ARE ELECTRIC VEHICLES INCENTIVES EFFECTIVE? EVIDENCE FROM THE FIFTY U.S. STATES

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ABSTRACT

This study evaluates the effectiveness of state-level electric vehicles (EVs) incentives in the United States. Many barriers can prevent electric vehicles from gaining a larger market share. This study will mainly focus on two of these – "model availability" on the EV supply-side; and the "knowledge gap" on the EV demand-side to examine the heterogeneities in state-level incentive allocation structure and effectiveness. A three-level Stackelberg game model is used to illustrate the interactions among state governments, electric vehicle manufacturers, and electric vehicle consumers to understand how government subsidies should be allocated. A rich panel data set of annual state-level EV data is used to empirically evaluate the effectiveness of state incentives and policies. In addition, result of sentiment analysis of twitter data is introduced to categorize state-level public perception of electric vehicles, which can explain the importance of campaign plans and the networks among states, to better inform the future policies.

My results show an overall 5%-14% increase in EV sales per every $1000 increase in subsidies across all the states. State-level climate commitments such as ZEV mandates and emissions reduction targets have a positive effect on the promotion of EV purchases, but do not significantly increase the effect of other policies instruments. Regional alliance and educational campaign activities can increase the effectiveness of incentives. More specifically, the results from frequency words and Latent Dirichlet Allocation (LDA) model on Twitter data indicate that linking electric vehicles to some topics such as climate change, healthcare, battery etc. will gain more public attention.

Keywords: Electric Vehicles, Stackelberg Game, Incentives, Twitter API, Sentiment analysis

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION 1: INTRODUCTION

Electrification[1] is an important part of the solution to the challenge of growing transportation sector emissions because it eliminates tailpipe emissions and harnesses the potential to decarbonize the power grid. Transport emissions – which primarily involve road, rail, air and marine transportation – account for over 24% of global CO2 emissions[2] in 2016. They're also expected to grow at a faster rate than that from any other sector, posing a major challenge to efforts to reduce emissions in line with the Paris Agreement[3] and other global goals.

After experiencing a decline in transport-related emissions from their peak in 2005, the United States transport emissions plateaued and have now risen every year since 2012[4]. In 2016, the transport sector surpassed the electric power industry as the single greatest U.S. emitter of greenhouse gas (GHG) for the first time. To encourage the development and adoption of electric vehicle (EV) to mitigate the challenge from fast growing transport emissions, the federal government, the U.S. state governments and even many private stakeholders have offered various incentives. This study is proposed to evaluate the effectiveness of state-level electric vehicles incentives in the United States.

However, there are also many barriers which can prevent the electric vehicles from gaining a larger market share[5]. This study will mainly focus on two barriers, which are the

[1]Memo to Carmakers: The Future Is Electric https://thecityfix.com/blog/memo-carmakers-future-electric-dan-lashof-camron-gorguinpour/
[2]CO2 Emissions from Fuel Combustion 2018 Highlights, EIA https://webstore.iea.org/co2-emissions-from-fuel-combustion-2018-highlights
[3] "The Paris Agreement central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius." https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
[4] https://www.epa.gov/sites/production/files/2018-01/documents/2018_complete_report.pdf
[5]Plug-In Electric Vehicle Policy: Evaluating the Effectiveness of State Policies for Increasing Deployment https://www.americanprogress.org/issues/green/reports/2018/06/07/451722/plug-electric-vehicle-policy/

limited availability of EVs models from supply-side ("model availability[6]") and consumers (demand-side) limited information regarding electric vehicles ("knowledge gap[7]").

A simple three-level Stackelberg game model is proposed to understand the interactions among the state governments, electric vehicles manufacturers (supply-side), and electric vehicles consumers (demand-side). The purpose of this model is to gain some insight on how different government's incentive allocation may mitigate the effect of potential EVs adoption barriers and it's social welfare implications. To evaluate the effectiveness of government's incentives empirically, we then use several regression models to see the effect of state incentives and policies, state energy consumption structure, state energy price, previous environmental performance, consumer awareness, and some socio-economics factors on the EV sales and the GHG emissions.

The reminder of the thesis is organized as follows: Section 2 provides a more detailed background of this research topic; Section 3 gives a comprehensive literature review from electric vehicles incentive efficiency, the U.S. electric vehicles market to the application of Stackelberg game and public awareness; Section 4 outlines the theoretical conceptual model, described as three-level Stackelberg game, the main hypothesis; Section 5 and 6 further present the data, methods; Section 7 shows the regression results, followed by results, implications, conclusions in Section 8 and 9.

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6 The model availability means that there is not enough available EVs models provided by automobile manufacturers now. Research indicated that a variety of PEV model options is a prerequisite for market growth. (Peter Slowik and Nic Lutsey, "Expanding the Electric Vehicle Market in U.S. Cities" (Washington: International Council on Clean Transportation, 2017), available at https://www.theicct.org/sites/default/files/publications/US-Cities-EVs_ICCT-White-Paper_25072017_vF.pdf.)

7 The knowledge gap means that many consumers are unaware of the cost, model details, available incentives and many other information about electric vehicles. For example, one previous survey indicated that 95 percent of respondents were not aware of state or local incentives available. (Rachel M. Krause and others, "Perception and reality: Public knowledge of plug-in electric vehicles in 21 U.S. cities," Energy Policy 63 (2013): 433–440.)

SECTION 2: BACKGROUND

Greenhouse gas emissions (GHG) have been proven to threat public health and contribute to climate change. In 2009, the U.S. Environmental Protection Agency (EPA) made an endangerment finding that stated that greenhouse gases "endanger both the public health and the public welfare of current and future generations."[8] The EPA also found that GHGs from motor vehicles "contribute to the total greenhouse gas air pollution, and thus to the climate change problem, which is reasonably anticipated to endanger public health and welfare."[9] Further data from the EPA has shown that the transportation sector is a major emitter of GHGs. It breaks down GHG emissions by sector in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016*. This report shows that in 2016, the transportation sector was responsible for emissions of 1854 million metric tons of CO2e, or 28.5 percent of all U.S. GHG emissions.[10] Light-duty vehicles (cars and light trucks) were responsible for 60 percent of these emissions, and another 23 percent came from medium- and heavy-duty trucks. The vast majority of emissions (96.7 percent) were CO2.[11]

Increased fuel efficiency for gas-powered vehicles has not been enough to prevent the transportation sector GHG emissions from increasing. To truly tackle the problem of rising transportation sector emissions, per-vehicle emissions need to decrease drastically, or Americans need to drive less. Switching to electric vehicles (EVs) takes the former approach. EVs are an effective solution to this problem because they produce little to no emissions. Replacing gas-

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[8] Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act, 40 Fed. Reg. 66,496 (Dec. 15, 2009).
[9] Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act, 40 Fed. Reg. 66,499 (Dec. 15, 2009).
[10] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016" (EPA 430-R-18-003). (P. 2-25). Retrieved from https://www.epa.gov/sites/production/files/2018-01/documents/2018_complete_report.pdf
[11] Environmental Protection Agency. "Fast Facts: U.S. Transportation Sector Greenhouse Gas Emissions: 1990-2016" (EPA-420-F-18-013). (P. 2). Retrieved from https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100USI5.pdf

powered vehicles with EVs would lead to lower GHG emissions from the transportation sector. The EPA reported that alternative fuel vehicles are "beginning to have a measurable and meaningful impact on overall new vehicle fuel economy and CO2 emissions," increasing overall fuel economy in 2016 by 0.1 mpg with just 1% of new vehicle production.[12] Furthermore, switching to EVs would allow Americans to continue their current driving patterns, and not require them to drive significantly less than what they are accustomed to.

