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Driving Factors: The Effects of State Tax Incentives on the Market Penetration of Electric Vehicles

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By
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This thesis is submitted in partial fulfillment of the requirements for the course Senior Seminar (EC 375) during the Spring Semester of 2022.

While writing this thesis, I have not witnessed any wrongdoing, nor have I personally violated any conditions of the Skidmore College Honor Code.

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List of Acronyms

BEV	Battery Electric Vehicle
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
LDV	Light Duty Vehicle
PHEV	Plug-In Hybrid Electric Vehicle

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Abstract

This research examines the effects of state tax incentives on the market penetration of electric vehicles (EVs), while also delving into other variables such as charging port availability, state political affiliation, state gas prices, and vehicle price levels, utilizing data ranging from 2011 to 2020. These definable variables influence in an individual's decision when considering purchasing an EV. Using Ordinary Least Squares (OLS) methodology, I am able to analyze the specific effects of these independent variables on the number of fuel cell electric vehicles (FCEVs), battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and all EVs sold in each state. My results find a significant positive relationship between states who offer charging station incentives and vehicle tax credits and the number of EVs sold in that state. Specifically, a 2.93% increase in EVs sold per capita in states who offered charging station incentives and a 2.52% increase in EVs sold per capita in states who offered vehicle tax rebates. I conclude that in order to increase the market penetration of EVs in a state, state governments should adopt state tax incentives and legislators must think of ways to responsibly recycle these batteries when they are no longer usable.

Introduction

The purpose of this paper is to examine the effects of state tax incentives on the market penetration of electric vehicles (EVs). EVs are categorized into three major categories: fuel cell electric vehicles (FCEVs), battery electric vehicles (BEVs), and plug-in hybrid electric vehicles (PHEVs). Due to the presence of an electric motor component, these vehicles have low emission characteristics which significantly contribute to their current popularity.

Although low emission characteristics contribute to EV popularity, rising climate concerns prove the need for government incentives to further push the needle. The International Energy Agency predicts global transportation to double and car ownership rates to increase by 60%. These factors combined would result in a large increase in transport emissions (Ritchie, 2020). Examining the effects of gasoline powered engines in the United States, the United States Environmental Protection Agency estimates that 29% of the United States' greenhouse gas emissions is due to the transportation sector and 82% of the transportation sectors' greenhouse gas emissions is from light, medium, and heavy-duty vehicles (Fast Facts on Transportation Greenhouse Gas Emissions, n.d.). According to the United States Department of Energy, an all-electric vehicle emits one third of the annual greenhouse gases that a gasoline powered car emits and provide motivation for federal and state governments to incentivize consumers to purchase EVs to slow the rate of future climate change.

Even though there might be a reemergence of demand for these vehicles nowadays, it has not always been that way. After the 2006 documentary *Who Killed the Electric Car?*, the EV industry appeared obsolete. The film explored the creation, limited commercialization, and subsequent destruction of BEVs in the United States. The primary vehicle in focus during this film was General Motors' EV1, which was introduced to the marketplace in the mid-1990s (see

Figure 1). The EV1 was the first of its kind and revolutionized the industry by offering consumers 70 – 90 miles of range on a single charge. However, GM cited high build costs and a small customer base which led to its' demise (Brown, 2019). Presently, automakers are back again, trying to convince consumers that EVs are the future.

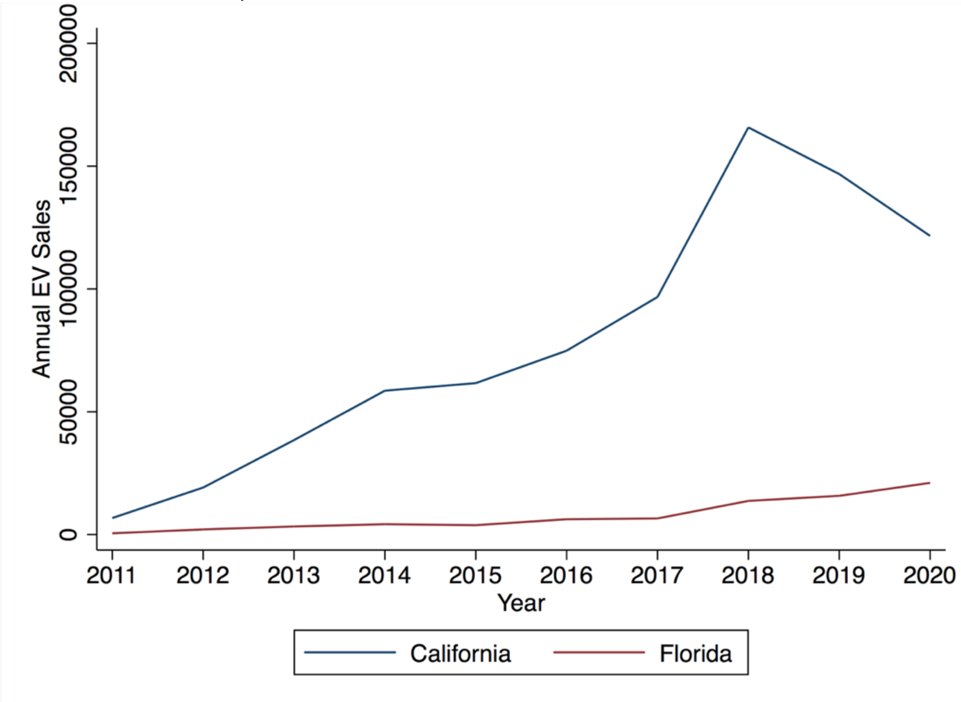
Figure 1. General Motors' EV1

Note. From GM EV1 History by A. Brown, 2019.

Automakers have the support of the Biden Administration who aim at increasing sales through a current GOP bill. In addition, the current federal infrastructure bill will see $174 billion directed towards improving the charging infrastructure across the country. "Dotting the interstate-highway corridors with charging stations is considered a priority because it will give EV motorists confidence that they can take long-distance trips without the trouble of recharging" (Puko, 2022). Battery range is an important issue in the mind of prospective EV owners and improvements to the charging infrastructure will help alleviate this stress.

When analyzing the current landscape of EVs in the United States, California has emerged as a leader in sales. Referring to Figure 2, from 2011 to 2020, California has sold 790,402 EVs, which is 10 times more than Florida with 77,399 EVs sold. Interestingly, Florida is second behind California in the number of EVs sold. This sales increase in California might be driven by their numerous tax incentives for the purchase of an EV and the operating cost of owning one. This graph is the motivation behind this paper, which is to understand why some states see higher sales than others through the perspective of tax state incentives.

Figure 2. Annual Sales of EVs, California & Florida



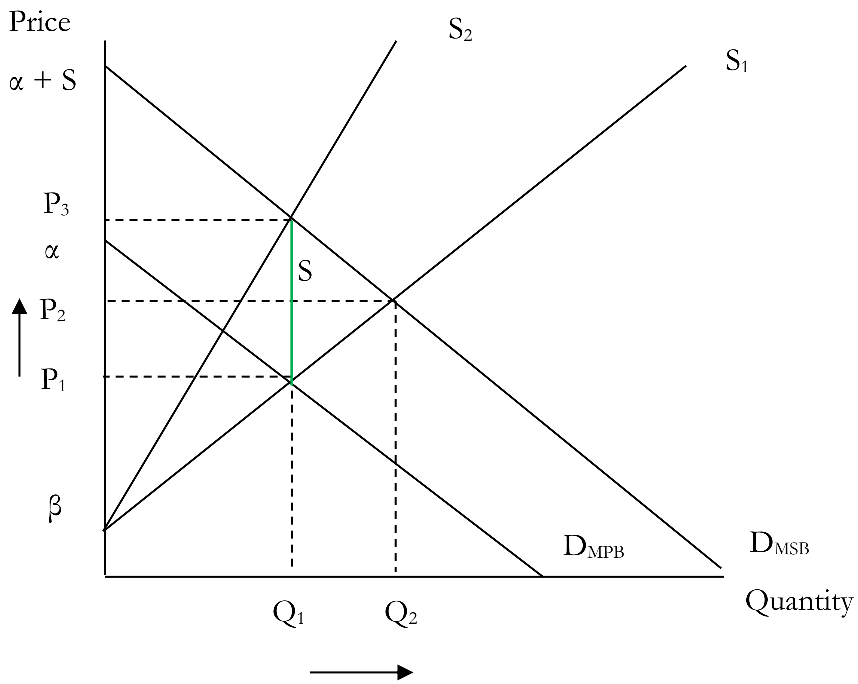
The following research is categorized by these sections; Economic Logic of Subsidies, Literature Review, Discussion of Data and Variables, Analytical Framework, Discussion of Results, Robustness Checks, Limitations, Future Work, Policy Implications, and Conclusion.

