use of a log function in the independent variable of number of charging stations.

**Summary Statistics**

*Table 1. Summary statistics of variables*

| VARIABLES | (1)<br>N | (2)<br>mean | (3)<br>sd | (4)<br>min | (5)<br>max |
|---|---|---|---|---|---|
| percentEstimatePercentHighSchool | 1,572 | 83.36 | 14.07 | 22.70 | 100 |
| percentageOfElectricVehicles | 1,572 | 0.586 | 0.937 | 0 | 14.03 |
| numberOfChargingStations | 1,572 | 212.7 | 161.0 | 1 | 489 |
| publicTransportationRate | 1,572 | 3.663 | 6.231 | 0 | 50.40 |
| percentageOfPeople50kTo99k | 1,572 | 28.43 | 7.994 | 0 | 100 |
| percentageOfPeople100kTo150k | 1,572 | 14.02 | 6.447 | 0 | 47.60 |
| percentageOfPeople150kAndAbove | 1,572 | 14.30 | 12.75 | 0 | 100 |
| meanCommuteTime | 1,572 | 28.08 | 7.781 | 4.900 | 127.9 |
| percentageOfPHEV | 1,572 | .4871 | .484 | 0 | 3 |

**Theory of Equations**

*First Regression- EV Cross Section*

I will use the following econometric model to discern the effect of public charging station availability on electric vehicle adoption:

$$\text{ElectricVehicleMarketShare}_i = \beta_0 + \beta_1\text{log(ChargingStationDensity)}_{it} + \beta_2\text{HighschoolGraduationRate}_i + \beta_3\text{\%ofPopulationEarningAbove150k}_i + \beta_4\text{\%ofPopulationEarning100-150k}_i + \beta_5\text{\%ofPopulationEarning50-100k}_i + \beta_6\text{AvgCommuteTime}_i + \beta_7\text{PublicTransportationCommutingRate}_i$$

I will use the ordinary least squares (OLS) estimation technique to estimate this linear regression model. Other than charging station density, which is logged, I assume that the marginal effect of the other explanatory variables is constant. Other than the key independent variable of interest, charging station density, I assert that the high school graduation rate, the percentage of people in the various income brackets, the average commute time, and the public transportation rate would all also correlate with the electric vehicle market share and charging station density. I hypothesize that $\beta_1$ will be positive given that the more charging stations in a given zip code, the more convenient recharging an EV would be so people would be more willing to purchase an EV. I believe that $\beta_2$ would be positive as well because I believe the more educated the population of a zip code, the more likely they to recognize the environmental benefits of driving an electric vehicle and ascribe social capital to driving an EV. In my model, I include three income brackets. I have dropped the lowest income bracket to avoid multicollinearity. I hypothesize that $\beta_3$ coefficient for the highest income bracket will be positive because the higher income the population of a zip code, the more likely they are to be able to afford EVs which are often more expensive that conventional ICEs. I suspect that the $\beta_4$ & $\beta_5$ coefficients will be negative given the higher cost of purchasing an EV. I hypothesize that $\beta_6$ will be negative—as the length of people's commute increases, they will be less willing to purchase an electric vehicle given the anticipated range anxiety if adequate charging infrastructure is not accessible. $\beta_7$ will be negative as well because the larger the percentage of commuters that take public transportation to work suggests that the public transportation in a zip code is adequate, and people would be less willing to make an expensive automobile purchase. Additionally, public transport is commonly taken by lower-income workers who may not be able to afford an electric vehicle. A counter argument—many environmentalists commute by public transportation, so if the percentage of commuters that preferred public transportation was a proxy for community environmentalism, then I could see $\beta_7$ being positive suggesting that more public transportation commuters indicates that the zip code would have more environmentally minded people who would prefer to adopt emission-reducing electric vehicles.

*Second Regression- Plug-in Hybrid Cross Section*

$PlugInHybridVehicleMarketShare_i = \beta_0 + \beta_1 log(ChargingStationDensity)_{it} + \beta_2 HighschoolGraduationRate_i + \beta_3 \%ofPopulationEarningAbove150k_i + \beta_4 \%ofPopulationEarning100\text{-}150k_i + \beta_5 \%ofPopulationEarning50\text{-}100k_i + \beta_6 AvgCommuteLength_i + \beta_7 PublicTransportationCommutingRate_i$

I will conduct the same regression model as above, but instead of using electric vehicle market share as my dependent vehicle, I will use the plug-in hybrid market share to see if the same effects that influence electric vehicle adoption would influence plug-in hybrid adoption. In addition to running the two cross sectional regressions, I will run a time series regression that measures relationship between the concentration of electric vehicles in a zip code and the charging station availability over time to discern the effect of public charging station availability on EV adoption.