The United States government has employed a variety of EV industry-oriented subsidies to support the EV market, including monetary incentives as well as non-monetary incentives. This study aims to analyze the interactions among participants in the EV market and provide state-level policy implications for EV promotion. Specifically, this study will try to answer the following questions: (1) What are the heterogeneities of EV diffusion and policy design among states? (2) How do participants (manufactures, consumers, and government) in the EV market interact with each other and make decisions? (3) What is the socially optimal allocation of incentives? (4) What's the role of public perception in electric vehicles markets?

SECTION 3: LITERATURE REVIEW

3.1 Electric Vehicles Incentives Efficiency

There is a long history of studies about advanced technology vehicle (ATVs). Basically, ATVs are consisted of four vehicle types: hybrid electric vehicles (HEVs) which run on gasoline and are not able to plug in to recharge; plug-in hybrid electric vehicles (PHEVs) which run on either or both gasoline and electric fuel; battery electric vehicles (BEVs) which only run on

[12] Environmental Protection Agency. "Light-Duty Automotive Technology, Carbon-Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2017" (EPA-420-R-18-001). (P. 52-53). Retrieved from https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100TGDW.pdf

electric fuel and Fuel-cell electric vehicles (FCEVs) which run on hydrogen fuel generated electricity (Alliance of Automobile Manufacturers, 2019.)[13] In terms of evaluating the effectiveness of vehicle incentives, previous studies give us many different perspectives. Since the battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) are relatively new to the market, studies of incentive evaluation about hybrid electric vehicles (HEVs) are greatly worth for reference here.[14] Diamond (2009) does a cross-sectional analysis to estimate the U.S. hybrid electric vehicles incentives and suggests that gasoline prices have more significant effect on HEV adoption than incentives policies do. The broader HEV literature suggests that besides higher gas prices, upfront vehicle purchase incentives and larger incentive amounts will also have a great effect on HEV sales.

3.2 The U.S. Electric Vehicles Market

With the promotion of plug-in electric vehicles in the U.S., studies on BEVs and PHEVs incentive evaluation increase a lot recently. These studies are estimating the effectiveness at different levels. Lutsey et al. conduct research at the cities-level to explain the variances. At state-level, Wee, Coffman, and La Croix (2018) and Jenn, Springel, and Gopal (2018) give detailed classification of different state-level incentives. Consumer awareness is also measured here to better estimate the effect of incentives on EV sales. Besides studies on the U.S. electric vehicle market, the studies which are focusing on the effectiveness of Chinese EV market (Ou et al., 2019) (Zhu, Wang, & Zhang, 2019) and northern-European countries' EV market

[13] Advanced Technology Vehicle Sales Dashboard, https://autoalliance.org/energy-environment/advanced-technology-vehicle-sales-dashboard/

[14] To the best of my knowledge there is no detailed studies which solely focus on the incentive evaluation of fuel-cell electric vehicles, because of the limited model availability of FCEV (only 3 according to the data from Advanced Technology Vehicle Sales Dashboard).

(Langbroek, Franklin, & Susilo, 2016) (Springel, 2016) are also informative because of the successful practice in electrification in these regions.[15]

3.3 The Applications of Stackelberg Model

The Stackelberg game is dynamic or sequential move game a strategic game in which a player (the leader) moves first. The competitors (the followers) obverse the leader's decision and the make their choices. The leader is said to have "the first-mover advantage" followed by the other players (the followers) follower firms move sequentially[16]. The Stackelberg model - a sequential move game - has been employed to many empirical studies about the strategic interactions among multi-players in marketing or policy analysis areas.

The application of Stackelberg Model in environmental policy subject gains more and more attention recently. For example, Andre and de Castro (2015) used Stackelberg model to evaluate the emissions permit market. And Le Cadre (2019) evaluated the local electricity market by implementing the Stackelberg competition. More specifically, there are emerging studies using Stackelberg Game model to estimate the adoption of electric vehicles. Laha, Yin, Cheng, Cai, and Wang (2019) employed a multi-leaders and multi-followers Stackelberg game to model the interactions among vehicles and charging stations. Gu, Ieromonachou, and Zhou (2019) studied the electric vehicle supply chain subsidies by using a four-players imperfect information Stackelberg game model, which includes governments, automobile manufacturers, retailers and EV consumers. Zhu, Wang, and Zhang (2019) also used a two-stage Stackelberg game to model the phasing our subsidies in China.

[15] https://www.wri.org/news/2019/05/release-electric-bus-adoption-critical-sustainable-cities-here-s-how-get-there

[16] Gibbons, (1992)

3.4 Electric Vehicles Model Availability and Public Awareness

Public attention is being regarded as scarce resources and central of the current market competitions[17]. Hilgartner and Bosk (1988) further illustrated that the focus of community attention at any given time is not exogenously given, but rather endogenous and manipulable. In more recent researches, Heyes, Lyon, and Martin (2018) employed a signaling game to see the strategic interactions between NGO and private firms when the public attention to the social impact of a certain sector is limited. Jenn, Springel, and Gopal (2018) also introduced a novel "knowledge index[18]", which using the number of local news related to EV incentives to represent the public awareness, to their evaluation of the EV incentives. However, most of the current studies about public awareness are using the continuous value to estimate the degree of awareness, but not the categorical value to represent the different kinds of attitudes. .

3.5 Greenhouse Gas (GHG) Emissions

In the transportation study area, there are some studies focusing on the relationship between electric vehicle adaptation and GHG emissions. Spangher, Gorman, Bauer, Xu, and Atkinson (2019) used a novel agent-based simulation to quantify the impact of U.S. electric vehicle sales and CO2 emissions. The authors found that rather than EV adoption, decarbonizing the grid actually has a more significant effect on GHG emissions reduction. In terms of public policy study, a recent study by Jenn, Azevedo, and Michalek (2019) estimates the effect of alternative-fuel-vehicle (AFV) policy on the greenhouse gas emissions. The study shows that if the federal incentives which relief the GHG standard for AFV are adopted with the state zero-

[17] Davenport and Beck (2001, p.8): assert that managing scarce attention is the central task of modern business (including both gaining attention and avoiding attention.)

[18] They introduced a novel variable to capture consumer knowledge of EVs and associated incentives in the model to help explain the state level heterogeneity in response to incentives and find that raising consumer awareness is critical to the success of EV incentive programs.

emissions vehicle[19] (ZEV) policy together, there will be a larger increase in GHG emissions compared with adopting either policy alone. However, to the best of my knowledge, there is no studies which use the state GHG emissions as an indicator of states' previous environmental performance to estimate the effectiveness of incentives.

My study distinguishes from existent literature from the following perspectives: this study will explore a three-level Stackelberg game theory model into the U.S. state-level electric vehicle market (from 2011 to 2015); the study will also take previous environmental performance (GHG emissions) into the incentive evaluation process; the study will include the monetary incentives for demand-side players; what's more, different categories of the consumer awareness will be considered.

SECTION 4: CONCEPTUAL FRAMEWORK AND HYPOTHESIS

4.1 Interdependence Between Government, Manufacture and Consumer's Decisions

One of the main assumptions in this study is that the actions of government, manufacture, and consumers are interdependent. The interaction of these three agents may be describe as a three stage Stackelberg game.