Economic Logic of Subsidies

Federal and state tax incentives are a form of a government subsidy. A subsidy is a direct payment to individuals or firms that are used to offset externalities and achieve greater economic efficiency (Scott, 2022). The EV market exhibits a positive externality because EVs are omitting less harmful emissions than a normal combustion powered engine. This reduction in harmful emissions benefits more than just EV owners but the general society, thus, the government would want to subsidize this market. Referring to Figure 3, S, the length of the green line or the vertical difference between D_{MPB} and D_{MSB}, represents the value of the tax incentive. In the case of the federal vehicle tax credit, this vertical distance would be $7,500 if the vehicle purchased qualified for the full amount. For the purchase of a new EV, a consumer would receive $2,500 plus $417 per each kilowatt-hour of battery capacity over 4 kWh. The specifics of federal and state tax incentives will be discussed in the literature review section. Thus, by offering this allotted amount, the government is stating the presence of electrical motor component saves society $2,500 worth of harmful emissions. The government is also stating every additional 4 kWh saves society $417 in harmful emissions. However, even with these benefits, the federal and state tax incentives are considered a regressive tax. The funding for these incentives is supplied by the income of the individuals and households across the country. As mentioned, the demand for any type of vehicle is generally a replacement demand affected by macro-environment factors, thus a majority of the individuals purchasing EVs are considered to be from medium to high-income. Liu et al. (2022) found that low-income households in the United States do not have equal accessibility to the EV federal tax credit compared to high-income households. Thus, low-income households are paying the tax but are not able to take advantage of this subsidy.

To analyze the effects of a subsidy on the equilibrium price and quantity, I assign Greek letters to the values of the y-intercepts and slopes of the demand and supply curve, I am able to analyze the effects of a subsidy on the equilibrium price and quantity. First, I solve for equilibrium quantity and price, Q^* and P^*. Adding S, the value of the subsidy, I can understand the specific effects of the subsidy. From Q^T, which is the equilibrium quantity with the tax incentive, one could see that as S increases, the equilibrium quantity also increases, this results in an increase in demand from Q_1 to Q_2. From P^T, which is the equilibrium price with the tax incentive, one could see that as S increases, the equilibrium price exponentially increases. Finally, if the supply of EVs is inelastic, this market would shift supply from S_1 to S_2. This means σ, the slope of the supply curve, would increase. One could argue the supply for vehicles is relatively inelastic because manufacturers must order parts and components in advance in order to build a vehicle. From P^T, if we are using the slope of S_2, one could see that the price level exponentially increases as the government introduces a subsidy, S.

Figure 3. Supply & Demand of Consumer Subsidy



D_{MPB} represents marginal private benefit
D_{MSB} represents marginal societal benefit
γ represents the slope of D_{MPB}
σ represents the slope of S_1
α represents the value of the y-intercept for the D_{MPB}
β represents the value of the y-intercept of S_1
S represents the vertical distance between D_{MPB} and D_{MSB} or the dollar value of the subsidy
α + S represents the value of the y-intercept for D_{MSB}

$$Demand = P^D = \alpha - \gamma(Q^D)$$

$$Supply = P^S = \beta + \sigma(Q^S)$$

$$Equilibrium: \alpha - \beta = (\gamma + \sigma)Q^*$$

$$Q^T = \text{Equilibrium quantity with subsidy}$$

$$P^T = \text{Equilibrium price with subsidy}$$

$$Q^* = \frac{\alpha - \beta}{\gamma + \sigma}$$

$$P^* = \alpha - \gamma \frac{\alpha - \beta}{\gamma + \sigma}$$

$$P^* = \frac{\alpha\sigma + \gamma\beta}{(\gamma + \sigma)}$$

$$Q^T = \frac{(\alpha + S) - \beta}{\gamma + \sigma}$$

$$P^T = \frac{(\alpha + S)\sigma + \gamma\beta}{(\gamma + \sigma)}$$

Literature Review

Overview of EV Industry

This overview section is taken from "Electric Vehicles Industry Report, 2021" (Rook, 2021).

Thanks to William Morrison, a chemist from Des Moines, Iowa, the first successful introduction of an EV was in 1890. Over the next several years, EVs from different automakers began popping up across the United States. By 1900, electric cars were in their heyday. However, this period of success did not last very long. In the early 1900s, Henry Ford's mass-produced Model T exploded into the automobile industry, forcing EVs to take the back seat. Arguably, the 1960s and 1970s are the "dark ages" for the EV industry. Lower-price, abundant gasoline-powered vehicles dominated the marketplace, which hampered the demand for alternative fuel vehicles (Department of Energy, 2014). The 1990 Clean Air Act and 1992 Energy Policy Act renewed interest in EVs (Department of Energy, 2014). Reflecting on the history of EVs reveals a bumpy and long evolution.

Two events are credited with sparking renewed interest in EVs. In 1997, the Toyota Prius was introduced in Japan. In 2000, the Prius was released worldwide and became an instant success.

Since then, continued rising gasoline prices and growing concern about carbon pollution have helped make the Prius the best-selling hybrid worldwide for the past decade (Department of Energy, 2014). The second event considered an industry turning point was in 2006 when a small Silicon Valley startup, Tesla Motors, announced it would start producing a luxury electric sports car that could go more than 200 miles on a single charge. The Prius and Tesla have paved the way for other automakers to make their mark in this growing industry.

Nowadays, there are many different types of EVs available to consumers. A fuel cell electric vehicle (FCEV) is a vehicle that uses a propulsion system where energy is stored as hydrogen and is converted to electricity by the fuel cell. A plug-in hybrid electric vehicle (PHEV) is a vehicle with plug-in capability and uses energy from its electrical battery or combustion engine. Finally, a battery electric vehicle (BEV) is a vehicle that only uses energy from its electrical battery and can only recharge via a plug. Table 1 shows the current EV offerings for consumers in the United States by vehicle type. Some of these EVs are low-priced fuel-efficient options for consumers. For example, the 2022 Toyota Prius has a MSRP of $24,625 and has a highway miles per gallon (mpg) of 53 and a city mpg of 58. However, the electric engine component in some of the other vehicles in Table 1 are not used for better mpg but rather for engine performance. The 2020 Ferrari SF90 Stradale has a MSRP of $625,000. With its three electric motors, this EV gains an additional 217 more horsepower (Duff, 2020). To further differentiate vehicle categories, industry standards define light-duty vehicles (i.e. passenger cars) as having a maximum gross vehicle weight rating of less than 8,500 lbs. Medium-duty passenger vehicles have a gross vehicle weight rating of 8,501 lbs to 10,000 lbs. A majority of the available EVs on the market are categorized as a light-duty vehicle, however, automakers have started to bring trucks/medium-duty vehicles to the marketplace. For example, the Rivian R1T, a medium-duty pickup truck was introduced in 2022.

Table 1. Available EVs on US Market

FCEV	BEV	PHEV
Honda Clarity Fuel Cell	Audi e-tron	Audi A7 e
Hyundai Nexo	Audi RS e-tron GT	Audi A8
Toyota Mirai Fuel Cell	BMW i3	Audi Q5
	Chevrolet Bolt EV	Bentley Bentayga
	Ford Mustang Mach-E	BMW 330e
	Hyundai Kona Electric	BMW 530e
	Jaguar I-PACE	BMW 745e
	Kia Niro EV	BMW X3
	MINI Cooper SE Hardtop	BMW X5
	Nissan LEAF	Chrysler Pacifica
	Polestar 2	Ferrari SF90 Stradale
	Porsche Taycan	Ford Escape
	Rivian R1T	Honda Clarity Plug-In
	Tesla Model 3	Hyundai Ioniq Plug-In
	Tesla Model S	Hyundai Santa Fe
	Tesla Model X	Hyundai Tucson
	Tesla Model Y	Jeep Wrangler 4xe
	Volkswagen ID.4	Karma GS-6
	Volvo XC40 Recharge	Karma Revero
		Kia Niro Plug-In Hybrid
		Kia Sorento Plug-In Hybrid
		Land Rover Range Rover
		Lincoln Aviator Grar
		Lincoln Corsair Grar
		MINI Cooper SE Coupe
		Mitsubishi Outlander
		Polestar 1
		Porsche Cayenne S
		Porsche Panamera 4S
		Subaru Crosstrek Hybrid
		Toyota Prius Prime
		Toyota RAV4 Prime
		Volvo S60
		Volvo S90
		Volvo V60
		Volvo XC60
		Volvo XC90

Electric Vehicle Demand

To understand the effects of government incentives on the market penetration of EVs, I must examine the factors impacting the demand for these vehicles. In a basic supply and demand model, the factors that can shift demand are; changes in consumer tastes/preferences, fluctuation of the number of the buyers, changes in the prices of related goods, and changes in consumer expectations. The demand for any automobile is influenced by economic and demographic factors. For example, the demand for a new car is predominantly a replacement demand. Also, because the purchase of a new car can be postponed, market demand can be quite volatile (Brock, 2016). Additionally, the purchase of an automobile represents a significant investment and the demand for new cars is highly sensitive to macroeconomic conditions, including income, unemployment, and interest rates (Brock, 2016).

