The Role of Public Policy in Technology Diffusion: The case of Plug-in Electric Vehicles

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Abstract

The plug-in electric vehicle (PEV) is regarded by many as a viable alternative to the internal combustion engine, so long as the disruptive technology is able to overcome technical and financial shortcomings that dictate consumer acceptance. States have instituted a variety of policies aimed at mitigating these shortcomings and simultaneously increasing consumer demand for PEV vehicles. Motivated by a limited body of literature on the effects of these policies, and a significant need for information about policy efficacy, in the present study we evaluate the relationship between a suite of state-level policies and PEV registrations. Results reveal that tax credits for individuals, grants programs for charging infrastructure and PEV purchases, and incentives for state-owned PEVs fleets increase PEV registrations. The observed impact of grant incentives is mediated by charging capacity or, alternative phrased, much of the influence of grants on registrations is through the channel of first improving the charging infrastructure within a state.

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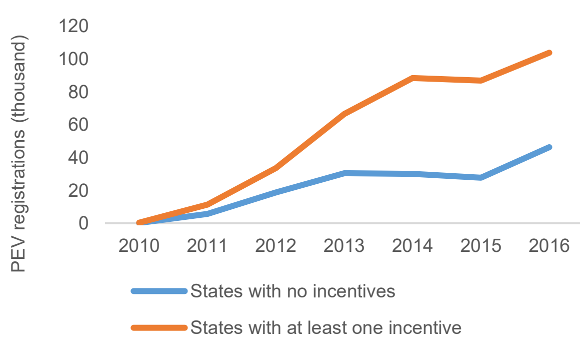

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Introduction

The plug-in electric vehicle (PEV) is a classic case of a disruptive technology. It is touted for its potential to compete with, and potentially displace, the internal combustion engine (ICE) as a dominant vehicle technology. As with other "disruptive" technologies (*1*), however, this technological shift will require a confluence of policy, infrastructural, and behavioral developments in its favor. Generally speaking, scholars interested in the adoption and diffusion of product innovations have long recognized that government policies can facilitate the adaptation of consumer expectations *(2-4)*. Work on disruptive technologies suggest that these "pushes" from government are particularly important when an innovation represents something truly new or disruptive to the current technological regime with which consumers are familiar (*5-6*).

The first mass-marketed PEVs hit the U.S. automobile market in 2010. As of 2016, the stock of PEVs had grown to 563,710 (*7*), with uneven distributions of these vehicles across states. A number of factors are known to dissuade potential consumers from adopting PEVs, including cost, range, and battery recharging requirements (*8-9*). PEVs tend to have an upfront cost that is 50 to 100% higher than similar internal combustion engine vehicles, though the level of subsidies offered by government affects what the consumer pays (*8*). The range of most current PEVs on a fully-charged battery without a hybrid engine is typically between 70 and 100 miles, significantly less than the 250- to 350-mile range of a conventional ICE. These distance limitations contribute to "range anxiety" (*8*), a fear that one's battery will die when on the road. Finally, PEVs require specific charging infrastructure that must be installed in an owners' home or an accessible public facility. Previous work on the intent to purchase PEVs (*10*) find that perceptions of these disadvantages damage consumer interest in adoption more than any other factor.

States and municipalities have adopted a number of policies designed to overcome these barriers and facilitate PEV consumption, though this policy response has been very heterogeneous across the country. Not surprisingly, there have been a number of studies of the relationship between these policy incentives and the spread of PEVs; but these studies have reached mixed conclusions about policy impacts. For example, several studies have focused exclusively on the most prominent policy incentives for PEV purchase – direct financial incentives and charging infrastructure. Sierzchula et al. (2014)[11] find that both are important, but that neither has a particularly large impact on PEV purchases. Lutsey et al. (2015)[12] identify an interactive effect between these variables, suggesting that financial incentives are positively associated with PEV sales, but only in states with sufficient charging availability. A key drawback to both of these studies, however, is that they are estimated in a single year of data and, as such, cannot include fixed effects to account for time or unmeasured state-level characteristics, including other policies.

Li et al. (2017)[13] also focus on tax incentives, in the form of the federal income tax credit, and municipal level charging capacity. They adopt a more sophisticated design, examining quarterly sales over a two-year period and explicitly accounting for endogeneity between previous PEV sales and investment in charging infrastructure. Because of the longer time frame, they are also able to estimate a two-way fixed effects model, which helps to isolate within-jurisdiction effects. However, it is important to note that fixed effects cannot account for state-level policy incentives that are time-variant but otherwise omitted from the analysis, such as grant programs and incentives for state-owned PEVs fleets. Li et al. found that federal incentive does increase sales, but that almost half of the effect is due to charging capacity, and that a direct incentive for charging station deployment would have a larger overall effect on PEV consumption.