Figure 1 depicts the interdependence between the three agents. Government is the leader in this Stackelberg game and chooses the amount of incentives to allocate to manufactures and consumers. It can choose from two potential actions, which is giving more incentives per vehicle to manufactures than to consumers or giving more incentives per vehicle to consumers than to manufactures.

[19] https://www.sciencedirect.com/topics/engineering/zero-emission-vehicle

After government chooses the allocation of incentives (try to anticipate how the reaction of the producers and consumers), manufactures will observe the government incentives and then choose the amount of output (try to anticipate what the reaction of the consumers will be). Then consumers will decide whether to buy an EV.

4.2 Conceptual Model

In this conceptual model, we assume that there are only two types of government incentives, which are those given to EV manufactures and those given to EV consumers[20]. The government objective is to mitigate the negative externalities caused by CO2 emissions and therefore increase the total welfare of the society. In addition, we assume that manufactures chose output with the sole objective to maximize profits despite of environmental impact. On the other hand, consumers are aware of the positive environmental impact of EV and take it in consideration when making purchase decisions.

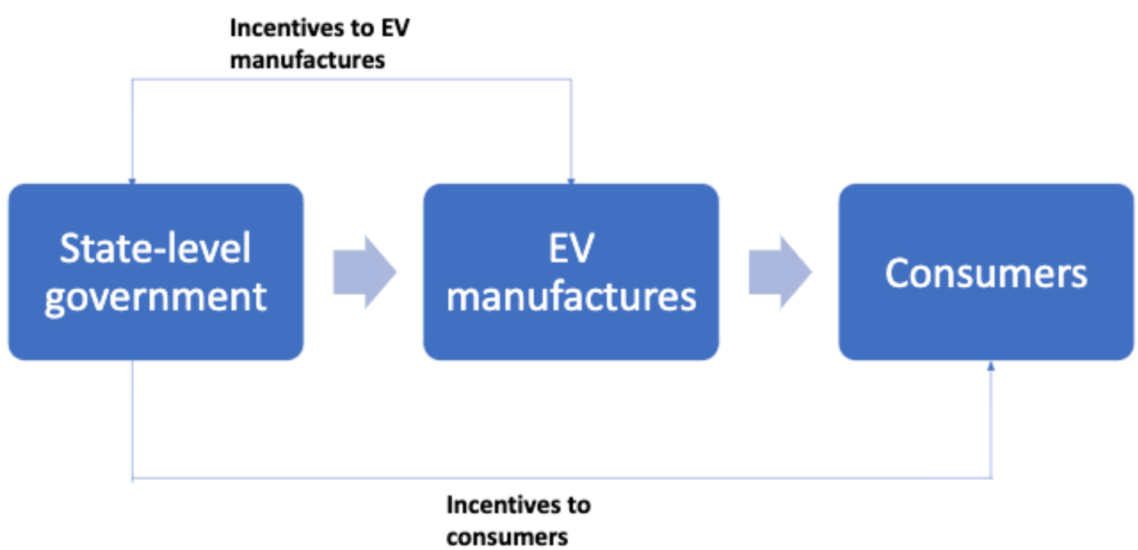

Figure 1: The Structure of Incentives

[20] It makes sense to only consider those two kinds of incentives here, since EV manufacturers and consumers are two players in our model. In the alternative scenarios we may want to include more types of incentives such as those for charging infrastructures and government fleets.

The generic utility functions[21]:

- Government (Maximize social welfare) = "utility from Demand-side" + "utility from Supply-side" + Environmental Benefit – Incentives
- Supply-side (Maximize profit) = incentives for supply-side + profit from customer – input
- Demand-side (Maximize own utility) = utility from having EV + incentives for demand-side – price of EV

4.3 Hypothesis

Then based on the conceptual model described above we will empirically test the following hypothesis.

4.3.1 Different incentives allocation structure hypothesis

When the governments give more incentives to supply-side players, model availability in that state will significantly increase. When the governments give more incentives to demand-side players, consumer awareness will significantly increase.

4.3.2 Correlation between previous environmental performance and incentives

States which have a better previous environmental performance tend to give more incentives. States which have a worse previous environmental performance tend to give less incentives.

4.3.3 The effect of having emissions reduction/ZEV sales targets/awards

Having state-level climate commitments such as emissions reduction targets or ZEV sales targets will make the EV incentives more effective.

4.3.4 The effect of public perceptions

[21] Due to data limitation and time constraints, other models will be discussed in results and future research part.

EV incentives tend to be more effective in states which have a higher level of public awareness towards climate change issue and electric vehicles.

SECTION 5: DATA AND METHODS

Figure 2: Empirical Model

This study intends to evaluate the effectiveness of state-level electric vehicle incentives by using panel data of all 50 U.S. states from 2011-2015. The dataset contains annually state-level EV sales by different EV types from 2011-2015, state-level policies, state environmental performance, consumer awareness and other socioeconomics factors may affect the correlation of state-level policies and the EV sales.

5.1 Data Sources

In this study, given data constrains, I will focus on the EV sales data from 2011-2015[22]. For the incentives and policies, the main data source will be the U.S. Department of Energy's

[22] Advanced Technology Vehicle Sales Dashboard.

Alternative Fuel Database Center (AFDC)[23]. I also add the data from Wee, Coffman, and Croix (2019) to give more information about the incentives' timeframe. What's more, I will further analysis the data based on different users (supply-side or demand-side). EV community readiness awards data will also be considered here as a dummy.[24]

For energy related factors, I will include time-series data about state-level electricity price, motor gasoline price, total transportation energy consumption and per capita transportation energy consumption. For previous environmental performance, I will use the state-level transport emissions data from EIA. For consumer awareness, I will use Twitter data to estimate the popularity and salience of "Electric vehicles" topic in that state. A sentiment analysis will also be deployed on Twitter posts to better capture the public attitudes toward EVs. I will also include some socio-demographic indicators such as population and income level.

Below is the detailed list of variables and data sources.

Table 1: Data Description and Sources

VARIABLE	DESCRIPTION	DATA SOURCES
EV SALES	Total new sales of a certain type of vehicles	Alliance of Automobile Manufactures[25]; IHS Markit
PURCHASE INCENTIVE	Dollar value of vehicle purchase incentives (include rebate, subsidy, income tax credit, excise tax credit or sales tax credit)	AFDC; Wee et al.[26]
MOTORGAS PRICE	Motor gasoline average price, all sectors	U.S. Energy Information Administration[27]
ELECTRICITY PRICE	Electricity average price, all sectors	U.S. Energy Information Administration[28]

[23] Data sources: AFDC; https://www.sciencedirect.com/science/article/pii/S2352340919300071#ec0005
[24] https://cleancities.energy.gov/partnerships/search?project_search=Electric+Vehicle+Community+Readiness#EVCR-southeast
[25] Retrieved Nov.27 2019 from https://autoalliance.org/energy-environment/advanced-technology-vehicle-sales-dashboard/
[26] https://www.sciencedirect.com/science/article/pii/S2352340919300071#ec0005
[27] State Energy Data System (SEDS), Release Date: June 28, 2019
[28] State Energy Data System (SEDS), Release Date: June 28, 2019