Federal Government Incentives

In the United States today, individuals are eligible to receive up to $7,500 as a tax credit when they purchase a qualified EV. This federal tax incentive was introduced in 2008 with the implementation of the Energy Improvement and Extension Act. This incentive applies to EVs purchased after December 31, 2009. The amount each consumer receives depends on the specific vehicle they choose to buy. For the purchase of a new EV, a consumer would receive $2,500 plus $417 per each kilowatt-hour of battery capacity over 4 kWh (U.S. Department of Energy's Vehicle Technologies Office, n.d.). Thus, vehicles with higher battery capacity will be eligible for a higher tax credit. This tax credit is applied to the individual/household’s annual tax bill. They will not receive a refund check for the difference if the tax bill is less than the amount the consumer is eligible for. For example, an individual purchases a new Prius and qualifies for the full $7,500 tax credit. Their tax bill is $5,000. They will only receive $5,000 and not the full

$7,500 tax credit. In addition to this federal tax credit, the federal government also offers a charging station incentive. This incentive states that individuals are eligible to receive up to 30% off a JuiceBox home charging station, plus installation costs up to $1,000. The consumer must purchase and install the JuiceBox by December 31, 2021, as well as claim the credit on their federal tax return (Federal and State Electric Car Tax Credits, Incentives & Rebates, n.d.).

While the federal tax incentive may have a significant positive effect on the number of EVs sold, it might not be as beneficial as one would think. Diamond (2009) conducted a study examining the effects of federal government incentives on the number of hybrid-electric cars purchased. Diamond's (2009) results found that the federal incentive had no significant effect on the number of hybrids purchased. It is important to note that this study was conducted in 2009. Since that time, the characteristics and capabilities of EVs has grown tremendously, which has resulted in an increasing number of EVs on the road. Furthermore, it is interesting to note that Diamond's (2009) results showed a strong relationship between gasoline prices and the number of EVs sold. While this does not directly relate to government subsidies, gasoline prices do play a major role in this scenario. The data in my analysis will examine Diamond's (2009) findings.

To further explore why federal incentives do not have a significant positive effect on market penetration, Liu et al. (2022) give a potential reason for why this incentive has not reached its' intended target. By aggregating the number of households and population by tax filing status, income level, and the number of children in the state of Georgia, the authors were able to create an estimated federal income tax equation. The analysis found that low-income households in the United States do not have equal accessibility to the EV federal tax credit compared to high-income households. It would not be as beneficial for a low-income family to purchase an EV because the initial purchase cost (including the tax incentive) would be higher compared to a gasoline-powered automobile. However, it is important to note that consumers considered more than the upfront cost of a vehicle. Specifically, for EVs, consumers may consider the number of charging stations nearby, the price of gasoline, and many other factors. By accounting for these variables, my paper will be able to differentiate the effects on the demand of EVs. The authors were also able to use demographic data to analyze racial groups' accessibility to this incentive. The authors state 20.2% of Black households and 29.1% of Hispanic households in the surveyed demographic qualified for the full tax credit, while 42.1% of White households qualified for the full amount. These results indicate a clear equity issue related to this government incentive. It will be imperative for the government to create an incentive program that is equitable to all income levels in the United States. My research will comment on the future of government incentives and weighs in on modifications the government should take to be equitable for all consumers.

State Incentives

Compared to the federal tax incentive, state tax incentives differ from state to state. Some states do not have any incentives while others offer rebates on the cost of the vehicle and an at-home charging unit. State incentives can be categorized into four major sections; charging station incentives, vehicle tax credits and rebates, electricity discounts, and driving perks. For example, New York's "Plug-in Electric Rebate Program" states that consumers are eligible for rebates of up to $2,000 for the purchase or lease of qualified new plug-in EVs (Electric car tax credits & incentive, 2021). Delaware does not offer an incentive for the cost of EVs, but instead offers an "Electric Vehicle Supply Equipment Rebate" which offers amounts to 50% of the cost of a residential charging station (Electric car tax credits & incentives, 2021). Finally, Alaska, Kentucky, and North Dakota do not offer any incentives at all.

In addition to his examination of the federal tax incentive, Diamond (2009) analyzed the effects of state-level incentives. Diamond used a cross-sectional model for hybrid vehicle market share which he derived from the behavioral utility function vehicle demand presented by Berry et al. (1995). Diamond (2009) used a log-log model due to a better fit to the data than OLS methodology. From this model, Diamond (2009) is able to interpret the coefficient of his independent variables as the elasticity of market share with respect to that specific independent variable. Diamond (2009) ran these models with the market share of the Toyota Prius, Honda Civic Hybrid, and the Ford Escape Hybrid representing his dependent variables. These specific vehicles may have been popular during the time of Diamond's (2009) analysis but represent only a few options available for consumers. My work will aim to fill this gap by providing an examination of all EVs, not just specific models. At the time of his analysis, Diamond (2009) found that in Connecticut, Florida, and Virginia the implementation of a state incentive was consistent with significant changes in the number of EVs on the road. As previously noted, Diamond's (2009) analysis was conducted in 2009 and used data ranging from 2001 to 2006. Since that time many states have implemented new incentives to encourage consumers to purchase EVs. Also, the mood around EVs have changed since this time as more individuals are choosing to be more environmentally friendly. My work will look to comment on the impact of new state tax incentives. Similar to Diamond's findings, Gallagher & Muehlegger (2011) found that state tax incentives are positively correlated with increased hybrid vehicle adoption. Gallagher & Muehlegger (2011) analyzed quarterly state-level data from 2002 – 2006 and estimated the relationship between hybrid sales and incentives by regressing the log of per-capita sales on state-level hybrid incentives while also accounting for state and time fixed effects. It is important to note that the Gallagher and Muehlegger (2011) study used hybrid vehicle adoption as their dependent variable and not BEV, PHEV, or FCEV. For this paper, I will differentiate the effects of state-level incentives on the number of BEVs, PHEVs, and FCEVs sold in each state. A critique of Gallagher and Muehlegger's (2011) work is that the authors only focused on the most valuable state incentives. They omitted variables such as local incentive programs including parking fee waivers and state vehicle registration fee waivers. This characteristic of Gallagher and Muehlegger's paper will be a point my paper looks to improve upon. The further exploration of my analysis will examine the current EV industry and state tax incentive's effect on EVs sold.

In the United States today, California is the "gold standard" for EVs because of the numerous incentives for the purchase and ownership of EVs, including parking incentive programs, charging unit rebates, and rebates on a replacement battery. Furthermore, California was one of the first states to pledge to be all-electric by 2035. Since this announcement in March of 2022, other states such as Washington, New York, and Massachusetts have also made this pledge. Leading the electric charge, California has seen a dramatic increase in the number of EVs on their roads. According to data used in this paper from the "U.S. Light-Duty Advanced Technology Vehicle Sales", from 2011 to 2020, there have been about 800 thousand EV sales recorded in California. This figure compares to Florida, which has the second most recorded sales of just over 70 thousand in the same period (Alliance for Automotive Innovation, 2021). While there are significant differences in policy and incentives between California and Florida, this comparison proves how advanced California is compared to other states. My analysis will examine whether there is specific characteristics of California driving this EV growth and determine if other states should consider adopting these trends.

Barriers and Drivers of Adoption

EVs are becoming more popular in the United States due to their low emission characteristics, however, there are still some major barriers that prevent mass-scale adoption. Through their survey of 500 prospective EV owners, Egbue and Long (2012) found that the three main obstacles preventing mass-scale adoption are high purchasing costs, lack of charging infrastructure, and limited battery range. It is important to note that a majority of the respondents in Egbue and Long's (2012) survey were EV owners, which give opportunity to biases playing a role in how they filled out the survey. It would have been better to survey non-EV owners to understand their reasons for not purchasing one. However, the themes Egbue and Long (2012) found are consistent among other literature and serve as a foundational discussion point. While the number of charging units has increased over the past 10 years and there are more options for buyers, some individuals are still reluctant to switch to electric. This reluctance is driven by the public's perception of EVs. While the arguments that Egbue and Long (2012) present are common across relevant literature, there are some aspects of EVs that are drivers for mass-scale adoption. This section of the literature review will outline and supply foundational knowledge on each of these major barriers.