Some studies have also sought to analyze the impact of a larger suite of PEV related policy incentives, but again, with varying results. Studies have found a positive association between financial incentives, investment in charging infrastructure, high occupancy vehicle (HOV) lane access, and, in one case, emissions testing exceptions (*14-15*). Santini and colleagues[16, 17] find that DOE grants affected state-level registrations in the absence of other policies, while activities by public utilities to promote PEVs only worked in conjunction with other state-level incentives. Unfortunately, all of these studies employ a cross-sectional research design and, thus, cannot isolate within-jurisdiction effects.

Clinton et al. (2015)[18] analyze sales over a slightly longer time period—two years—and find that tax credit and charging infrastructure are significant predictors, while direct rebates and HOV lane access are not. These authors use an instrumental variables approach to deal with endogeneity between sales and charging infrastructure. Unfortunately, the financial incentives analyzed by Clinton et al. do not vary over the short time span of their study, so they were unable to estimate within-state effects.

We suggest that mixed findings in previous research, along with uncertainty regarding the best way for governments to incentivize the spread of PEVs, are due to inconsistencies in the design of previous studies. Studies to date tend to focus on sales in a single year or limited number of years, evaluate a limited number of policy incentives, or employ methodological approaches that compromise internal validity. In the present analysis, we seek to build on the foundation of these studies with the analysis of a larger number of policies, more PEV models, over a much longer period of time, and using an identification strategy aimed at causal inference and the use of mediated or indirect impacts of policy on the spread of PEVs.

More specifically, we analyze the effect of nine policy incentives on the spread of PEVs between 2010 and 2016. We find that tax credits for individuals, grants programs targeting charging infrastructure and the purchase of PEVs, and incentives for state-owned PEVs fleets increase registrations even when controlling for other incentives. We also find that the observed impact of grant incentives is mediated by charging capacity or, more specifically that much of their influence on registrations comes through their role in improving the charging infrastructure within a state. The paper concludes with a discussion of the implications of these results for our understanding of the diffusion of disruptive technologies and the ability for systems to overcome technological "lock-in" (*19*).

Methods

We examine PEV registrations in the American states between 2010 and 2016, a time frame that spans from the introduction of modern PEVs through the last year for which data are currently available. Our dataset is a longer time series than has been used in previous studies and the set of PEV adoption policies—nine in total—is more extensive than those studied previously. Following the precedent set by previous scholars (*13,18*), we employ a methodological approach that accounts for endogeneity between charging infrastructure and PEV sales. We also employ a research design that allows us to investigate the degree to which the impact of policy on PEV diffusion actually operates through its impact on charging infrastructure.

Dependent Variable: PEV Registrations

The data for new PEV registrations come from IHS Markit[20], a private provider. They include information for battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) registrations for each year between 2010 and 2016 by state. This study includes 50 PEV models but does not include data on low-speed electric vehicle registrations, since their technology is not comparable with the mass marketed PEVs.

The primary dependent variable for this study is the number of annual new PEV registrations by state. As displayed in Figure 1, the spread of PEVs has been unequal between states. The state of California accounts for 48% of the total PEVs registrations during 2010-2016, followed by Georgia with 5%; and Washington, New York, and Florida each one with approximately 4% of the PEV registrations. The rest of states have a participation between 0.02% (Wyoming) and 3.19% (Texas).

[Figure 1 here]

Independent Variables: Public Policies

Data on PEV related policies come from LexisNexis State Capital[21], which provides access to legislative statutes from the fifty states. Using keywords "low emission vehicles OR zero emission vehicles OR electric vehicles", we found 150 out of 557 relevant results containing information related to PEV incentives between 1990 and 2016. Search results that are not part of this study only provide definitions about our keywords (70%) or do not contain new information about policy incentives (30%). The history of the modifications in the statutory codes are available and linked to a respective bill; the latter of which contains the year the policy went into effect. In some occasions (30% of the useable cases), the bill only contains the adoption year, in which case this study assumes that the following year is the effective year.

Our data extraction technique identified a total of 24 different types of PEV incentives at the state level. Many of these policies, however, had diffused to only a single state or were adopted long before modern PEVs hit the market, making assessments of their causal impacts impossible. In our analyses, we chose to focus on nine public policies that diffused to two or more states and were adopted by at least two states after 2010. Figure 1 reveals that, like PEVs, the spread of these 9 policies among the states has been very heterogeneous. The policies include financial incentives, infrastructure related incentives, and symbolic policies as fully described in Table 1.