TRANSPORT ENERGY CONSUMPTION	Total energy consumed by the transportation sector	U.S. Energy Information Administration[29]
TOTAL EMISSIONS	Total CO2 emissions	U.S. Energy Information Administration[30]
TRANSPORTATION EMISSIONS	Transportation sector CO2 emissions	U.S. Energy Information Administration[31]
AWARDS	Completed awards that were announced and funded by DOE[32]	Clean Cities Coalition Network[33]
ZEV MANDATE[34]	Dummy variable indicating whether the state has a Zero-Emission Vehicle (ZEV) sales goal	Auto Alliance[35]; ZEV Task Force[36]
EMISSION REDUCTION TARGETS	Dummy variable indicating whether the state has a greenhouse gas emissions reduction target	Center for Climate and Energy Solutions[37]
PUBLIC PERCEPTIONS	Content and the number of Electric Vehicles tweets	Twitter API[38]
ALL INDUSTRY TOTAL GDP	Gross domestic product (GDP) from all industries	Bureau of Economic Analysis[39]
MINING, QUARRYING, AND OIL AND GAS EXTRACTION GDP	Gross domestic product (GDP) from Mining, quarrying, and oil and gas extraction industry	Bureau of Economic Analysis[40]
POPULATION	Annual estimates of the resident population for states	U.S. Census Bureau, Population Division[41]

[29] State Energy Data System (SEDS), Release Date: June 28, 2019
[30] States total (without the discrepancy adjustment), U.S. Energy Information Administration, State Energy Data System and calculations made for this data series.
[31] U.S. Energy Information Administration (EIA), State Energy Data System and EIA calculations made for this analysis.
[32] We only include projects that are already completed here for empirical analysis. Those projects include Alternative Fuel Market Project Awards, Electric Vehicle Community Readiness and American Recovery and Reinvestment Act Project Awards.
[33] https://cleancities.energy.gov/partnerships/projects#electric-vehicle-projects
[34] Currently (updated Nov. 2019), ten states are following California adopting the ZEV mandate, including Colorado, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island and Vermont. But in our empirical analysis we may only include the eight states which signed the memorandum of understanding (MoU) committing to coordinated action to ensure their state zero-emission vehicle (ZEV) programs before 2015.
[35] https://autoalliance.org/energy-environment/state-electric-vehicle-mandate/
[36] https://www.zevstates.us/about-us/
[37] https://www.c2es.org/document/greenhouse-gas-emissions-targets/
[38] https://developer.twitter.com/en
[39] https://www.bea.gov/data/gdp/gdp-state
[40] https://www.bea.gov/data/gdp/gdp-state
[41] https://www.census.gov/data/tables/time-series/demo/popest/2010s-state-total.html#par_textimage_1574439295

5.2 Methods

I will use five different models here, which are baseline generalized model, target interaction model, energy structure model, environmental performance model and consumer awareness model, to evaluate the effectiveness of incentives. Fixed effects regression model will be used to capture unobserved characteristics in each factor.

5.2.1 Baseline specification: Only include policies variables

In my baseline specification, the electric vehicles sales are a function of monetary incentives, non-monetary incentives, socioeconomics factors and fixed effects.

$$log\ (EV\_Sales_{its}) = \beta_1 subsidies_{its} + \beta_2 index_{its} \quad (1)$$

$$log(EV\_Sales_{its}) = \beta_1 subsidies\_HOV_{its} + \beta_2 subsidies\_purchase_{its} + \beta_3 subsidies\_emissions_{its} + \beta_4 subsidies\_other_{its} + \beta_5 index_{it} \quad (2)$$ [42]

In the second specification, quantifiable incentives are further separated as High-occupancy vehicle lane access, purchase incentives and emissions inspection exemptions. We expect positive correlations between incentives and electric vehicles sales here.

5.2.2 Target interaction model: Add state-level environmental target

Many climate commitments, such as emissions reduction target and sectoral non-GHG targets, are adopted at state-level to mitigate the effects of climate change. To better tackle the effect of greenhouse gas targets and non-greenhouse gas targets, emissions reduction targets and zero-emissions vehicles targets are incorporated here representing the state-level climate commitments. I expect that having a state-level targets can have a positive effect on electric

[42] In specification (2), we further estimate the different effects of the following three incentives: EV purchase incentives, emissions inspection exemptions and HOV exemptions, which can represent direct monetary incentives, operating incentives and preferred access incentives, respectively.

vehicles sale. In the specification (3), electric vehicles sale is a function of incentives and state-level mitigation targets.

$$\begin{aligned} log\ (EV\_Sales_{its}) = \ & \beta_1 subsidies_{its} + \beta_2 index_{its} \\ & + \beta_3 has\_ZEV\_target_{is} + \beta_4 has\_emission\_target_{is} \qquad (3) \end{aligned}$$

I also expect that state-level climate targets can make electric vehicles incentive more effective, so the interactive terms of targets and incentives are included in specification (4).

$$\begin{aligned} log\ (EV\_Sales_{its}) = \ & \beta_1 subsidies_{its} + \beta_2 index_{its} \\ & + \beta_3 has\_ZEV\_target_{is} + \beta_4 has\_emission\_target_{is} \\ & + \beta_5 (subsidies_{its} * has\_ZEV\_target_{is}) + \beta_6 (index_{its} * has\_ZEV\_target_{is}) \\ & + \beta_7 (subsidies_{its} * has\_emission\_target_{is}) \\ & + \beta_8 (index_{its} * has\_emission\_target_{is}) + \beta_9 has\_ZEV\_target_{is} \\ & + \beta_{10} has\_emission\_target_{is} \qquad (4) \end{aligned}$$

5.2.3 Energy structure model: Add energy-related variables

In specification (5) of the energy structure model, price of electricity and gasoline are included. A negative correlation between electricity price and electric vehicle sales is expected, which means that the EV sales will increase as the price of electricity decreases. Meanwhile, a positive correlation between gasoline price and electric vehicle sales is expected, which means that the EV sales will increase as the price of gasoline increases.

$$\begin{aligned} log\ (EV\_Sales_{its}) = \ & \beta_1 subsidies_{its} + \beta_2 index_{its} + \beta_3 has\_ZEV\_target_{is} \\ & + \beta_4 has\_emission\_target_{is} + \beta_5 price\_electricity_{is} + \beta_6 price\_motorgas_{is} \\ & + \beta_7 transportation\_energy\_consumption_{is} \qquad (5) \end{aligned}$$

What's more, transportation energy consumption is incorporated here to better capture the effect of different energy structure. EV sale is a function of incentives, targets and energy structures.