The most commonly noted barrier across relevant literature is the high purchasing costs of EVs. Since their reemergence on the market, on average, EVs have always been priced higher than internal combustion engine vehicles (ICEV) due to the high cost of the battery. In 2010, the cost of a PHEV was $41,000, while the average cost of a comparable ICEV was under $30,000 (Gohlke, 2021). For individual EV models across different brands, the prices have largely dropped or stayed steady; however, consumers have opted for more expensive models, which has increased the average costs of EVs (Gohlke, 2021). Although the upfront cost of an EV is higher, there are non-priced related advantages. The operating costs of EVs are less than that of a ICEV because with current prices electricity is cheaper than gasoline. In their review of the industry, Rezvani et al. (2015) support this argument by stating the high purchasing costs of EVs serve as a barrier. However, they also claim the low operating costs of EVs serve as encouragement for adoption. To examine this cost relationship more closely, Liu et al. (2021) used a total cost ownership (TCO) model to calculate the number of years needed for the owner to recoup the higher purchase price of a BEV. Liu et al.'s (2021) main model is broken down into the initial cost and operating cost of a vehicle. The initial cost is comprised of the vehicle price, registration fees, and home charger cost for EVs. The operating cost is comprised of maintenance costs, insurance premiums, fuel consumption cost, annual registration fee, and alternative transportation cost. The TCO model controls for environmental factors such as greenhouse gas emissions, social factors, and consumer interests such as purchase price, operating costs, and performance. The authors found a break-even point of 6 years before EVs become more cost-efficient. Due to limited data, Liu et al.'s (2021) paper could only analyze powertrain costs and weight from three EVs: the Chevrolet Bolt, Tesla Model 3, and the Jaguar I-Pace. Although these might be some of the more popular EV models, there are many more options for consumers (see Table 1). The data used for this paper will provide a more holistic view. By using specific price levels, I will be able to analyze the effect of price on the market penetration of EVs. In closing, the upfront costs of EVs are seen as a deterrent for mass adoption, but if consumers are more future-focused they could benefit by purchasing an EV due to low operating costs.

The next major barrier that Egbue and Long (2012) discuss in their paper is the lack of charging infrastructure available for EV owners. EV charging and ICEV refueling hold different characteristics. Therefore, they need to be treated differently when it comes to infrastructure.

Currently in the United States, there are three main types of charging stations; Level 1, Level 2, and DC Fast. Level 1 charging stations will provide users with 2 to 5 miles of range per 1 hour of charging. Level 2 charging stations will provide 10 to 20 miles of range per 1 hour of charging. Finally, DC Fast Charging stations will provide 60 to 80 miles of range per 20 minutes of charging (U.S. Department of Energy, n.d.). Since 2010, the number of public charging ports in the United States has dramatically increased. According to data from Alternative Fuels Data Center, in 2010, there were 25,518 public charging units available for consumer use. Currently in 2021, there are 108,636 public charging units available for consumer use (U.S. Department of Energy, n.d.). The majority of chargers are Level 2 and DC Fast charging units, which are more efficient. These public stations are useful for longer trips that require multiple charges or for individuals who do not have the accessibility of at-home charging. At-home charging has become increasingly popular with 80% of EV drivers charging their cars at home (Voelcker, 2021). Companies such as ChargePoint, JuiceBox, Grizzl-E, and EVoCharge all make charging units for consumers to charge their vehicle in the privacy of their own home with innovative features such as smart connectivity and outdoor charging. Similar to public stations, most of the at-home chargers are Level 2 charging units because they can charge EVs at a faster rate compared to Level 1 units. Level 1 charging units might be convenient because they can use a standard 110-volt wall outlet, but this method would take almost 24-hours to complete a full charge. By utilizing a 240-volt outlet, Level 2 chargers can bring an EV to full charge in about 4-hours. Even with all the improvements in infrastructure and technology, the United States must grow its infrastructure at a rapid pace to keep up with demand. The International Council on Clean Transportation estimates that public and workplace charging will need to grow from approximately 216,000 chargers in 2020 to 2.4 million by 2030, including 1.3 million workplace, 900,000 public Level 2, and 180,000 direct current fast chargers (Bauer et al., 2021). The year 2030 will be a milestone year in the EV industry as states such as Washington have promised to be all-electric. It is crucial that the United States government quickly increases the infrastructure to respond to growing demand. My paper will examine the gaps in the literature by looking at data from 2011 and 2020 and determine whether the increase in the number of public charging units had a positive effect on the number of EVs on the road.

Battery limitations were cited as the biggest consumer concern with 33% of respondents noting it as a barrier in Egbue and Long's (2012) study. Battery technology has improved over the past 10 years, but still poses a challenge for potential buyers. As stated earlier, battery costs are a majority of an EV price tag and is one of the most important components in the vehicle. In their "Assessment of Light-Duty Plug-In Electric Vehicles", Gohlke & Zhou (2021) argue the range of EVs has increased since 2010. They found on average, the range of BEVs has grown from 70 miles in 2010 to over 200 miles in 2020. The authors cite the introduction of the Tesla Model S as the main reason for the steep incline. The Model S had a range of 265 miles, which forced other competitors to advance their technology to be competitive in the marketplace. However, even with all of these advancements it might still be challenging for EVs to compete with ICEVs. In their industry report, Haddadian et al. (2015) note that "a Nissan LEAF offers about 20 percent of the range of a similar conventional vehicle." Due to this lack of range, purchasing an EV would not be beneficial for consumers who have to commute far distances daily. Many authors within the automobile industry identify this characteristic as range anxiety. Range anxiety refers to what an electric driver feels when the battery charge is low and the usual sources of electricity are unavailable. It sparks fear of getting stranded somewhere, which adds time, inconvenience, and stress to a journey (Wardlaw, 2020). Should consumers be worried about the range of these new EVs? While this anxiety can be very real for consumers in a dire situation, the average United States vehicle travels less than 40 miles per day, so an EV with a range of at least 120 miles should be more than adequate for most users (Voelcker, 2021). Furthermore, some experts say to alleviate this stress consumers should purchase an at-home charging unit, find local public charging ports, or use a gasoline-powered vehicle for long road trips. While my paper does not have an independent variable accounting for this increase in battery technology, it is still a very important factor in the decision-making process.

A final barrier to full scale adoption is the way certain social groups view EVs. To understand this dynamic, Egbue and Long (2012) cite the theory of planned behavior (TPB) (Azjen, 1991), which states principle determining factors influencing behavioral intention are attitudes. Consumer attitudes are influenced by knowledge and experience, subjective norms, and the perceived impact of the behavior. TPB explains why some consumers will decide to purchase an EV and some will not based on their perceived knowledge of the EV industry. Looking from the technological viewpoint, Egbue and Long (2012) reference individual resistance to new technology as being “alien” or “unproven.” Some consumer groups might be unaware of the potential benefits of owning an EV, which explains the reluctance they would have when deciding to purchase one. However, early adopters might want to own an EV as soon as they come out. Rezvani et al. (2015) dive deeper into this dynamic by analyzing the situation from a societal viewpoint and discussing the symbol an EV represents. Referring back to TPB, the authors found that certain groups of people do not want to feel embarrassed or associated with the lifestyle of an EV. This lifestyle can be described as “slow-moving” or “green-driving” by social standards and would serve as a barrier for EV adoption. There is the other side of this conversation with people who want to be seen as “environmentally friendly.” Haddadian et al.

(2015) found that the transportation sector accounts for 22.34% of the world's C02 emissions from fuel combustion. Furthermore, Egbue and Long (2012) concluded the elimination of the use of petroleum was the most appealing aspect of owning an EV. As people become more conscious of how their actions affect Earth's future, more people may feel obligated to switch to EVs.

Political Affiliation

As mentioned, cars can serve as a status symbol for consumers but they can also represent a certain belief system of the buyer. According to Sintov et al. (2020), political identity can predict various consumer behavior. It is a generally accepted notion that individuals who "identify as liberal or Democratic are more likely to believe in climate change, express higher levels of environmental concern, and engage in more pro-environmental behaviors than those who identify as conservative or Republican" (Sintov). Sintov et al. (2020) surveyed 900 respondents from seven counties in central Ohio who either had a bachelor's degree or an annual household income of greater than or equal to $100,000. Respondents were asked to answer seven questions by using a 7-point Likert scale. Through ordinary least squares (OLS) methodology, Sintov et al. (2020) found that generally Democrats living in the United States were significantly more likely to adopt EV technology compared to Republicans. Their paper is useful in understanding the effects of political affiliation on the EV market in the United States, but this analysis is at an individual-level.

