Structural Determinants of Electric Vehicle Market Growth

February 2017

A Research Report from the National Center for Sustainable Transportation

Gustavo Collantes, Policy Institute for Energy, Environment and the Economy, University of California, Davis

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U.S. Department of Transportation (USDOT) Disclaimer

Acknowledgments

This study was funded in part by a grant from the National Center for Sustainable Transportation (NCST), supported by USDOT through the University Transportation Centers program. The authors wish to thank Sydney Vergis for her invaluable input on various parts of this report and the National Center for Sustainable Transportation for financial support. We are indebted to all stakeholders for the information they shared and for their trust in us to find practical lessons that they could use in their work to further vehicle electrification.

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EXECUTIVE SUMMARY

Zero emission vehicles (ZEV) and plug-in electric vehicles (PEV) are critical technologies to attain deep reductions in greenhouse gases from transportation. PEV markets, however, have grown more slowly than anticipated by many observers. In this study, we seek a deeper understanding of the challenges facing PEV markets and how they might evolve in different regions. Using a Technology Innovation Systems (TIS) framework, we examine the major conditions—political, technological, economic, and societal—that drive the development, deployment and use of these vehicles at the state level. With this holistic approach, we identify strengths and weakness of the innovation systems in a few representative states, which we translate into recommendations for policy strategy. We find that while significant efforts have been undertaken to support PEV innovation, there are significant deterrents to the broader market uptake of PEV.

Introduction

The transport sector will need to undergo nothing short of a dramatic transformation to achieve the deep reductions in greenhouse gases needed for climate stabilization. Zero emission vehicles (ZEV), comprised of plug-in electric and hydrogen fuel cell vehicles, are essential components of this transformation. Key studies support this conclusion, including a report by the National Academies of Science (National Research Council, 2013). That report suggests an 80% reduction in greenhouse gas (GHG) emissions from light-duty vehicles by the year 2050 can best be achieved through promotion of plug-in electric vehicles (PEVs) and hydrogen fuel cell vehicles (FCVs). Other researchers reach similar conclusions for global markets: for example, Ou, Zhang and Chang (2010) show that only scenarios with tangible market penetration of electric drive vehicles may be successful at substantially reducing emissions from transportation in China.

Stakeholders in the United States and other key global markets (e.g. China) have increasingly expressed interest in understanding the drivers and obstacles for PEV markets. Many seek effective strategies to drive sales growth aimed at meeting economic and environmental goals. Unpublished ongoing research suggests that incentive programs show statistical efficacy[1] in accelerating PEV markets, the pace of growth in most states remains too sluggish to place the transportation sector on a clear trajectory to meet carbon mitigation goals. In conversations with stakeholders, we heard concerns about "structural" factors or factors affecting market demand that are not fully understood or even identified, and that could constrain the effectiveness of incentive programs, thereby hindering overall market development.

To provide answers in this area, a holistic understanding of the factors that mobilize the process of ZEV innovation is needed. Factors related to the vehicle-consumer interface, such as vehicle price, financial and non-financial incentives, infrastructure availability, income, and others, are important to inform policy. However, these aspects constitute only a part of the innovation process, which also includes a host of relevant socio-technical factors. We expect that a holistic understanding of factors affecting innovation processes will yield critical lessons for public policy, corporate strategy, non-profit advocacy, resource allocation decisions and academic research agendas. A review of the literature revealed no holistic studies of PEV innovation in the U.S.

The overarching objective of this research is to help bridge this gap and identify systemic factors that affect—positively and negatively—the development, deployment, and use of plug-in electric vehicles. In this study we focus only on plug-in hybrid and battery electric vehicles for two reasons: First, PEVs remain the only ZEVs currently produced and commercialized at scale. Hydrogen fuel cell vehicles, on the other hand, remain relegated to limited production trials. Second, the innovation systems of these two ZEV technologies are not one and the same. Specifically, this research is concerned with:

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[1] Unpublished work by one of the authors involving empirical data analysis.

- Describing the interrelated factors—policy, social, economic, institutional, technological, and others—needed to develop PEV markets;
- Assessing these factors in the context of technology innovation systems; and
- Identifying policies and strategies that could improve conditions for PEV innovation.