5.2.4 Environmental performance model: Add historical emissions data

According to previous hypothesis, historical environmental performance should also have an effect on the effectiveness of electric vehicle incentives. I use time-lagged emissions data here to reduce the endogeneities in specification (6), since more EV sales could lead to less CO2 emissions.

$$\begin{aligned} log\ (EV\_Sales_{its}) = \ & \beta_1 incentives_{its} + \beta_2 has\_ZEV\_target_{is} + \beta_3 has\_emission\_target_{is} \\ & + \beta_4 price\_electricity_{is} + \beta_5 price\_motorgas_{is} \\ & + \beta_6 transportation\_energy\_consumption_{is} + \beta_7 CO_2 emissions\_transport_{i-1s} + \\ & \beta_8 total\_emissionss_{i-1s} \qquad (6) \end{aligned}$$

5.2.5 Consumer awareness model: Add twitter data

While previous models can give us estimation on the effect of electric vehicle incentives, there are still different outcomes among states given similar incentives structure. The levels of consumer awareness could explain the heterogeneities here. The number and content of tweets using #ElectricVehicles hashtag can represent the consumer awareness level in that state. The interaction term here could explain the different effect of incentives by state.

$$\begin{aligned} log\ (EV\_Sales_{its}) = \ & \beta_1\ (incentivesits * perceptions_{is}) \\ & + \beta_2 has\_ZEV\_target_{is} + \beta_3 has\_emission\_target_{is} \\ & + \beta_4 price\_electricity_{is} + \beta_5 price\_motorgas_{is} \\ & + \beta_8 total\_emissions_{is} + \beta_9 perceptions_{is} \qquad (7) \end{aligned}$$

5.2.6 IV on consumer awareness data

However, there could be an endogeneity issue: higher electric vehicle sales could lead to more tweets about EV topics and a better consumer perception towards EV. So instrumental variables should be introduced. I will use the total number of tweets as an instrument, since it is correlated with the count of electric vehicle related tweets but may not be correlated with my dependent variable, electric vehicle sales.

Two-Stage least squares (2SLS) regression analysis is used here. While the perception variable contains total number of tweets, the second-stage main equation is described in specification (7).

5.2.7 Robustness check

I need to account for heteroskedasticity and/or autocorrelation via clustered standard errors by using fixed-effects model, and Hausman tests are conducted here to further detect endogenous independent variables.

SECTION 6: DESCRIPTIVE DATA

6.1 Electric Vehicles Sales

Under the ZEV regulation[43], there are three types of advanced technology vehicle being considered as "zero emission," including Plug-in Hybrid Electric Vehicles (PHEV), Battery Electric Vehicles (BEV) and Fuel Cell Electric Vehicles (FCEV).

However, in this paper, only Plug-in Hybrid Electric Vehicles and Battery Electric Vehicles are considered in the EV category, due to the limited model availability of Fuel Cell Electric Vehicles.

[43] https://ww2.arb.ca.gov/our-work/programs/zero-emission-vehicle-program/about

Table 2: Summary Statistics of Electric Vehicle Sales, 2011-2015.

VARIABLE	TIME PERIOD	OBS	MEAN	S.D.	MIN	MAX
Annual ATV sales	Jan 2011–Dec 2015	250	9065.9	20201.9	245	178380
Annual HEV sales	Jan 2011–Dec 2015	250	7554.7	14661	230	117530
Annual ZEV sales	Jan 2011–Dec 2015	250	1511.2	5978.3	3	61664
Annual FCEV sales	Jan 2011–Dec 2015	250	0.75	6	0	74
Annual PHEV sales	Jan 2011–Dec 2015	250	752.1	2890.8	3	29797
Annual BEV sales	Jan 2011–Dec 2015	250	758.3	3183.3	0	33945

Hybrid Electric Vehicle (HEV) is considered as Alternative Technology Vehicle (ATV) here but not Zero-emissions Vehicle or Electric Vehicle.

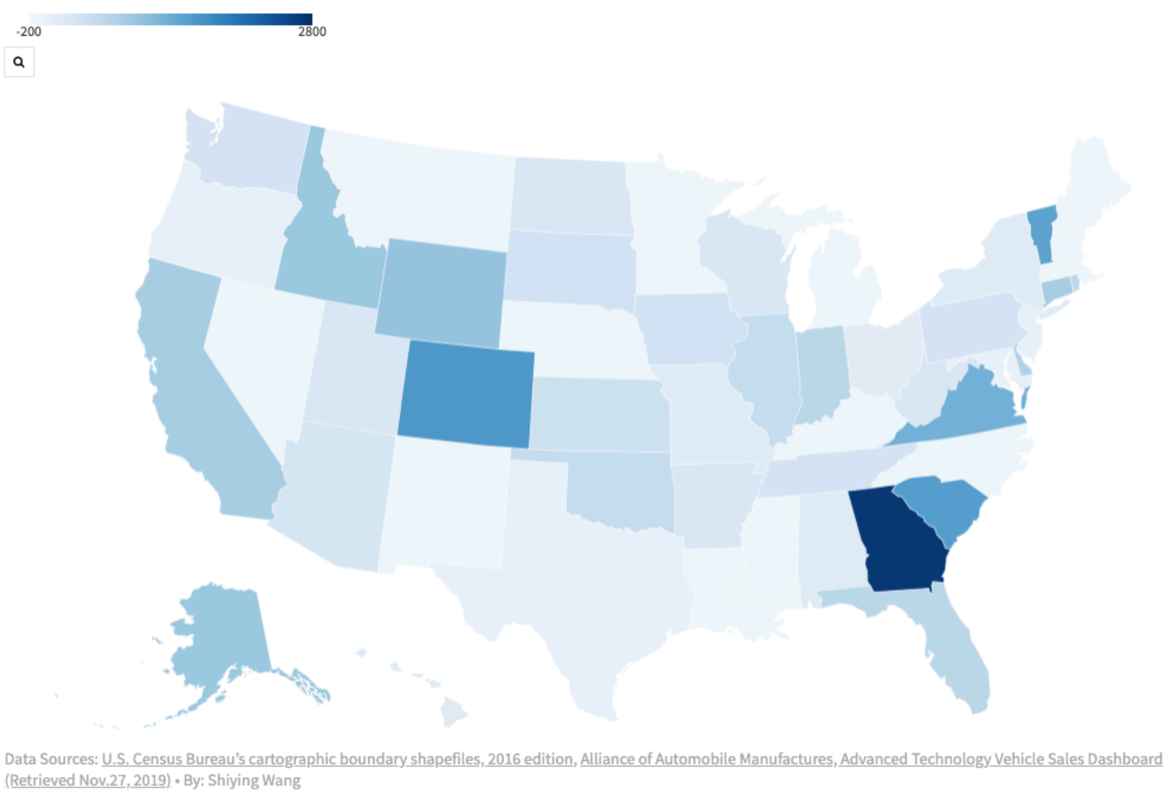

Figure 3: Zero-emission Vehicle Sales Growth Rate by State, 2011-2015.[44]

[44] See full published visualization here: https://public.flourish.studio/visualisation/1011281/

6.2 Policy

While both monetary and non-monetary incentives are included in the regressions, the number of policies here only includes the non-monetarized policies such as designated parking or free parking.

For the state-level climate commitments, the count data is presented. For Zero-emissions Vehicles mandate, there are eight states[45] which have ZEV mandate since 2013. And twenty-three states[46] have emissions reduction targets.

Table 3: Summary Statistics of Policies, 2011-2015.

VARIABLE	OBS	MEAN	S.D.	MIN	MAX	COUNT
Total subsidies	250	1338.736	1896.971	-799.4215	7615.174	-
Number of policies	250	0.268	0.6242875	0	3	-
HOV subsidies	250	569.0184	1158.44	0	3827.95	-
EV purchase subsidies	250	669.0392	1334.442	0	6000	-
Emissions inspection exemption	250	13.77926	35.20042	0	184.4357	-
ZEV mandate	250	-	-	-	-	24
Emissions reduction target	250	-	-	-	-	69

45 They are California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island and Vermont.For New Jersey, Maine and Colorado, since they adopted ZEV mandate after 2015, I do not include them in my models.