Currently, there are no academic papers examining the relationship between state political affiliations and the market penetration of EVs. Although, if this scenario is anything like the voting on the current GOP bill, my results would indicate a strong positive relationship between Democratic governed states and the number of EVs on the road. President Joe Biden has shared his plans for the current GOP Bill, which includes $174 billion for EV infrastructure to help combat climate change (Newburger, 2021). Within this proposed amount, $100 billion would be spent towards consumer incentives and $15 billion to improve the nationwide charging network (Newburger, 2021). These amounts are heavily argued between the Republican and Democratic parties, but that is not the main issue. Republicans argue that the current incentive program only benefits the wealthy. Liu et al. (2022) came to the same conclusion: government incentives are only incentivizing the consumers who can afford it. Another reason for Republican push back on this GOP bill is that governors will want to protect their state industries. Governors from "Big Oil" states may want to protect their overall profit margins and limit the switch from gasoline to electric. My paper will fill a large gap in the literature by analyzing the effects of whether state political affiliation plays a role in the number of EVs on the roads in each state.

Discussion of data and variables

To analyze the effects of state incentives on the sales of EVs, I collected yearly data from all 50 states ranging from 2011 to 2020. Table 2 provides the summary statistics (description, observations, mean, std. dev., min, and max) for each of the variables used in this paper. From Table 1, the standard deviation of EV sales, and the number of charging ports in each state can be relatively high because states like California have made a concerted effort to improve the EV climate in their state compared to states like North Dakota which have not. Furthermore, FCEV Sales has a minimum of 0 because fuel cell technology is a relatively new technology that was recently introduced in the marketplace. Most people have not considered purchasing a car with fuel cell technology yet and BEV Sales has a minimum of 0 in 2011 and 2012 because there were many states that did not have any BEV sales due to consumers not fully trusting battery technology at that point in time.

Table 2. Descriptive Statistics of Variables

Variable	Description	N	Mean	Std. Dev.	Min	Max
Dependent Variables						
$FCEVSALES_{it}$	Number of FCEV sales per capita	500	.06	.61	0	7.87
$BEVSALES_{it}$	Number of BEV sales per capita	500	10.71	34.66	0	392.77
$PHEVSALES_{it}$	Number of PHEV sales per capita	500	7.04	21.61	.01	265.79
$EVSALES_{it}$	Number of EV sales per capita	500	17.81	54.44	.01	650.12
Independent Variables						
$STATEGAS_{it}$	Average state gas price	500	2.58	.69	.98	4.61
$CHARGEPORT_{it}$	Number of public charging ports	500	367.05	713.41	0	7671
$AVGCHARGETAX_{it}$	Average value of charging station incentive	500	983.95	1508.54	0	7500
$AVGVEHICLEINC_{it}$	Average value of vehicle rebate incentive	500	541.55	1188.74	0	5000
$AVGELECTDIS_{it}$	Average value of electricity discount	500	61.5	200.53	0	1200
$FCEVPRICE_{it}$	Average price of all FCEVs	300	57644.33	1112.38	55913	68750
$BEVPRICE_{it}$	Average price of all BEVs	500	52513.6	8910.87	34376	68446
$PHEVPRICE_{it}$	Average price of all PHEVs	500	39833.4	2855.98	35653	44940
$EVPRICE_{it}$	Average price of all EVs	500	46720.9	5807.64	36958	55297
$LDVPRICE_{it}$	Average price of ICE LDV	500	26397.7	537.53	25747	27221
$AGI25_{it}$	Adjusted Gross Income, 25th percentile	300	80915.1	10423.48	58659	109375
$CHARGEINC_{it}$	State offers charging station incentive	500	.8	.4	0	1
$VEHICLETAX_{it}$	State offers vehicle rebate incentive	500	.18	.38	0	1
$ELECTDIS_{it}$	State offers electricity discount	500	.3	.46	0	1
$DRIVEPERK_{it}$	State offers driving perk	500	.04	.2	0	1
$GOVAFF_{it}$	State governor political affiliation	500	.394	.49	0	1

Dependent Variables

To examine the market penetration of EVs by state, I will use a form of yearly EV sales per capita by state as my dependent variable for all the regression models. I want to note that I understand this is not an ideal measurement of how to analyze the effects of state tax incentives. It would be ideal to have individual-level data because two consumers deciding to purchase an EV in New York City may be considering different factors when purchasing an EV due to their race, gender, and income. This limitation will be discussed further. There are four different models each with its own dependent variable. These dependent variables represent the number of EVs per capita sold in state *i* in year *t*. The four different dependent variables are; FCEV sales ($FCEVSALES_{it}$), BEV sales ($BEVSALES_{it}$), PHEV sales ($PHEVSALES_{it}$) and all sales ($EVSALES_{it}$). Data was extracted from The Alliance for Automotive Innovation's "U.S. Light-

Duty Advanced Technology Vehicle (ATV) Sales Dashboard" and yearly sales span from 2011 to 2020. Sales figures were divided by estimates of state population from 2011 to 2020, which were recorded from the United States Census Bureau. Gallagher and Muehlegger (2011) also used a form of vehicle sales per capita as their dependent variable to explain the effects of state-level incentives on the adoption of hybrid vehicle technology. Instead of using per capita, they used vehicle sales per thousand people. The Honda Fit EV, Honda FCX Clarity, BMW ActivEare, nonhighway-capable EVs, electric commercial vans, electric motorcycles, and medium/heavy-duty vehicles are excluded from this data (Alliance for Automotive Innovation, 2021). Thus, the data may underestimate the number of EVs on the road in each state. The source of my data did not include medium-heavy-duty EVs because of their recent introduction into the marketplace. Finally, the number of HEV sales was recorded before the creation of my empirical model, however, I decided not to use this measurement as a dependent variable. Rezvani et al. (2015) "argue that even though HEVs have been considered as EVs in some previous research, they are mainly fuel-efficient cars that do not require a drastic behavior change by consumers." I support this decision by arguing HEVs do not qualify for any federal or state level tax incentive, nor do they have the capability of plugging into a charging station.

Independent Variables

The main motivation of this paper is to analyze the effects of state tax incentives on the number of EVs purchased. Thus, these state incentives will serve as my main independent variables. As mentioned in the literature review, different states offer a variety of incentives and rebates for either the purchase of an EV or at-home charging units. Through OLS methodology, I will be able to analyze the effects of each of these rebates on the market penetration of EVs. For state incentive data, I referenced EnelX's "Federal and State Electric Car Tax Credits, Incentives

& Rebates." There are four main categories to the incentives offered by states; charging station incentives ($CHARGEINC_{it}$), vehicle tax credits & rebates ($VEHICLETAX_{it}$), electricity discounts ($ELECTDIS_{it}$), and driving perks ($DRIVEPERK_{it}$). These four independent variables are also dummy variables that are representative of all years I have data for (2011-2020) and are equal to 0 if the state does not offer any incentive and equal to 1 if the state offers an incentive in each specific category.

I will not be regressing the federal tax incentive on EV sales because theoretically all consumers should have access to this incentive even though Liu et al. (2022) argue this is not true. In addition to the dummy variables for whether the state offers a specific incentive, I also recorded the average value of the rebates for each state to further understand the effects of these incentives. The average charge incentive rebate value ($AVGCHARGEINC_{it}$), the average vehicle tax credit value ($AVGVEHICLETAX_{it}$), and the average electricity discount value ($AVGELECTDIS_{it}$) are all measured in dollars. The average driving perk discount was not recorded because there was no dollar value to the specific perks that states offered. In their paper, Gallagher and Muehlegger (2011) also use the value of the state tax incentive as one of their independent variables to understand its effect on the number of hybrid sales.