[Table 1 here]

We use data on PEV incentives to create two different types of independent variables. First, we create dichotomous indicators coded 1 if a state has a particular policy and 0 otherwise, which allows us to estimate the impact of adopting an individual policy while controlling for the adoption of other policies. Afterwards, we code the dollar amounts of grants and tax credits to explore whether the size, rather than simply the presence, of a financial incentive influences the number of PEV registrations within a state.

Control Variables

We control for internal state characteristics that may influence both PEV diffusion and PEV policy adoption. The control variables represent obstacles and motivations to the adoption of new technology by consumers within a state. All data sources are outlined in Table 2. One of the primary impediments to the spread of PEVs identified in previous research is extent of the charging infrastructure within a jurisdiction. In order to capture that capacity, we create a measure of the number of charging stations in each state and year.

Because of their expense, both in terms of purchase price and investment required by communities, there are also likely to be a number of socioeconomic obstacles to the spread of PEVs. We capture these with measures of wealth, education and, employment. Specifically, we measure gross state product (GSP) per capita, the proportion of the population with at least high school education, and the unemployment rate.

Citizens may also purchase PEVs in an effort to reduce negative environmental consequences of ICEs, such as carbon dioxide (CO_2) emissions. This analysis includes the CO_2 emissions produced by the transportation sector as a proportion of the total CO_2 emissions at each state. States with higher proportion of CO_2 emissions are expected to have a higher level of PEV registrations. The data for CO_2 emissions are only available until 2014, therefore we interpolate the values for 2015 and 2016 as a function of the GSP. One remark about PEVs is that their combustion emission take place during the stage of electricity generation (*22-23*). For that reason, we include renewable energy use within a state to capture the readiness of each state to embrace less pollutant technologies.

Of course, the level of concern over issues such as CO_2 emissions and the willingness to embrace technologies such as PEVs more broadly is likely to be partially a function of the environmental ideology of state residents. We capture this orientation with two political measures. The first is the percent of Democratic legislators in the Senate and House of Representatives. We also include the total number of victories of members from the Green Party across different popularly elected positions in each state.

If one extends the literature on conventional hybrids to the context of the PEV, we could hypothesize that consumers in states with higher gasoline prices are more likely (motivated) to accept PEVs as an ICE alternative than those that live in states with lower gasoline prices (*24-*

25). We include annual data for average gasoline price per gallon, which incorporates federal and state gasoline taxes, but excludes local taxes. In a related argument, previous work has assumed that the price of electricity will influence the decisions of consumers considering PEVs. Therefore, we control for the average price for electricity (cents/kilowatt-hour) in each state and year. Finally, the number of licensed drivers operationalize the size of the potential market for PEV at each state.

[Table 2 here]

Design and Estimators

For the primary analysis, this study exploits variation in the timing and extent of PEV policy adoption in the American states in order to estimate a generalized difference-in-differences model. As is standard in these estimators, the model includes two-way fixed effects (FEs) which allows for the estimation of the within-state effects of a policy on PEV registrations in the period following its adoption. Standard errors are clustered at the state level in this specification.

As noted above, previous work suggests that charging infrastructure within a jurisdiction not only incentivizes potential consumers of PEVs but may also be endogenous to previous sales. Diagnostics reveal that this is also the case in our sample of states and years. In order to correct for potential bias arising from this endogeneity, we implement an instrumental variables approach with the differences-in-differences framework. Following the suggestion of Li et al. (2017)[13], we instrument the number of charging stations with the interaction between the number of stations in all states other than the state-year observation under analysis and the number of grocery stores in each state (lagged one year). The first stage shows an F-test for the excluded instrument of 10.01, suggesting that the instrument is acceptable.

Finally, we run a mediating variables analysis in order to determine whether the observed impact of PEV policies on sales is in part a function of their impact on charging infrastructure. Evidence of mediation requires us to show that: 1) the number of charging stations influences registrations; 2) policies influence the number of charging stations; 3) policies influence registrations in the absence of a control for charging stations; and 4) the impact of policies on registrations changes when we include the mediator in the model. The first of these requirements can be met in our primary analysis presented in Table 3 (Column 1). We test for number 2 in a two-way fixed effects model where number of charging stations is the dependent variable, which is presented in the first column of Table 4. The last two requirements are tested with difference-in-difference models of registrations presented in columns 2 and 3 of that table. We instrument for charging stations in each of the last two models because we still need to correct for diagnosed endogeneity. Thus, the final analysis in Table 4 is identical to the main model presented in Table 3 (Column 1), but we present it again in order to facilitate the observation of any mediating effects.

Results

The first column of Table 3 contains the difference-in-differences analysis of the impact of nine policy incentives on PEV registrations between 2010 and 2016. Consistent with previous work, instrumented charging infrastructure has a significant and positive impact on registrations. The results suggest that a 1-standard deviation increase in charging stations is associated with an increase of PEV registrations between 5,052 and 5,131 units.