46 They are Washington, Oregon, California, Arizona, New Mexico, Minnesota, Illinois, Michigan, Maine, New Hampshire, Vermont, New York, Massachusetts, Connecticut, Pennsylvania, New Jersey, Delaware, Maryland, North Carolina, Florida, Rhode Island, Hawaii.
Colorado enacted targets in 2017 for reducing emissions more than 26% from 2005 levels by 2025 and revised them in 2019 for reducing emissions: more than 50% by 2030, and more than 90% by 2050. So, I do not include it in my models.

Figure 4. shows the relationship between having state targets and the 2015 market share of electric vehicles. We can tell from the map that state-level targets could be positively correlated with the market shares of electric vehicles. What's more, states which have both ZEV mandate and emissions reduction target tend to gain a larger market share of electric vehicles.

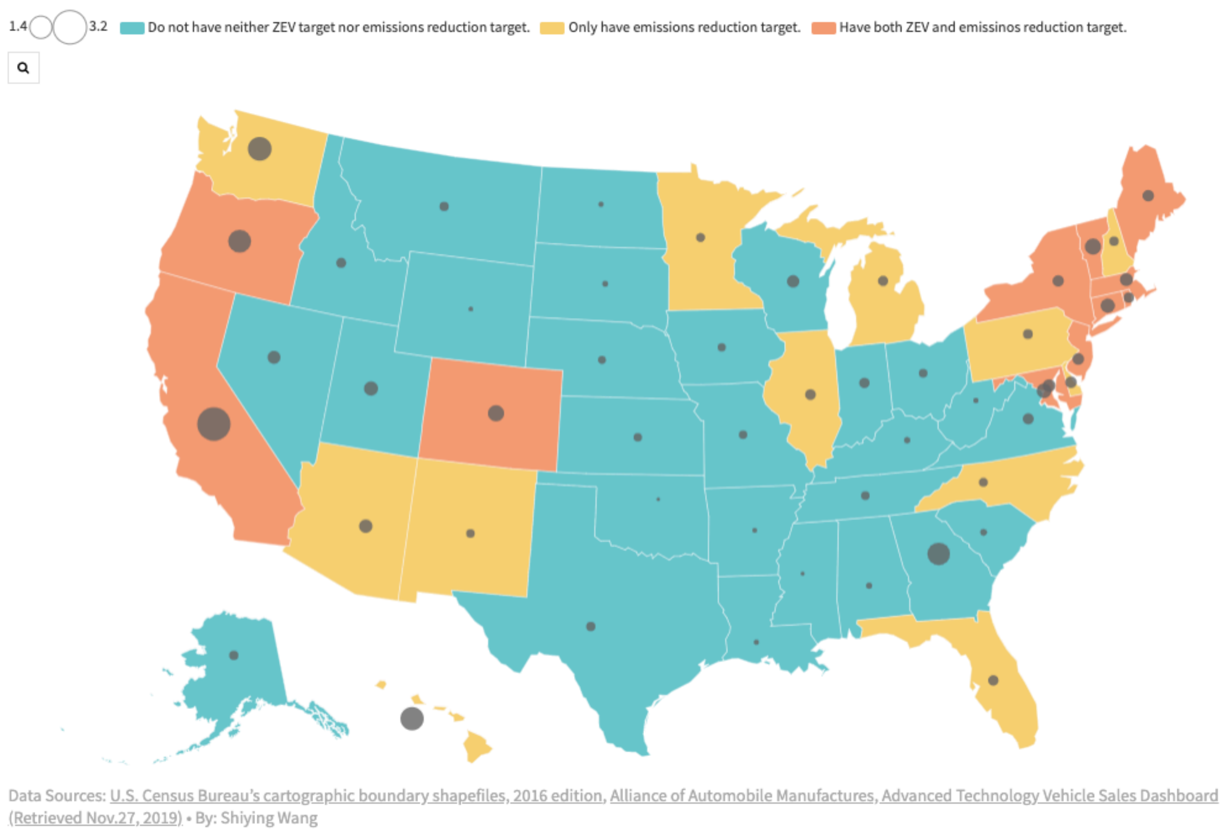

Figure 4: State Targets and 2015 Market Share of Electric Vehicle[47]

6.3 Twitter Data

Public awareness will also play an important role in policy outcomes, in this case the EV adoption. A time-series twitter dataset which contains more than 300,000 tweets will be accessed using Twitter API Premium to evaluate the heterogeneity of incentives effectiveness among states. First the per capita number of tweets using #ElectricVehicles hashtag will be scraped to

[47] See full published visualization here: https://public.flourish.studio/visualisation/1011835/

estimate the degree of public awareness towards electric vehicles topic. Then a more in-depth sentiment analysis will be conducted to further estimate the content of public perceptions in that state. For an instance, Figure 5. below shows the top 50 popular words in tweets that using #ElectricVehicles hashtag, sized by their frequencies, which can give us a general idea of what people are thinking when they talk about electric vehicles.

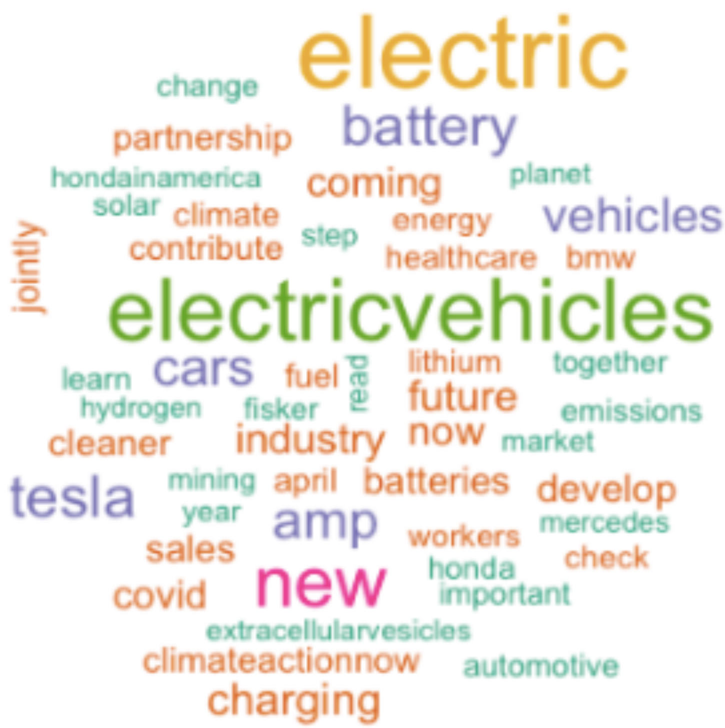

Figure 5: Top 50 Popular Words in Tweets Using #ElectricVehicles Hashtag, 2020.

6.4 Socioeconomics Factors

Apart from incentive policies data and twitter data, other variables such as energy price, historical GHG emissions, state-level GDP and population are included in the regression model. Table 4. shows the summary statistics for important socioeconomics factors.