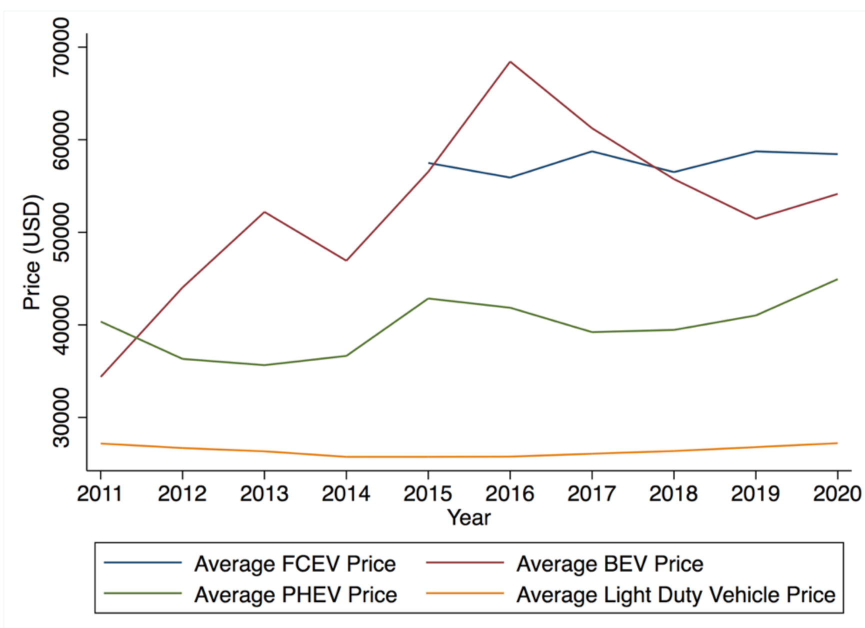
As discussed in the literature review, one factor that can affect demand is changes in the prices of related goods. Related goods refer to substitute goods and compliment goods. Gasoline can be seen as a substitute for electricity thus price changes in gasoline will impact the demand for EVs. The data for state gas prices ($STATEGAS_{it}$) was found via U.S. Energy Information Administration and represents all formulations of retail gas prices in dollars. Data ranges from 2011 to 2020. Data for national level gas prices was taken but due to collinearity issues, this variable had to be dropped. State-level gas prices are more relative because consumers purchase gas locally. Diamond (2009) and Gallagher and Muehlegger (2011) also use gasoline prices as an independent variable in each of their studies to understand its effect on the number of EV sales.

While gasoline is a substitute for EVs, charging ports are categorized as a complement to EVs. As discussed in the literature review, charging port availability is noted as one of the major barriers to mass-scale adoption (Egbue & Long, 2012). The changes in the availability of these stations, in theory, will impact demand. The number of charging ports ($CHARGEPORT_{it}$) in each state were collected from the Alternative Fuels Data Center "Locate Stations" dashboard. This dashboard records the number of public charging stations by state and by year ranging from 2011 to 2020. At-home charging ports are also a complement good to EVs and play a role in their demand. At-home charging ports are accounted for in the charging station incentive variable ($CHARGEINC_{it}$).

Another important factor that can affect demand is the price levels of these vehicles. The price levels of all EVs ($EVPRICE_{it}$), FCEVs ($FCEVPRICE_{it}$), BEVs ($BEVPRICE_{it}$), and PHEVs ($PHEVPRICE_{it}$) were taken from Gohlke and Zhou's (2021) "Assessment of Light-Duty Plug-In Electric Vehicles in the United States." These statistics are sales-weighted MSRP in thousands of dollars for vehicles available from 2011 to 2020 and account for the base trim model of each vehicle type. In reviewing Table 2, BEVs had the highest average price of $52,514 and PHEVs had the lowest average price of $39,833. BEVs exhibit higher purchase costs because these vehicles require larger batteries compared to the smaller batteries in a PHEV. From my literature, review I learned that the larger the battery the higher the cost. Data for prices of FCEVs is only recorded from 2015 to 2020. From 2011 to 2015, there was only one FCEV on the market, the Honda FCX Clarity. This car was only available to consumers in California for a three-year lease at $600 a month (Blackwood, 2019). Due to this restriction, I was not able to determine a MSRP value of this car. From 2015 to 2020, there were three FCEV options available to consumers.

I also collected data on the price level of internal combustion engine light-duty vehicles (ICE LDVs) ($LDVPRICE_{it}$) to understand how the price levels of substitutes affect the demand for EVs. I chose LDV vehicles because they are most similar to EVs in size, capacity, and range. The data measured in thousands of dollars was collected from the U.S. Department of Energy's "Average Price of a New Light Vehicle" and spans from 2011 to 2020. The average price for an LDV over the period examined is $26,398. As examined in Figure 3, all three EV categories are more expensive than ICE LDVs. Referring back to the literature review, Gohlke & Zhou (2021) mention that even though price levels are decreasing for EVs, consumers are opting for more expensive models, thus, raising the average price of the vehicles. This trend can be shown in Figure 4, along with the lower average prices of LDVs compared to EVs.

Figure 4. Average Price Levels by EV Category



Changes in consumers' income are also a major factor for shifts in demand. To account for, I have collected data on income percentiles by state from 2013 to 2018. Instead of an average or median income statistic, percentiles will give a more holistic view of how income plays a role in the demand for EVs. As mentioned in the literature review, Liu et al. (2022) argue that low-income individuals and families do not have the same access to the federal tax incentive compared to high-income individuals and families. Due to the data collected for this paper, I will not be able to comment on that specific issue, but I will be able to comment on how income percentiles affect the demand for EVs. The income percentiles were collected from the Internal Revenue Service (IRS) and represent Adjusted Gross Income (AGI) in dollars. The percentiles recorded were the 1st, 5th, 10th, 25th ($AGI25_{it}$), 50th, and 75th. However, due to collinearity issues, I had to only use one income variable. I decided to only use $AGI25_{it}$ to analyze wealthy individuals' decision-making when purchasing an EV. I was unable to collect data for 2011-2012 and 2019-2020, which is a limitation in this paper.

Finally, changes in tastes and preferences can affect demand. State political affiliation falls under this category. As mentioned in the literature review, Sintov et al. (2020) argue that Democratic parties are more likely to adopt EV technology than their Republican counterparts. To understand the effects of partisanship at the state level, I define state political affiliation as the political affiliation of the state governor ($GOVAFF_{it}$). I was able to collect data from the National Governors Association on each state's governor's political affiliation from 2011 to 2020. Political affiliation is categorized as either Republican, Democratic, or Independent. As shown in Table 3, out of the 500 observations recorded, Republican affiliation represents 59.8%, Democratic affiliation represents 39.4%, and Independent represents .8% of the total observations. This independent variable is a dummy variable defined as 0 if the state governor is Republican or an Independent and defined as 1 if the state governor is Democratic.

Table 3. Tabulation of State Governor Affiliation

Political Affiliation	Freq.	Percent	Cum.
Democratic	197	39.40	39.40
Independent	4	0.80	40.20
Republican	299	59.80	100.00
Total	500	100.00	

To control for state and year effects, I added a state and year dummy variables, $ST1\text{-}ST50_{it}$ & $Y1\text{-}Y10_{it}$, to the model, but these two variables were dropped in the results of my analysis.

Analytical Framework

For the empirical framework, I used Ordinary Least Squares (OLS) methodology to run each model. Beta (*β)* denotes the coefficients for the independent variables in this model. I regressed the log of the number of sales of FCEV, BEV, PHEV, and all EVs per capita on all the independent variables discussed in the data and variables section of this paper. Each price variable is matched with its dependent variable (i.e. $logFCEVSALES_{it} = \beta_6(FCEVPRICE_{it})$) Epsilon ($\varepsilon$) represents the error term in this model. The equation of the empirical model is listed below.

$$\log Y = \beta_0 + \beta_1(STATEGAS_{it}) + \beta_2(CHARGEPORT_{it}) + \beta_3(AVGCHARGEINC_{it}) + \beta_4(AVGVEHICLEINC_{it}) + \beta_5(AVGELECTINC_{it}) + \beta_6(PRICE_{it}) + \beta_7(LDVPRICE_{it}) + \beta_8(AGI25_{it}) + \beta_9(CHARGEINC_{it}) + \beta_{10}(VEHICLETAX_{it}) + \beta_{11}(ELECTDIS_{it}) + \beta_{12}(DRIVEPERK_{it}) + \beta_{13}(GOVAFF_{it}) + \beta_{14}(ST1\text{-}50_{it}) + \beta_{15}(Y1\text{-}10_{it}) + \varepsilon_{it}$$

Where,

$Y = FCEVSALES_{it}, BEVSALES_{it}, PHEVSALES_{it}, EVSALES_{it}$.

$PRICE = FCEVPRICE_{it}, BEVPRICE_{it}, PHEVPRICE_{it}, EVPRICE_{it}$

Discussion of Results

Table 4 shows the results from my OLS regression on the four different dependent variables. Each independent and dependent variable except $AGI25_{it}$ had 500 observations, $AGI25_{it}$ had 300 observations because I am missing data from the years 2011-2012 and 2019-2020. In addition, all models accounted for state and year fixed effects.