A significant body of research has looked at the reasons that consumers buy advanced technology vehicles (e.g. Ozaki and Sevastyanova, 2011; Heffner, Reid R., 2007) and the extent to which these factors may impact consumers' choices (e.g. Bunch et al., 2000; Collantes, 2010; Liu and Greene, 2014). This very important body of research focuses on the interface between the individual consumers and the technology. The success of a technology in the marketplace, however, depends on a larger system, sometimes referred to as the *innovation system* (Bergek, Jacobsson, Carlsson, Lindmark, and Rickne, 2008; Carlsson and Stankiewicz, 1991). Scholars have developed the field of Innovation Systems and tested it as a research tool to understand how different innovations or technologies are developed, diffused and used (Hekkert, Suurs, Negro, Kuhlmann, and Smits, 2007; Negro, Hekkert, and Smits, 2007; Suurs and Hekkert, 2009).

Methodology

We respond to the need for a systems approach to the study of ZEV innovation by adopting the Technology Innovation Systems (TIS) framework. The TIS framework provides a holistic approach to the study of innovation processes by assessing a number of interconnected *functions*, which affect the market development and diffusion of new sustainable technologies (Bergek et al., 2008; Hekkert et al., 2007). Like every systemic approach, TIS methods takes a broad perspective and look at the parts of a system as an integrated whole. Central to the TIS framework that we use is the notion that barriers to technology innovation can be found not only in actors and markets, but also in institutions (such as policies) and networks. We define a technology innovation system as the interrelated set of actors, networks and institutions that contribute – in a supporting or detracting way – to the development, diffusion and applications of knowledge and/or products related to a given technology.

Recognizing that many contributions have been made toward frameworks for the study of innovation, we adopt several concepts proposed or adapted by Schumpeter (Schumpeter, 1934). We understand innovation in the Schumpeterian sense, as embodying not only the technological development (invention) but also the adoption and effective use of the technologies of interest in the marketplace. Innovation is not just about the idea (or the technology) itself; it is rather a process of discovery followed by implementation and use in a market setting. We also subscribe to Schumpeter's perspective on innovation and entrepreneurship as essential forces to create the disequilibrium needed for endogenous economic growth.

TIS frameworks have been applied to the study of aspects of ZEV markets (Vergis, 2014; Vergis and Mehta, 2012) as well as to the development of policy interventions to address market barriers (Bergek, Jacobsson, Carlsson, Lindmark, and Rickne, 2005). The literature proposes that TIS are characterized by a set of seven functions (Hekkert et al., 2007). These seven functions are defined at a conceptual level, giving researchers latitude to design operationalization's and measurements that are suitable to the problem at hand. In Table 1 we show the seven functions, including descriptions of the factors in the innovation system that they represent.

Table 1. Functions of Technology Innovation Systems

Function Technical Name	Description	Example Indicators
Knowledge development and diffusion	Refers to the knowledge related to the technology that is accumulated and disseminated by actors and networks in the TIS.	Patent filing, research, conferences,
Influence on the direction of search	Refers to the pressures on actors and networks to actively support or deter the TIS.	Technology bottlenecks, regulations and policy incentives or articulations of technology expectations.
Entrepreneurial experimentation	Refers to the probing of new ideas with the goal of supporting innovation around the particular technology.	Pilot and demonstration projects, and variety of products available on the market
Market formation	Refers to the creation of conditions that directly lead to increased adoption of the technology, either in niche markets or broader markets.	Market size, customer groups, and procurement procedures.
Legitimation	Refers to the social acceptance of the technology by conformance with existing cultural values and institutional frameworks, or developing new values and institutional frameworks.	Attitudes towards the technology among consumers and stakeholders.
Resource mobilization	Refers to the financial, material and human resources that are made available with the goal to support or detract from innovation in the technology.	Personnel dedicated to the support programs related to the technology, capital committed by states to support market uptake, increasing volume of seed and venture capital.
Development of positive externalities	Refers to economic and non-economic factors indirectly related to a technology that help strengthen the other six functions.	Spillover effects from and to other industries

An in-depth investigation of all these functions for any given U.S. state is a laborious endeavor. In this particular research, we will focus on three states for such in-depth investigation. In addition to obtaining a deep understanding of the innovation system in these states, this exercise will help us identify indicators and themes for each of the functions that would enable the assessment of plug-in electric vehicle technology innovation systems in other states. In this report we focus on the states of Georgia, Massachusetts and Washington. We selected these states to represent some of the diversity across states while sharing some commonalities. For example:

- All three states had ongoing programs to support PEV deployment at the onset of our study;
- This set includes states with and without regulatory requirements on sales;
- All states have large, vibrant cities with strong technical universities and high-tech communities;
- These states have different characteristics in terms of the carbon intensity of their electricity;
- They fall in different parts of the spectra in a variety of variables, including geography, overall political inclinations, weather, and topography.