Table 4: Summary Statistics of Other Important Variables, 2011-2015

VARIABLE	TIME PERIOD	OBS	MEAN	S.D.	MIN	MAX
Gasoline price	Jan 2011–Dec 2015	250	27.1342	3.873416	18.17	36.2
Electricity price	Jan 2011–Dec 2015	250	31.156	11.73665	18.87	99.96
Transport energy consumption	Jan 2011–Dec 2015	250	533441.3	582177.8	48150	3145471
Total emissions	Jan 2011–Dec 2015	250	106.848	109.761	5	694
Transportation emissions	Jan 2011–Dec 2015	250	36.3096	39.79816	3.3	216.6
State-level GDP[48]	Jan 2011–Dec 2015	250	332521.3	411270.1	28135.1	2553772
Mining, quarrying, and oil and gas extraction GDP	Jan 2011–Dec 2015	250	7111.474	23246.62	0.1	201808.9
Population	Jan 2011–Dec 2015	250	6308299	7004324	567299	38900000

SECTION 7: REGRESSION RESULTS[49]

Table 5. shows the results for our baseline specification, in which we only include electric vehicle policies. In Model (2) of the baseline specification, we further estimate the different effects of the following three monetized incentives: EV purchase incentives, emissions inspection exemptions and HOV exemptions, which can represent direct monetary incentives, operating incentives and preferred access incentives, respectively. The result shows that, on average a $1000 increase in a state's EV subsidies will lead to around 8.5% increase in registration of EVs in that state. Moreover, the result in model two tells us that EV purchase incentives, emissions inspection exemptions and HOV exemptions are incentives which can

[48] Million$, in chained 2012 U.S. dollars.

[49] Since almost all the EV policies which apply to PHEV also apply to BEV, here we use the BEV policies data to aggregate the general EV policies. Due to the consideration of model availability and the discrepancy among the vehicles prices, for BEV specific policies data we use Nissan Leaf as an example; for PHEV data, we use Chevrolet Volt.

significantly affect EV sales, while the effect of other incentives[50] may not be statistically significant.

Table 5: Regression Results for Baseline Specification, 2011-2015.

	(1)	(2)
Subsidies amount	0.0000846*** (0.0000321)	-
Index	0. 2115419 (0.1380327)	0.1392921 (0.1393048)
HOV subsidies amount	-	0.0005227*** (0.0001657)
Purchase subsidies amount	-	0.0001014** (0.0000367)
Emissions inspection exemption	-	-0.0011924 (0.0024104)
Other subsidies	-	0.0001079** (0.0000909)
Observations	250	250
Adjusted R^2	0.33	0.42

** indicates the coefficient is statistically significance at the 10% level;*
*** indicates the coefficient is statistically significance at 5% level;*
**** indicates the coefficient is statistically significance at 1% level.*

In previous hypothesis, we assumed that state-level climate commitments and sectoral targets may play an important role in the promotion of EVs, so two state-level targets which are Zero-emissions Vehicle (ZEV) target and emissions reductions target are introduced in model (3) and (4). Table 6. gives us both the result with and without interaction terms. All the policies and targets will significantly increase the sale of EVs in model (3). Interestingly, none of the interaction terms is statistically significant in model (4), which is different from what was expected. The results indicate that, while having a state-level target can increase the EV sale, the effectiveness of other EV policies may not differ a lot with the state-level targets. In other words, state-level targets may not be as effective as we thought.

[50] Other incentives include disincentives (annual fee) and home charger subsidies.

The effect of a $1000 increase in a state's EV subsidies will lead to around 6.5% increase in registration of EVs in that state in specifications here. The estimates coefficients for subsidies are almost identical in robustness tests, and they are all statistically significant at 5% level.

Table 6: Regression Results for Targets Interaction Models, 2011-2015.

	(3)	(4)
Subsidies amount	0.0000666** (0.000032)	0.0000645** (0.0000558)
Index	0.4643964*** (0.1401656)	0.6696244*** (0.2178929)
Has ZEV target	0.8049323*** (0.2880915)	0.591757 0.4245312
Has emissions reduction target	0.7853461*** (0.1951712)	1.036161*** (0.2724803)
Has ZEV target * Subsidies	-	-0.0000626 (0.0001586)
Has ZEV target * Index	-	0.7160077 (0.547074)
Has emissions reduction target * Subsidies	-	-0.0000672 (0.0001114)
Has emissions reduction target * Index	-	-0.396766 (0.3022713)
Observations	250	250
Adjusted R^2	0.3631	0.3429

** indicates the coefficient is statistically significance at the 10% level;*
*** indicates the coefficient is statistically significance at 5% level;*
**** indicates the coefficient is statistically significance at 1% level.*

More specifically, in this research we include two type of EV, which are Battery electric vehicles (BEV) and Plug-in electric vehicles (PHEV). Although many incentives apply to both of them, there still are some BEV-only policies. Table 7. presents the result for those two types of EV respectively.

Table 7: Disaggregated Regression Results for Battery Electric Vehicles and Plug-in Hybrid Electric Vehicles, Respectively.

	BEV			PHEV		
	(1)	(2)	(5)	(1)	(2)	(5)
Subsidies amount	0.0001346** (0.0000563)	-	0.0001238** (0.0000576)	0.0000335*** (0.0000053)	-	0.0000543*** (0.0000042)
Index	0.8024395*** (0.1820495)	0.883038*** (0.1960828)	0.6707788*** (0.1704173)	0.1993447* (0.1199735)	0.5750398** (0.1581628)	0.3401197* (0.1760858)
HOV subsidies amount	-	0.0006963** (0.0002921)	-	-	0.0003623*** (0.0000885)	-
Purchase subsidies amount	-	0.0001302** (0.0000646)	-	-	0.000273*** (0.0000864)	-
Emissions inspection exemption	-	0.0130081 (0.0151507)	-	-	-0.0307461 (0.0190813)	-
Other subsidies	-	0.0002964** (0.0001602)	-	-	0.0005135** (0.000239)	-
Has ZEV target	-	-	0.8861776*** (0.3254974)	-	-	0.522981*** (0.1014984)
Has emissions reduction target	-	-	0.9883167*** (0.2268031)	-	-	0.7361143*** (0.165236)
Electricity price	-	-	-0.0088425 (0.0097689)	-	-	-0.0097785 (0.0112926)
Motor gasoline price	-	-	-0.104185*** (0.0236545)	-	-	0.2009145*** (0.0448599)
Transportation energy consumption	-	-	-2.82e-06*** (1.69e-07)	-	-	1.29e-06*** (1.21e-07)
Observations	246	246	246	250	250	250
Adjusted R^2	0.2841	0.4156	0.5603	0.2242	0.2268	0.5534

** indicates the coefficient is statistically significance at the 10% level;*
*** indicates the coefficient is statistically significance at 5% level;*
**** indicates the coefficient is statistically significance at 1% level.*

Overall, BEV incentives have a larger effect on sales than PHEV incentives do. The effect of a $1000 increase in a state's BEV subsidies will lead to around 13% increase in registration of BEVs in that state, while for PHEV the increase will only be 3%.

What's more, if we take a deeper look at different monetized incentives, other types of incentives such as can be more effective when it is applied to PHEV. In terms of state-level targets, having a ZEV target may have a more significant effect on the sales of BEV.

Table 8: Regression Results for Consumer Awareness Specification, 2011-2015.

	(1)	(2)
Interaction	0.0001135*** (0.0000621)	-
Index	0. 2156719 (0.1553568)	0.1392921 (0.1393048)
HOV subsidies amount	-	0.0005227*** (0.0001657)
Purchase subsidies amount	-	0.0001014** (0.0000367)
Emissions inspection exemption	-	-0.0011924 (0.0024104)
Other subsidies	-	0.0001079** (0.0000909)
Observations	250	250
Adjusted R^2	0.33	0.42

** indicates the coefficient is statistically significance at the 10% level;*
*** indicates the coefficient is statistically significance at 5% level;*
**** indicates the coefficient is statistically significance at 1% level.*

However, some states which have similar or less incentives could have a more dramatic increase in EV sales. For example, in Georgia, the EV sales increased almost ten folds from 2012 to 2014, while there were no newly introduced incentives during that period compared to other states. To understand the heterogeneity, the sentiment analysis[51] on twitter data from 2012 to 2014 can be introduced here.