In terms of policy impact, the results suggest that grant programs to finance the installation of PEV charging infrastructure and the purchase of PEVs respectively, and tax credits for individuals both have a positive impact on the number of new PEV registrations in each state. Substantively, the findings suggest that the presence of PEV-related grants within a state increases PEV registrations by 7862.54, which is a 1.2 standard deviation increase. Interestingly, when controlling for these other incentives over a longer period of time, tax credits for individuals—a policy that has been shown to increase sales in other studies—has a positive effect on PEV registrations. However, its incidence, at least in terms of average treatment effect, is lower than the one from grant programs and symbolic incentives as state-owned PEV fleets. In fact, a 1-standard deviation increment in tax credits for individuals is associated with an increase of 191 PEV registrations. Meanwhile, an increment of 1-standard deviation in grant programs is associated with an increase of 5,394 PEV registrations. Likewise, an increment of 1-standard deviation in state-owned PEV fleets is associated with an increase of 2,053 PEV registrations.

[Table 3 here]

In order to check the robustness of the results in discussed above, the second column of Table 3 presents models testing whether it is the dollar amounts of grants and tax credits, rather than simply the presence of these financial incentives, that influences the number of PEVs per registered driver within a state. Both monetary incentives are associated with an increase in PEV registrations. Importantly, the incidence of grant programs is higher than the ones for tax credits to individuals since that a 1-standard deviation increase in grants (US$4.95 million) is associated with an increase of 6,439 PEV registrations while a 1-standard deviation increase in tax credits for individuals (US$1,466.19) is associated with an increase of 140 PEV registrations.

Before moving on, it is important to note that 2 policies had a *negative* and significant impact on PEV sales. Specifically, models suggest that states that adopted regulations intended to standardize public charging stations within a state and those that adopted policies reserving special parking spots for PEV drivers actually saw a decrease in new registrations following those adoptions. We will return to these negative findings in the discussion section, where we offer some potential explanations.

Exploring the mediating impact of charging infrastructure

The results thus far suggest that policies designed, at least in part, to contribute to a state's charging infrastructure may have an influence on PEV registrations. This raises the possibility that this observed impact is in fact mediated by the degree to which these policies actually increase the number of stations available to PEV owners.

The analyses presented in Tables 3 and 4 provide the information necessary to test that possibility. First, the primary analysis presented in the first column of Table 3 confirms that charging stations (instrumented) have a positive and significant impact on PEV registrations. Turning now to Table 4, the two-way fixed effects model of charging stations in the first column shows that public policies do have an impact on charging infrastructure, which is the next prerequisite for demonstrating a mediating effect. Specifically, the analysis suggests that the presence of grants that can be used to enhance charging capacity are positively associated with the number of charging stations within a state.

[Table 4 here]

The final piece in the mediating variables analysis is to compare the impact of these policies on registrations when the potential mediator—number of charging stations—is excluded versus included in the models. Looking at the final two columns of Table 4 we can see that grants increase registrations in both models, but that the impact shrinks significantly when the instrumented charging station variable is included in the model. Specifically, the results suggest that 52% of the total impact of PEV grant policies on new registrations actually comes through the increase in available charging capacity that the policy stimulates.

Discussion

There has been significant growth in the ownership of PEVs since the first mass-marketed models became available in 2010. That diffusion has, however, been very heterogeneous across states. Incentives to facilitate the spread of PEVs have also varied dramatically across the states and we test whether heterogeneity in the latter can explain the observed variation in the former. This study represents a contribution to existing research on this subject because it investigates a larger number of PEV related policies, over a longer time period, using causal identification strategies that explores both direct and mediated effects of public policy.

Analyses of PEV ownership and nine PEV statutory policy-incentives across all 50 states between 2010 and 2016 provide some evidence for the positive role of government incentives on PEVs uptake. Specifically, they suggest that the adoption of grants targeting infrastructure and ownership, as well as policies creating special financing for PEV-related equipment increase PEV registrations within a state. These policies remain the significant predictors of registrations even if we use the dollar amounts of financial incentives, such as grants and tax credits, as the independent variables.

These results offer an important confirmation of previous findings which suggest that individual tax credits can spur PEV diffusion, even when we control for a much larger number of policies and analyze registrations over a much longer time period. They also add significantly to previous work by suggesting that other policies can also influence PEV registrations. Indeed, the findings indicate that states may be able to overcome the observability problem inherent in new technologies such as PEVs simply by putting these vehicles on the road in public fleets. Interestingly, the influence of incentives for state-owned electric fleets on new registrations is *larger* than the impact for individual tax incentives, which have been one of the most widely touted mechanisms for incentivizing uptake of PEVs.