Table 4. OLS Regression Results

	(1) FCEV	(2) BEV	(3) PHEV	(4) ALL
$STATEGAS_{it}$	3.64	-.07	.05	-.02
	(0)	(.13)	(.11)	(.11)
$CHARGEPORT_{it}$		.0001	.0001	.0001
		(.0001)	(.0001)	(.0001)
$AVGCHARGETAX_{it}$	-.005	0	.0002***	.0001***
	(0)	(0)	(0)	(0)
$AVGVEHICLEINC_{it}$	-.005	-.0004***	-.0004***	-.0004***
	(0)	(.0001)	(.0001)	(.0001)
$AVGELECTDIS_{it}$		-.0006*	.001***	.0003
		(.0003)	(.0003)	(.0003)
$FCEVPRICE_{it}$	.624			
	(0)			
$BEVPRICE_{it}$		.02**		
		(.009)		
$PHEVPRICE_{it}$			-.03	
			(.02)	
$EVPRICE_{it}$				.02*
				(.01)
$LDVPRICE_{it}$	-.03	.004***	.0008***	.002***
	(0)	(.0003)	(.0003)	(.0003)
$AGI25_{it}$	.002	-.0001***	0**	0
	(0)	(0)	(0)	(0)
$CHARGEINC_{it}$		1.84***	4.01***	2.93***
		(.55)	(.48)	(.48)
$VEHICLETAX_{it}$		4.03***	1.05***	2.52***
		(.35)	(.3)	(.3)
$ELECTDIS_{it}$		.88***	1.53***	1.18***
		(.28)	(.25)	(.24)
$DRIVEPERK_{it}$		2.67***	2.55***	2.53***
		(.38)	(.33)	(.33)
$GOVAFF_{it}$		-.05	.03	.012
		(.09)	(.08)	(.07)
_cons	545.03	-86.89***	-28.64***	-50.68***
	(0)	(6.05)	(5.77)	(4.83)
Observations	500	500	500	500
R-squared	1	.97	.97	.98
State Dummy	Yes	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes	Yes

Standard errors are in parentheses
**** p<.01, ** p<.05, * p<.1*

The main research question of this paper is to see whether state incentives have a significant impact on the market penetration of EVs. To analyze the effects of these state incentives I will first look at the four state incentive dummy variables ($CHARGEINC_{it}$, $VEHICLETAX_{it}$, $ELECTDIS_{it}$, and $DRIVEPERK_{it}$). Due to collinearity issues, I had to omit $CHARGEINC_{it}$, $VEHICLETAX_{it}$, and $DRIVEPERK_{it}$ from the FCEV model. However, looking at the other results, states that offer incentives see an increase in the number of sales of EVs per capita. In the BEV, PHEV, and All models, all of these dummy variables had a positive significant impact on market penetration. $VEHICLETAX_{it}$ had the highest impact on the number of PHEVs sold per capita with a coefficient of 4.01. This coefficient means that by offering a tax incentive on the purchase cost of an EV, the state saw an increase of 4.01% PHEV sales per capita. Gallagher and Muehlegger (2011) found a significant positive effect in their analysis as their state tax incentive dummy yielded a 0.201% increase in the number of HEV sales per thousand people. As I suggested earlier, the most recent state-tax incentives do not apply to HEV vehicles nor do these vehicles require a drastic behavior change by consumers. This is a major gap my work fulfills by providing the specific effects of each type of incentive on the market penetration of varying EVs. In Model 2, a state that offered a driving perk would see an increase of 2.55% in BEV sales per capita. Furthermore, in Model 4, $CHARGEINC_{it}$ had the highest significant impact on all EV sales. With a coefficient of 2.93, states who offer an incentive on charging stations see a 2.93% increase in the number of sales of EVs per capita. $ELECTDIS_{it}$ also had positive significant coefficients, signifying a percentage increase in sales per capita if the specific state offered an electricity discount. My results are consistent with Diamond's (2009) results who found significant positive effects on market share of EVs in states who offered tax incentives. Instead of analyzing three vehicle models (Toyota Prius, Honda Civic Hybrid, and the

Ford Escape Hybrid) like Diamond (2009) did, my methodology and results comment on the total market penetration of different categories of EVs. Overall, my results provide a clear indication that states who offer EV incentives see a positive impact on the market penetration of EVs in their state. One potential issue that is important to note regarding these results is that I was unable to differentiate when states implemented different incentives. Thus, these results may not be as specific and will be discussed further in the limitations section and serves as a consideration for future work.

The average value of these state tax incentives ($AVGCHARGETAX_{it}$, $AVGVEHICLEINC_{it}$, $AVGELECTDIS_{it}$) provided some statistically significant results. However, the coefficients for all of these independent variables are approximately 0. In Models 2, 3, and 4, $AVGVEHICLEINC_{it}$ is statistically significant but the signs of the coefficients are not consistent with expectations. I would expect these coefficients to be positive because if the average value of a vehicle tax credit increased, the purchase cost would decrease. Thus, increasing demand for these vehicles.

$STATEGAS_{it}$ is not significant in any of my models and the sign of the coefficient is not consistent with expectations. Therefore, I am unable to refute or agree with Diamond (2009) and Gallagher & Muehlegger (2011). Both studies found a significant positive relationship between gasoline prices and the number of EVs sold. I would expect that the coefficient would be positive, as an increase in the price of gas would incentivize people to purchase electric, thus increasing the number of EVs on the road. State gas prices fluctuate at a volatile rate yearly and even monthly in different counties and further research would benefit from a county-level model to analyze the direct effects of the price of gas on the sales of EVs.

$CHARGEPORT_{it}$, the number of charging ports in each state, is not significant in any of the models. It was expected that the sign of this coefficient would be positive because charging stations are a complement to EVs. Thus, as the number of charging stations increases, so will the demand for EVs. Even though these statistics are not significant, the impact of $CHARGEPORT_{it}$ is very low. It is interesting that these coefficients are not significant because as Egbue and Long (2012) mentioned in their paper, the availability of charging ports plays a major role in the mass-scale adoption of EVs. I would expect that this variable would have a significant positive impact on the market penetration of EVs. With more availability of charging ports, consumers may be less worried about range anxiety, a major issue present in the minds of prospective buyers and owners.

For the income percentile, $AGI25_{it}$ had significant relationship with BEV and PHEV yearly sales in models 2 and 3. However, this coefficient for this variable is relatively low and opposite of what is expected. I would expect this coefficient to be positive because as income increases, consumers would have more disposable income to spend on EVs. I would analyze the results from model 2 by stating a $1,000 increase of the 25th percentile would decrease BEV sales per capita by .0001%. It may be the case that this variable has a low coefficient because these individuals already have the disposable income to spend on an EV and a relatively small increase in their AGI does not change their mind. Unfortunately, this variable does not allow me to directly comment on the arguments Liu et al. (2022) made in their paper because I do not have data on the incentives individual consumers used. However, the authors point out that higher-income individuals have more access to the federal tax incentive which might be one of the driving factors for this relatively small coefficient. For future work, I would like to run a model with higher income percentiles such as the 75th percentile to compare and contrast my findings.

$LDVPRICE_{it}$, which is the average price of an ICE LDV, showed significant positive effects on market penetration in models 2, 3, and 4. It would be expected that this coefficient would be positive because ICE LDVs are a substitute good to EVs. A positive coefficient would indicate that as the price of an ICE LDV increased, the number of the EV purchases increased. Specifically, the .004 coefficient in the BEV model would suggest that a $1,000 increase in the price of a LDV would result in .004% more sales of BEVs per capita. It may be worth considering that these price levels represent the MSRP value of a vehicle and not the negotiated price, thus, I may be over-estimating the true transaction cost of these specific vehicles.

Interestingly, the only significant result when analyzing the price levels of EVs was in model 2. Across all models, the effect of the price level was approximately 0. I know that the purchase of a vehicle is highly sensitive to macro-economic conditions, thus the price of EVs should play a major role in demand. However, it may be the case that consumers do not consider the price level of an EV when they have committed to adopting this new lifestyle. Once again, it is important to note that the price variables represent the average MSRP in dollars of a specific EV which does not account for the final transaction cost due to negotiations between seller and buyer.

State governor affiliation, $GOVAFF_{it}$, had no significant relationship with any of the models. This is another variable that did not have the expected outcome I anticipated. I decided to use this measurement for political affiliation due to the control state governors have over legislation regarding EVs. It would have been interesting if this variable was significant so I could argue for or against Sintov et al. (2020), who determined that Democrats are more likely to adopt EV technology.

From Table 4, we can also see that the R-Squared values are very high across all models. The R-Squared value for PHEV model is .97, which would suggest expected values are very close to my actual data points.