[51] Here I chose get_nrc_sentiment {syuzhet} package in R to conduct the sentiment analysis.

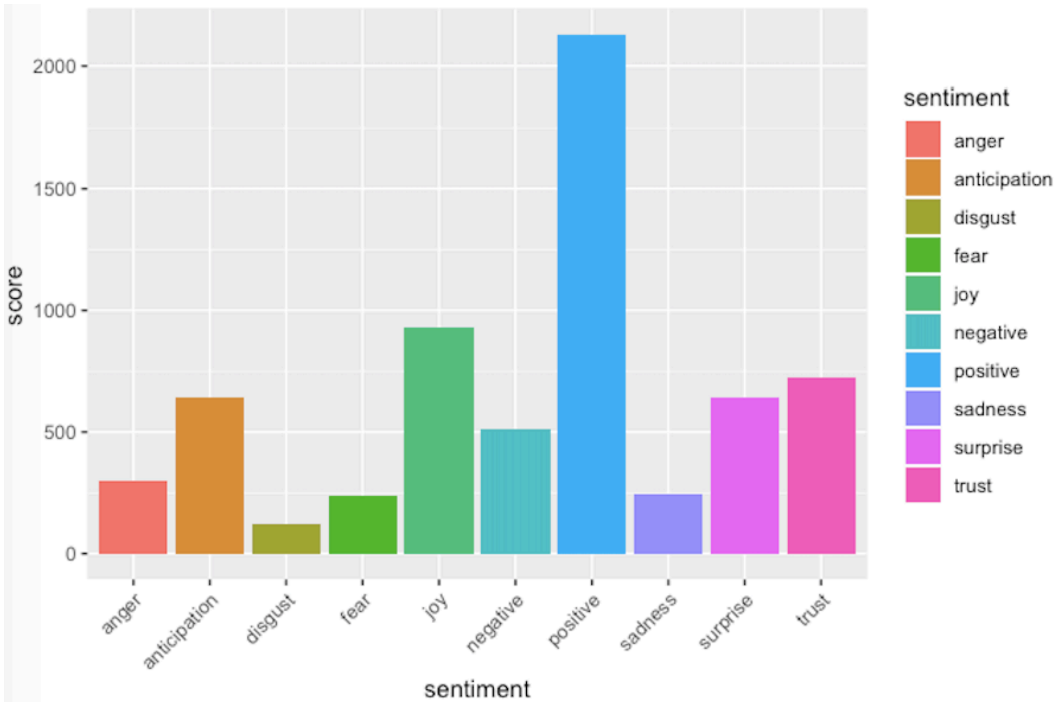

Figure 6: Sentiment Analysis on #ElectricVehicles Tweets from Georgia, 2012-2014.

Figure 6. above shows that in Georgia, the majority of public has a positive view towards electric vehicles; anticipation, trust and surprise are also in majority. While in many other states, the score of fear and negative sentiment is significantly higher than that of Georgia. An LDA model can be used to further indicate the popular topics.

Table 9: Results from LDA Model on Twitter Data, 2020.

Topic 1	Topic 2	Topic 3	Topic 4	Topic 5
"video"	"electricvehicles"	"electricvehicles"	"electricvehicles"	"electricvehicles"
"electricvehicles"	"tech"	"electric"	"tesla"	"electric"
"check"	"renewableenergy"	"future"	"greenenergy"	"tesla"
"electricvehicle"	"electric"	"coronavirus"	"electric"	"new"
"electric"	"renewables"	"covid"	"new"	"cars"
"youtube"	"autonomousvehicles"	"cars"	"tcnn"	"honda"
"music"	"automotive"	"tesla"	"procureevc"	"vehicles"
"talking"	"byd"	"new"	"amp"	"charging"
"cleanair"	"battery"	"amp"	"model"	"bmw"
"porsche"	"toyota"	"charging"	"charging"	"automotive"

Saif Mohammad and Peter Turney. "Emotions Evoked by Common Words and Phrases: Using Mechanical Turk to Create an Emotion Lexicon." In Proceedings of the NAACL-HLT 201 Workshop on Computational Approaches to Analysis and Generation of Emotion in Text, June 2010, LA, California. See: http://saifmohammad.com/WebPages/lexicons.html

SECTION 8: POLICY IMPLEMENTATION AND DISCUSSION

Are state-level incentives effective on increasing electric vehicle sales? As many of other policy issues, the answer is “it depends.” My results show an overall 5%-14% increase in EV sales per every $1000 increase in subsidies across all the states. What’s more, the effectiveness of each type of subsidy differs substantially from state to state. State-level climate commitments such as ZEV mandates and emissions reduction targets have a positive effect on the promotion of EV purchases, but do not significantly increase the effect of other policies instruments.

Based on my empirical results, I conclude that monetary incentives can increase the adoption of electric vehicles overall. However, the magnitude of effects in particular states depends on the mix of policies, difference in energy structure, and levels of consumer awareness. Here, recommendations for state regulators and policymakers can be made from different perspectives:

- Structure of incentive programs: Instead of implementing dramatic or simple changes, governments should consider a mix of incentive policies implemented incrementally. Meanwhile, more stakeholders such as utility companies, automobile manufacturers and dealers should be included in these programs, both as recipients of incentives and provider of incentives.
- Equity consideration: None of the states now has incentive programs that target low-income groups. From an equity perspective, policymakers should consider programs which can give vulnerable groups more access to electric vehicles.
- Climate commitments: Quantitative state-level environmental commitments such as emissions reduction targets can significantly help states to achieve their short-term and

long-term environmental goal. Also, effective regional coalitions such as the ZEV alliance, can help the states better utilize their limited political and economic resources.

- Community engagement: Whether or not a new policy or project succeeds is often determined by the public response. In this case, the level of consumer awareness will significantly affect the effectiveness of state incentive policies. More educational campaigns should be launched. Moreover, soliciting not only the support, but also the input of consumers, will lead to the best results. In the long-term, state regulators and policymakers should strive to engage more stakeholders in the decision-making process. More specifically, the results from frequency words and Latent Dirichlet Allocation (LDA) model on Twitter data indicate that linking electric vehicles to some topics such as climate change, healthcare issues, battery etc. will gain more public attention.

SECTION 9: CONCLUSION AND FURTHER RESEARCH

Electric vehicles incentives can significantly increase the sales of EVs, as long as the incentives are allocated efficiently. State governments should adopt various electric vehicles incentive packages based on the particular circumstances in their states. In addition to financial incentives, state-level climate commitments will also help promote the diffusion of electric vehicles. This study also demonstrates the importance of state-level consumer awareness, and the value of public education campaigns and awareness raising events.

Due to data constraints, I did not include model-specific sales and incentives data. Future studies can include other players such as the federal government, charging stations, and utility companies, and also state-level model availability data. Also, given current limited geo-tagged data, more in-depth twitter data analysis can be done in the future. Using the Stackelberg game model, future studies could also adopt other scenarios by relaxing some of the assumptions used in the present study, such as the incomplete information scenario (the signaling game) which considers “greenwashing” in governments and the imperfect information scenario.

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