The findings also suggest the import of another heretofore unexplored state-level incentive for PEV diffusion. Specifically, they suggest that grants targeted at improving charging infrastructure and providing better financing for PEV purchases have a positive and significant impact on new PEV registrations in the states that adopt them. Intuitively, we would expect that part of this impact would occur because they actually do improve charging capacity and a mediating variables analysis suggests that this is the case. The grants are positively associated with the number of charging stations, which in turn is positively associated with PEV registrations. The final part of the mediating variable analysis suggests that more than half of the observed treatment effect of adopting a PEV grants policy is, in fact, working through the impact of those policies on charging capacity.

Before moving on, it is important to note that the impacts of individual tax credits or policies to grow state-owned PEV fleets are *not* moderated by charging infrastructure. This is what we would expect, because these policies are not designed to overcome the barriers to PEV ownership by improving charging capacity. The fact that they are not mediated by the number of stations provides a good falsification test and, therefore, increase our confidence in the validity of the results of the mediating variables analysis.

Our results also suggest that numerous policy incentives *do not* appear to directly increase PEV registrations. Of course, we exercise caution in interpreting these nonfindings, as well as the positive results discussed above, with caution because we are analyzing only six years of data at the very outset of diffusion period for PEVs. Nonetheless, the failure of some of these policies, like laws authorizing feasibility studies (i.e., planning) or those providing some funding to PEV manufacturers for R&D, to influence sales should not, perhaps, be surprising. The mechanisms by which these policies might influence consumer behavior in a meaningful way are difficult to imagine.

It is harder to understand why policies that seek to improve charging infrastructure by standardizing charging stations within a state would not have a positive impact on PEV registrations. However, it is possible that the failure of these public charging station policies to incentivize potential consumers can be explained by the fact that they *do not* actually increase the number of charging stations (see Column 1, Table 4). As such, these policies do not do anything to reduce anxiety among those consumers about the range of PEVs. The fact that these policies appear to cause a significant reduction in new registrations is more difficult to explain. It is possible that the debate over these policies makes consumers aware that even if they find a charging station, they may not be able to plug their new vehicle into it, which creates additional uncertainty and hampers the diffusion of the technology. Obviously, however, more research is needed to understand the mechanisms underlying this counter-intuitive result.

Previous research on PEVs suggests that price and range anxiety are the two major factors that keep potential consumers from these vehicles. Older work also suggests that observability is one of the key impediments to the spread of any truly innovative or novel product (see Rogers 1962[2]). Our findings indicate that policies that directly address these barriers are most effective at facilitating the spread of this disruptive technology. Tax incentives directly reduce the higher price of PEVs; grants targeting charging infrastructure likely reduce range anxiety because they actually increase the number of available charging stations; finally, policies that grow state-owned PEV fleets allow consumers to see and become accustomed to the new technology.

Acknowledgments

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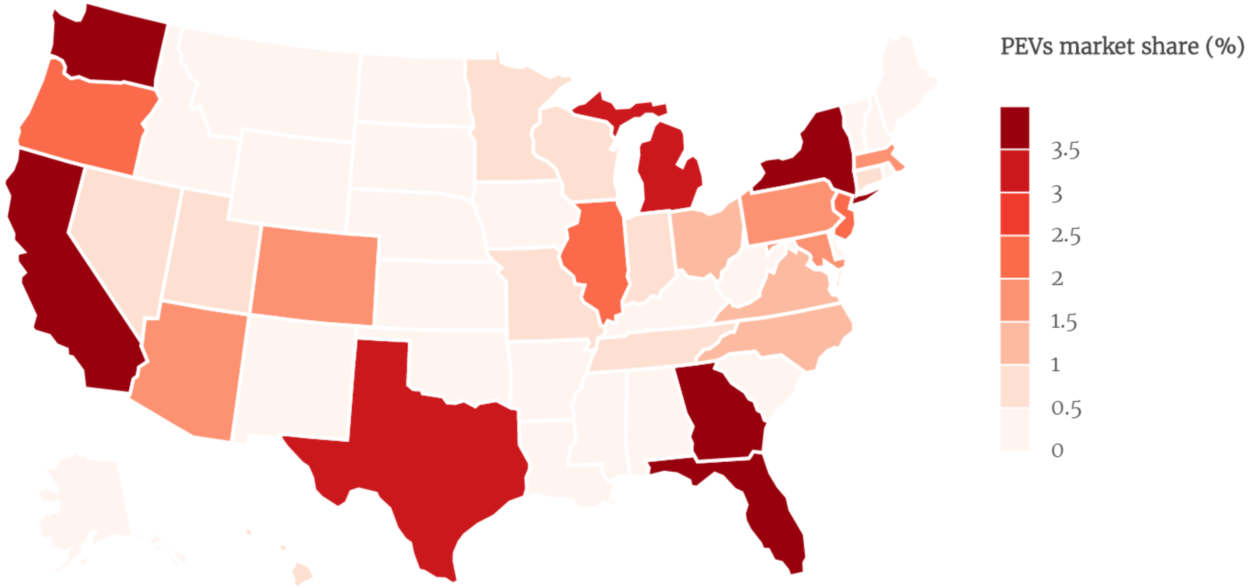
Figure 1. Plug-in electric vehicles (PEVs) statutory policy-incentives and market share (%) (2010-2016)