*Third Regression- EV Panel Data*

$ElectricVehicleMarketShare_{it} = \beta_0 + \beta_1 log(ChargingStationDensity)_{it} + \beta_2 HighschoolGraduationRate_i + + \beta_3 \%ofPopulationEarningAbove150k_i + \beta_4 \%ofPopulationEarning100\text{-}150k_i + \beta_5 \%ofPopulationEarning50\text{-}100k_i + \beta_6 AvgCommuteLength_i + \beta_7 PublicTransportationCommutingRate_i \beta_8 AverageGasolinePrice_t + \beta_9 Time_{it} + \alpha_{it}$

In the third regression, I again investigate the effect of charging station density within a zip code on the electric vehicle market share. For this regression, I use panel data from 2012-2015. The independent variable is charging station density, which is measured by the number of publicly available charging stations within 32 miles of the centroid of the zip code tabulation area in each year from 2012-2015. The dependent variable is ElectricVehicleMarketShare that is measured as the % of EVs registered to a given zip code in each year from 2012 to 2015. I hypothesize that $\beta_1$ will be positive as an increase in public charging infrastructure would incentivize consumers to purchase an EV. I will include data about the average gas price in a given year, though this data will only vary across time, not across zip code. I hypothesize that $\beta_8$ will be positive because a higher gas price will incentivize people to consider alternative fuel vehicles such as EVs. I will also include a time-trend variable to discern the difference in effect of time passing on EV adoption and charging station availability. I hypothesize that $\beta_9$ will be positive given that EV adoption is generally on the rise. In this model, I assume a fixed effects variable which captures all of the other variables that do not vary over time. I therefore assume that the variables considered in the regression such as education rate, commute time, public transportation rate, income, etc. that do not vary over time will be dropped by STATA and captured in this fixed effects variable.

**Results**

*Table 2. EV cross section regression results*

| VARIABLES | (1)<br>percentageOfElectricVehicles |
|---|---|
| Log(numberofchargingstations) | 0.0687*** |
| | (0.0175) |
| percentestimatepercenthighschool | 0.00689*** |
| | (0.00165) |
| percentageOfPeople150kAndAbove | 0.0386*** |
| | (0.00198) |
| percentageOfPeople100kTo150k | -0.0101*** |
| | (0.00352) |
| percentageOfPeople50kTo99k | -0.0152*** |
| | (0.00248) |
| meanCommuteTime | -0.0168*** |
| | (0.00243) |
| publicTransportationRate | 0.0131*** |
| | (0.00303) |
| Constant | 0.118 |
| | (0.166) |
| Observations | 1,572 |
| R-squared | 0.422 |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In the first regression, the number of charging stations does positively correlate with the percentage of electric vehicles at the one percent level. If the number of charging stations in a zip code increases by one percent, then the percentage of electric vehicles in a zip code increases by .068 percentage points. Education level is also positively correlated with percentage of electric vehicles at the 1 percent level. For every one percentage point increase in the high school graduation rate of a zip code, the percentage of electric vehicles in the zip code will increase by .006 percentage points.

Interestingly, out of the three income brackets, the percentage of people with an income of 150k and above is the only income bracket that is positively correlated with the percentage of electric vehicles. This speaks to the high income necessary to afford many EVs. Mean commute time is significantly negatively correlated with the percentage of electric vehicles. This suggests that people in zipcodes with longer average commute times would be less likely to adopt an electric vehicle. This can possibly be explained by range anxiety. The public transportation rate is significantly positively correlated with the percentage of electric vehicles. An increase in the public transportation rate by one percent is correlated with the percentage of electric vehicles in the zip code increasing .01 percentage points. percentage points. This could be explained by electric vehicles generally being concentrated in urban areas, rather than rural, and urban areas tend to have more developed public transportation rates. The R-squared suggests that 41 percent of the variance in the percentage of EV can be explained by the variance in the independent variables.

*Table 3. PHEV cross section regression results*

| VARIABLES | (1)<br>percentageOfPHEV |
|---|---|
| Log(numberofchargingstations) | 0.0753*** |
| | (0.00717) |
| percentestimatepercenthighschool | 0.00553*** |
| | (0.000675) |
| percentageOfPeople150kAndAbove | 0.0246*** |
| | (0.000809) |
| percentageOfPeople100kTo150k | -0.00423*** |
| | (0.00144) |
| percentageOfPeople50kTo99k | -0.00371*** |
| | (0.00102) |
| meanCommuteTime | -0.000721 |
| | (0.000993) |
| publicTransportationRate | 0.00346*** |
| | (0.00124) |
| Constant | -0.524*** |
| | (0.0677) |
| Observations | 1,572 |
| R-squared | 0.639 |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The second regression that examines the effect of public charging infrastructure availability on plug-in hybrid electric vehicles yielded a significant, positively correlates relationship. Every one percent increase in the number of public charging station installed within a 32-mile radius of the centroid zip code is correlated with an increase of .075 percentage point increase in the percentage of PHEV. High school graduation rate is also significantly positively correlated with the percentage of PHEV. Like EVs, PHEV seem to cater to the higher income population. The percentage of people in the highest income bracket of household earnings exceeding 150k is positively correlated with PHEV market share at the 1 percent level, however, the percentage of people in the income range from 50k to 100k and 100k to 150k are both negatively correlated with PHEV market share at the 1 percent and 5 percent level respectively. The R-squared suggests that 64 percent of the variance in the percentage of PHEV across zip codes can be explained by the variance in the independent variables.