Robustness Checks

During my analysis, I also ran robustness checks for multicollinearity issues with my independent variables. At first, I ran a model including all independent variables that I had recorded. With this preliminary model, I created a correlation matrix and ran the Variance Inflation Factor (VIF) test to look for multicollinearity. For most of the income variables and average price levels, the Variance Inflation Factor (VIF) values were greater than 5, thus signifying collinearity. The correlation matrix backed up these results by showing that income percentiles were highly correlated with each other and the price levels were as well. After careful deliberation, I decided to remove all income variables except the 25th percentile and use specific pricing levels for each type of EV category. The only other collinearity issue I identified was in the FCEV model where $CHARGEINC_{it}$, $GOVAFF_{it}$, $ELECTDIS_{it}$, $AVGELECTDIS_{it}$, $CHARGEPORT_{it}$, $VEHICLETAX_{it}$, and $DRIVEPERK_{it}$ had to be dropped due to multicollinearity. For all the other models, I ran the VIF test once again and all values were less than 5, signifying no collinearity (see Appendix A). From my robustness checks, I demonstrate the good performance of my model and am confident that my results are accurate and precise.

Limitations

Naturally, there are limitations with this analysis. The major limitation is the state-level data I have collected to represent market penetration, which does not account for consumer effects. As I stated in the discussion of variables, two consumers purchasing an EV in New York City may be in two very different scenarios based on their gender, race, and socioeconomic status. Thus, the data I have analyzed is from a high-level point of view which generates general results. While I have significant results that allow me to add and comment on existing literature, my data hinders me from getting at the root of what drives market penetration for EVs.

The next limitation deals with the type of data I recorded for the state incentives. To understand the effects of the state tax incentives, I used a dummy variable to represent whether a state offered a specific rebate or not (I was not able to account for when each of these rebates were introduced at the state level). In states such as California, they have many different rebates for different residential and commercial regions which may play a role in the number of EVs on the road. Unfortunately, I did not have the resources to incorporate this into my model. However, if I were able to collect this specific data and represent it in my model, I would be able to get a more accurate effect of these state incentives.

I must also note that omitted variable bias is also present. I chose these specific independent variables because I believe they represented the different factors of demand. However, there are many other variables that I may have omitted. As Egbue and Long (2012) discussed in their paper, battery technology limitation serves as one of the major barriers to mass-scale adoption. In my analysis, I did not have a variable for this specific measurement. However, this measurement would have been very interesting to examine and analyze the effects on market penetration. Improvements to battery technology would increase the range of an EV which would change consumers' expectations and increase demand for these vehicles.

Another form of potential bias may be present. One could argue that the state tax incentives are endogenous. As Gallagher & Muehlegger (2011) discuss in their paper, "a state may choose the most effective incentive for their local environment." For example, in areas with low congested parking areas, states are not motivated to offer free parking for EVs. However, states like California with busy urban areas will implement these incentives to motivate consumers to make the switch. Other states may focus more on offering a vehicle tax credit to increase market penetration. Thus, I may be overestimating the effect these incentives have on the market penetration of EVs.

The final limitation with my work is the method I used for recording data, which was predominantly done manually. This creates an opportunity for human error in the data collection process.

Future Work

The “gold standard” for this work would be to have access to all the sales data of EVs with the specific dollar amount in incentive form used by the consumer. This dollar amount would be different for every consumer depending on where they live, the car model they purchased, the number of charging ports in their vicinity, etc. To my knowledge, this information does not exist. With the bigger picture of understanding state-level tax incentives, the next step in this analysis would be to zoom in on one state. If individual state-level data is unobtainable, a county-level model would be the secondary analysis. Throughout my research, I saw some specific state incentives that were available to consumers depending on which county they lived in. In this county-level model, I would also be able to account for when each incentive was introduced to consumers, something I was unable to do in this paper. A county-level model would provide more specific detailed results compared to the state model in this paper.

Policy Implications

My results indicate a significant positive relationship between those states that offer a tax incentive and their market penetration of EVs compared to those states who do not. Thus, states who are looking to increase sales of EVs should consider implementing these incentives.

However, one important dynamic to reconsider regarding these state tax incentives is the accessibility to lower-income families and individuals. As stated, these federal and state tax incentives are a form of a regressive tax. Lower-income individuals and households may be paying to supply these incentives but are not reaping the rewards. Federal and state governments will need to establish incentives that are accessible to all.

While EVs are helping countries across the world become more carbon emission friendly, it is important to understand that there are some negative side-effects of this new technology. Lithium-ion batteries are very useful during their life span, but once they die, they are problematic. Many people may wonder, "why can't an EV's battery be recycled like any other battery?" Unlike regular car batteries, lithium-ion batteries are very heavy machines with dozens of components that contain dangerous levels of voltage (Gregory, 2021). Different manufacturers have different designs which make it difficult to have a uniform recycling system. Furthermore, unlike conventional vehicles, EVs are not able to be placed in a scrapyard to be salvaged. Salvagers, for the most part, do not know how to deal with EVs and there also is a very limited market for these parts. Due to all these characteristics, these batteries are placed in large storage facilities. "A recent EPA report found that lithium-ion batteries caused at least 65 fires at municipal waste facilities last year" (Gregory, 2021). The dilemma of responsibly recycling EV batteries will not only be important for states to implement proper tax incentives, but also legislation on how we handle EV batteries once they die.

Conclusion

This paper fills a literature gap by providing the effects of state tax incentives on the specific categories of EVs. Based on my results, I would suggest to state legislators that any form of additional incentives for EVs will increase consumer demand. Specifically, a 2.93% in EVs sold per capita in states who offered charging station incentives and a 2.52% increase in EVs sold per capita in states who offered vehicle tax rebates. Even with these considerations, it may still not make sense to consumers living in remote areas of the country to invest in an EV due to the lack of charging infrastructure in rural areas. Electric vehicle technology has come a long way since its creation in 1890. Many auto manufacturers are pledging to have an all-electric fleet at some point in the near future. Private sector pledges, along with additional state legislation, further enhance the United States' goals of adopting EV technology at a faster rate.

Appendix A – Robustness Checks

Table 5. Model 1 (FCEV) VIF Values

	VIF	1/VIF
$GOVAFF_{it}$	4.84	.21
$STATEGAS_{it}$	4.05	.25
$AVGVEHICLEINC_{it}$	3.92	.26
$AVGCHARGETAX_{it}$	3.89	.25
$AGI25_{it}$	3.0	.33
$LDVPRICE_{it}$	2.8	.36
$FCEVPRICE_{it}$	1.74	.58
Mean VIF	3.46	.

Table 6. Model 2 (BEV) VIF Values

	VIF	1/VIF
$VEHICLETAX_{it}$	3.36	.29
$AVGCHARGETAX_{it}$	3.15	.32
$CHARGEPORT_{it}$	2.41	.42
$STATEGAS_{it}$	2.32	.43
$BEVPRICE_{it}$	2.06	.49
$DRIVEPERK_{it}$	1.85	.54
$AVGELECTDIS_{it}$	1.84	.54
$ELECTDIS_{it}$	1.7	.59
$AGI25_{it}$	1.69	.59
$AVGVEHICLEINC_{it}$	1.36	.74
$GOVAFF_{it}$	1.29	.77
$CHARGEINC_{it}$	1.19	.84
$LDVPRICE_{it}$	1.15	.88
Mean VIF	1.95	.

Table 7. Model 3 (PHEV) VIF Values

	VIF	1/VIF
$VEHICLETAX_{it}$	3.4	.29
$AVGCHARGETAX_{it}$	3.15	.32
$PHEVPRICE_{it}$	2.52	.4
$CHARGEPORT_{it}$	2.36	.42
$STATEGAS_{it}$	2.15	.47
$AVGELECTDIS_{it}$	1.83	.55
$DRIVEPERK_{it}$	1.83	.55
$AGI25_{it}$	1.76	.57
$ELECTDIS_{it}$	1.68	.6
$LDVPRICE_{it}$	1.46	.7
$AVGVEHICLEINC_{it}$	1.36	.74
$GOVAFF_{it}$	1.3	.77
$CHARGEINC_{it}$	1.2	.84
Mean VIF	1.99	.

Appendix A -Robustness Checks (cont.)

Table 8. Model 4 (ALL) VIF Values

	VIF	1/VIF
$VEHICLETAX_{it}$	3.4	.3
$AVGCHARGETAX_{it}$	3.15	.32
$STATEGAS_{it}$	2.68	.37
$EVPRICE_{it}$	2.51	.4
$CHARGEPORT_{it}$	2.45	.41
$DRIVEPERK_{it}$	1.85	.54
$AVGELECTDIS_{it}$	1.84	.54
$AGI25_{it}$	1.75	.57
$ELECTDIS_{it}$	1.71	.59
$AVGVEHICLEINC_{it}$	1.36	.74
$GOVAFF_{it}$	1.3	.78
$CHARGEINC_{it}$	1.2	.84
$LDVPRICE_{it}$	1.15	.87
Mean VIF	2.02	.

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