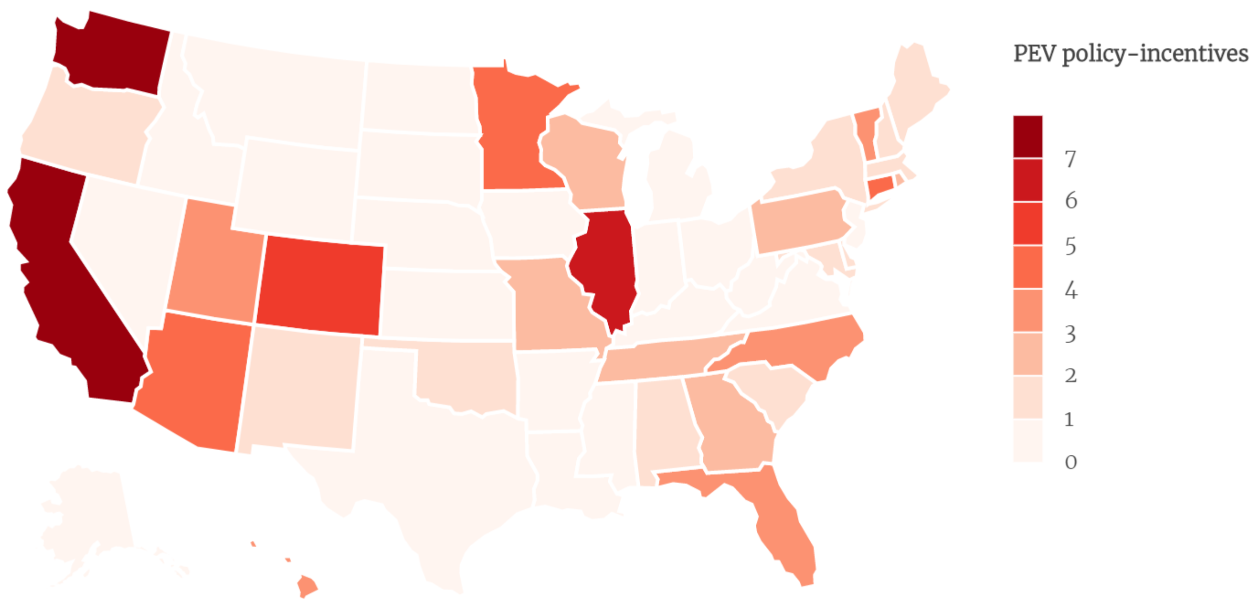


Table 1. Plug-in electric vehicle policy-incentives

Category	Incentive	Description	Example
Financial	Grants	Grant programs to finance the installation of electric vehicle charging infrastructure and the purchase of plug-in electric vehicles	California with its Alternative and Renewable Fuel and Vehicle Technology Program and its Air Quality Improvement Program provides funding for electric charging infrastructure and electric vehicle deployment up to $40 million per year
	Tax credits for individuals	Tax credits for individuals to purchase or lease plug-in electric vehicles, and to convert internal combustion engine vehicles into plug-in electric vehicles	Colorado offers tax credits to individuals who own low-emission vehicles, including PEVs, for an amount up to $6,000
	Electric vehicle supply equipment financing	Programs to issue bonds, notes and other types of financial instruments to finance the installation of electric vehicle charging station, electric vehicle conversions, and to support the deployment of plug-in electric vehicles	Alabama authorizes local governments to issue bonds, notes, or other type of financing methods to increase charging stations deployment
	Research and development	Financing research to facilitate the development and commercialization of electric vehicles and their parts, and the investment in technologies to improve load management of electric vehicle charging stations	South Carolina with its Distributed Energy Resource Program invests in technologies to improve the load management of electric vehicle charging
Infrastructure	Public charging stations availability	Reduction of administrative barriers to install electric vehicle charging stations, requirements to have charging stations in interstate highway rest areas, and compatibility requirements to use charging stations for any type of electric vehicle	Minnesota requires that any installed electric vehicle charging station must be compatible for utilization with any type of electric vehicle (make, model)