*Table 4. EV 2012-2015 panel data regression results*

| VARIABLES | (1)<br>ElectricVehicleMarketShare |
|---|---|
| Log(numberofchargingstations) | 0.00682 |
| | (0.0304) |
| o.percentestimatepercenthighschool | - |
| o.percentageOfPeople150kAndAbove | - |
| o.percentageOfPeople100kTo150k | - |
| o.percentageOfPeople50kTo99k | - |
| o.meanCommuteTime | - |
| o.publicTransportationRate | - |
| averagegasolineprice | -0.258*** |
| | (0.0355) |
| 2013.year | -0.0168** |
| | (0.00842) |
| 2014.year | 0.0387*** |
| | (0.00947) |
| 2015o.year | - |
| Constant | 1.103*** |
| | (0.262) |
| Observations | 3,541 |
| R-squared | 0.781 |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In the panel regression, the number of public charging stations within a 32-mile radius of a zip code centroid is positive correlated with the electric vehicle car registration market share. The coefficient of log(numberofchargingstations) suggests that every one percent increase in the number of charging stations within a 32-mile radius of the zip code centroid will positively correlate with a .007 percentage point increase in the percentage of electric vehicles registered in the zip code. This relationship is not significant. I ran a panel regression with the goal of capturing many non-observables across zip codes in the fixed effect. Stata purposefully dropped many of the variables that did not vary over time because they too are captured in the fixed effects variable. Gas price is significantly, negatively correlated with EV adoption. This violates my initial hypothesis that gas prices increase people would look to adopt EVs to save fuel costs. This could be explained by the low sample size of the gas price. In my model, I only include data about gas prices that vary over time, not across the various zip codes. Time is expectedly also significantly positively correlated with EV adoption.

**Discussion**

To meet the ambitious electric vehicle adoption goals that Gov. Jerry Brown January 2018, the California Public Utilities Commission approved the spending of $768 million on public charging infrastructure for electric vehicles in May 2018. The results of the cross sectional studies suggest that investing in public charging infrastructure does significantly positively correlate with EV and PHEV adoption. The results from the panel regression suggest positive relationship between public charging station availability and electric vehicle adoption, though this relationship is not significant. My findings do not undermine the CPUC's decision to invest $611 million in public charging station development. The CPUC's investment in public charging station development will likely decrease range anxiety amongst EV drivers and normalize electric vehicle adoption. Ultimately, there are pros and cons to directing public funds towards public charging infrastructure. The primary con of investing in public charging infrastructure is that EV drivers tend to charge their vehicles where they park normally, either at home or work. Therefore, public charging infrastructure may not be valued highly when making an EV vs ICEV purchase decision. As public charging becomes faster and more affordable over time, the importance of public charging station availability in the eyes of the consumer will increase. Until the technology reaches this level, it would be unwise to invest heavily in public charging infrastructure if the charging stations are not easily upgradable to newer technology. Investing in charging infrastructure could serve as a signal to society that communicates the progression towards electrified transport. This signal could help to normalize EV driving and nudge more people to consider purchasing an EV. In a future where autonomous driving is normalized, the importance of public charging infrastructure would increase. After dropping off a person to her destination, the autonomous vehicle could then drive itself to the nearest public charging station and charge while waiting for the person to finish their task at said location. Ultimately, I would recommend that investment in public charging infrastructure should be cautiously pursued with a strong emphasis placed on developing infrastructure that can be upgraded easily to more efficient charging technology.

Any claims of reverse causality between electric vehicle adoption and public charging infrastructure can be addressed by the fact that my independent variable of number of charging stations included all of the charging stations that were built up until a given year, while the dependent variable was the electric vehicle market share calculated using the vehicle registrations from one given year. I would hope that future researchers could build upon my work by including a proxy for community environmentalism. Other omitted variables include the penetration of the residential solar market, current and future expectations of gas prices at the zip code level, electricity prices, and a sound metric that captures community environmentalism. The omission of these variables does bias my model. Another limitation of the model is the use of electric vehicle registration as a proxy for electric vehicle adoption. An EV buyer may register her car in 2013, but have made the decision to preorder and purchase the car in 2012 based on availability of charging infrastructure in 2012. Lastly, I would encourage future researchers to take into account the type of charging station such as Level 1, Level 2, and DC fast charging, and their respective effect on EV adoption. I suspect that people will find a new DC fast charging station installation on their way to work far more valuable than multiple Level 2 chargers given the amount of time required to charge the battery. Lastly, I would be interested in knowing about the efficacy of utilities subsidizing the installment of in-home charging stations. Ultimately, more research into the factors that influence electric vehicle adoption is key in meeting emissions reduction targets to mitigate climate change.

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