	Private charging stations availability	Reduction of administrative barriers to install electric vehicle charging stations for personal residential use	Oregon forbids homeowners associations to prohibit the installation of charging stations in a parking lot or in another area subject to the exclusive use of the owner
	Parking availability	Assignation of parking spaces to plug-in electric vehicles and parking enforcement with monetary penalties	Hawaii mandates places with at least one hundred parking spaces to designate no less than 1% of the parking spaces to electric vehicles
Symbolic	Planning	Studies to evaluate the feasibility to deploy electric vehicles infrastructure, to purchase state-owned electric vehicle fleets, to reduce electricity rates to charge electric vehicles, and to use grid technology to facilitate the use of electric vehicles	Massachusetts requires an action plan to increase access to electric vehicle infrastructure, increment the purchase of PEV by reducing the cost of PEV purchase and identifying strategies to remove barriers to PEV deployment
	Incentives for state-owned electric vehicles fleets	Prioritize the purchase of new state-owned fleet to be plug-in electric vehicles and to increase progressively the proportion of plug-in electric vehicles in the state-owned fleet	Connecticut requires that alternative fuel cars must represent 50% of the light-duty trucks purchase by the state after 2008 and 100% after 2010

Table 2. Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max	Source
Dependent Variable					
PEV registrations	1570.91	6577.50	0.00	74749.0	IHS Markit[20]
Independent Variables					LexisNexis[21]
Financial incentives					
Grants	0.17	0.68	0.00	5.00	
Grants (Million US$)	0.83	4.95	0.00	40.20	
Tax credits for individuals	0.05	0.22	0.00	1.00	
Tax credits for individuals (US$)	263.57	1466.19	0.00	15000	
Electric vehicle supply equipment financing	0.06	0.24	0.00	1.00	
Research and development	0.04	0.24	0.00	2.00	
Infrastructure incentives					
Public charging stations availability	0.07	0.25	0.00	1.00	
Private charging stations availability	0.01	0.11	0.00	1.00	
Parking availability	0.06	0.24	0.00	1.00	
Symbolic incentives					
Planning	0.20	0.47	0.00	2.00	
Incentives for state-owned electric vehicles fleets	0.24	0.55	0.00	3.00	
Instrumental Variable					
Grocery stores and supermarkets	1322.86	1817.68	105.00	10073	US Census Bureau[26]
Control Variables					
Charging Stations	55.05	103.73	0.00	1180	Alternative Fuels Data Center[27]
GDP (2010 USD Millions per capita)	0.05	0.01	0.03	0.08	Bureau of Economic Analysis[28]
Unemployed (%)	3.90	1.08	1.36	7.07	American Community Survey[29]
High school education (%)	29.01	2.95	23.00	38.23	American Community Survey[29]
C0$_2$ Transportation sector (% total emission)	35.78	11.70	11.44	60.17	Environment al Protection Agency[30]
Renewable energy (% total energy)	30.27	23.13	0.92	99.77	U.S. Energy Information Administrati on[31]
Democrats in the legislature (%)	48.09	17.31	13.33	91.14	National Conference of State Legislature[32]

Green party victories	4.13	8.99	0.00	69.00	Green Party Elections Database[33]
Gasoline price (USD)	3.21	0.56	2.20	4.57	U.S. Energy Information Administration[34]
Price of electricity (USD Cents/kilowatthour)	10.42	3.87	6.08	34.04	U.S. Energy Information Administration[31]
Licensed drivers (Millions)	4.26	4.43	0.41	25.53	Federal Highway Administration[35]

Table 3. The effect of plug-in vehicle incentives on plug-in electric vehicle registrations

	IV-FEs	IV-FEs
Grants	7862.5387**	
	(2409.2195)	
Tax credit for individuals	877.1572*	
	(431.7596)	
Grants (US$)		0.0013**
		(0.0005)
Tax credit for individuals (US$)		0.0956**
		(0.0343)
Electric vehicle supply equipment financing	4594.7453	4473.8535
	(2930.5983)	(3327.8942)
Research and Development	4954.3477^{+}	2836.3378
	(2971.1035)	(2171.7783)
Public charging stations availability	-7176.0570***	-5557.0787***
	(1632.3650)	(1215.0968)
Private charging stations availability	-3573.9159^{+}	-3053.4600
	(2164.3250)	(2090.1183)
Parking availability	-3940.3049**	-3576.8604*
	(1428.0746)	(1642.3609)
Planning	-1527.4875^{+}	-692.4387
	(928.2332)	(633.9805)
Incentives for state-owned PEVs fleets	3729.3722**	3285.5945**
	(1345.6598)	(1201.3677)
Charging stations	48.7103***	49.4636***
	(8.3990)	(9.0757)
GDP (2010 USD Millions per capita)	6544.0788	9249.5432
	(59898.0928)	(61428.6736)
Unemployed (%)	576.8853	706.3882
	(454.2844)	(502.6291)
High school education (%)	112.9551	164.8302
	(166.4937)	(178.2132)
CO_2 Transportation sector (% total emissions)	-40.4975	-43.0483
	(27.5456)	(29.4087)

Renewable energy (%total energy)	27.2314^{+}	22.5939
	(14.5346)	(14.1543)
Democrats in the legislature (%)	12.3645	29.5103
	(34.6580)	(37.6318)
Green Party Victories	87.3069^{+}	35.4120
	(50.6592)	(40.7957)
Gasoline price (USD)	3951.2146	2195.0821
	(2457.5954)	(2179.1032)
Price of electricity (USD Cents/kilowatt-hour)	4.0680	-47.2342
	(184.2635)	(177.9960)
Licensed drivers (Millions)	897.7637	307.6121
	(1104.5166)	(913.2021)
Constant	-21503.7454*	-16839.7090*
	(8727.8439)	(8301.0355)
Observations	350	350
Clusters	50	50
State and Year fixed-effects	Yes	Yes
First-stage F statistic	10.01	11.52
R_2 within	0.8251	0.8349
Intra-class correlation	0.9654	0.9536

Cluster robust standard errors in parentheses: $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Note: all variables are lagged one period except tax credits for individuals

Table 4. Mediating analysis: How charging stations affect PEV registrations?

	Charging Stations FEs	Registrations FEs	Registrations FEs-IV
Grants	248.3892***	16438.4662***	7862.5387**
	(65.5210)	(4617.9133)	(2409.2195)
Tax credit for individuals	-2.2546	819.4993	877.1572*
	(23.0667)	(768.6576)	(431.7596)
EVs supply equipment financing	99.9639^{+}	8952.9378	4594.7453
	(50.7483)	(5581.6256)	(2930.5983)
Research and Development	129.4755	9788.4881^{+}	4954.3477^{+}
	(85.6547)	(5772.8445)	(2971.1035)
Public charging stations availability	-53.2136	-8379.9627*	-7176.0570***
	(54.3208)	(3507.3582)	(1632.3650)
Private charging stations availability	18.9983	-3157.5700	-3573.9159^{+}
	(52.5305)	(2184.7551)	(2164.3250)
Parking availability	58.9670	-868.8000	-3940.3049**
	(50.6744)	(2428.0111)	(1428.0746)
Planning	-11.2461	-2184.8530	-1527.4875^{+}
	(20.5676)	(1376.7589)	(928.2332)
Incentives for state-owned PEVs fleets	0.8489	3614.4064^{+}	3729.3722**
	(33.8284)	(2091.4976)	(1345.6598)
Charging stations			48.7103***
			(8.3990)
GDP (2010 USD Millions per capita)	1390.5219	77400.5163	6544.0788
	(2016.7421)	(64494.4128)	(59898.0928)
Unemployed (%)	-29.3950**	-789.3421*	576.8853
	(9.7263)	(333.7555)	(454.2844)
High school education (%)	-7.5130*	-185.2703	112.9551
	(3.6677)	(129.7733)	(166.4937)
CO_2 Transportation sector	-0.3147	-31.8661	-40.4975
	(0.7003)	(38.4237)	(27.5456)
Renewable energy (%total energy)	-0.6055	4.8535	27.2314^{+}
	(0.5898)	(20.7126)	(14.5346)
Democrats in the legislature (%)	0.3618	23.7343	12.3645

	(0.5330)	(24.8114)	(34.6580)
Green Party Victories	1.2210*	94.6295*	87.3069^{+}
	(0.5207)	(40.0875)	(50.6592)
Gasoline price (USD)	141.5656	9513.8500	3951.2146
	(169.2166)	(7036.6933)	(2457.5954)
Price of electricity	-6.1964^{+}	-264.1117	4.0680
	(3.6030)	(170.9291)	(184.2635)
Licensed drivers (Millions)	98.5847	4790.1470	897.7637
	(74.2998)	(3231.4137)	(1104.5166)
Constant	-433.6307	-38502.9290	-21503.7454*
	(637.1861)	(27607.5821)	(8727.8439)
Observations	350	350	350
Clusters	50	50	50
State and Year fixed-effects	Yes	Yes	Yes
First-stage F statistic			10.01
R_2 within	0.7431	0.7098	0.8251
Intra-class correlation	0.9913	0.9930	0.9654

Cluster robust standard errors in parentheses: $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Note: all variables are lagged one period except tax credits for individuals