To define the unit of analysis, and following (Bergek et al., 2008), we consider the following three aspects: field of knowledge vs. product; breadth vs. depth; and spatial domain. We choose to focus on a product, the plug-in electric vehicle (PEV). In terms of breadth, we are interested in a narrow universe, namely the aggregation of all models of highway capable, light-duty battery electric vehicles and plug-in hybrid electric vehicles. By choosing this system breadth we ensure that the actors, networks and institutions, for a particular region, are about the same. If we chose a broader system, for example by including heavy-duty vehicles, we would have to include a different (though likely overlapping) set of actors, networks and institutions. As for spatial focus, as discussed above we focus on three states in the United States. While in general a global scope is preferred for a TIS study to better account for likely spillover effects and additional network interactions, our main interest is with *variations* in innovation across states, which relieves us from the need to consider global aspect in much detail. Thus, our unit of analysis is the innovation system related to plug-in electric vehicles at the state level.

Our main sources of data were semi-structured informational meetings and newspaper articles associated with electric vehicles in each of these states. The newspaper articles were further classified and coded to provide relevant insights and context for the technology innovation systems in each state.

Through these meetings and phone calls we identified the elements and processes that affect, or are believed to affect, PEV innovation. Consistent with the system approach of our study, we communicated with actors from all relevant sectors, namely government and political, supply side, demand side, intermediary infrastructure and knowledge infrastructure actors (Alkemade, et al., 2007).

Examples of actors in these groups include auto manufacturers, consumer groups, university researchers, advocacy groups, and regulators. Technology innovation processes are inherently dynamic and one-time communications with stakeholders are not the best way to capture these dynamics. We made an effort, within the limitations of our communications, to collect information on trends as well as current conditions.

Using natural language processing techniques and machine learning algorithms, it is possible to analyze large data sets to determine if there are any significant trends across vast quantities of text (Cambria and White, 2014; Liddy, 2001). We utilized this approach for assessing news articles to better evaluate the technology innovation system for electric vehicles. This has been done to further help inform the innovation narrative, and elucidate interaction effects between government and the private sector. Through use of machine learning and text-classification, it is possible to evaluate news articles to determine the content of the stories being reported, yielding insight into the development of the innovation system overtime. Additional classification of these articles allows for geographic evaluation, which can provide robust datasets for inter-regional comparison. Inferences can be made using this methodology where regions exhibit significantly different innovation system trends from one another.

In the context of our study, during our informational meetings, we use the following areas to help with the identification of potential externalities in a given state:

- The potential for the growth of PEV markets to generate jobs in the state
- The potential for the growth of PEV markets to generate economic growth in the state
- The potential for the growth of PEV markets to create environmental benefits in the state
- The potential for the growth of PEV markets to create political, administrative or economic benefit or damage to any stakeholders in the state.

Understanding the TIS Functions

Typical applications of TIS frameworks do not postulate an established set of testable causal mechanisms. While scholars have made numerous valuable contributions to developing TIS research methodologies, we find that existing TIS frameworks still need refinement, and we hope that this study contributes in that regard. We believe it is important for TIS studies to clearly define their conceptualization of the TIS functions, and that is the purpose of this section. We start with proposing "elevator pitch" definitions of each of the functions, to help simplify these concepts for the readers who are not familiar with this approach to the study of innovation. We then dive deeper into a couple of the functions and offer a more substantive discussion of the meaning of these functions and their connections with other branches of science that relate to innovation.

Table 2. Elevator-pitch Definition of the TIS Functions

Entrepreneurial Experimentation
This function of the TIS is related to probing new ideas to support technology innovation. New ideas can relate to technologies, methods, and institutions, and is not solely limited to higher-risk business ventures.
Knowledge Development
This is the function of the TIS related to the creation of new knowledge about technology, methods related to the technology, or institutions that support the technology. Knowledge differs from data and information, though these are generally a condition toward knowledge creation. Knowledge creation is often one consequence of the probing that takes place as part of the Entrepreneurial Experimentation function.
Knowledge Diffusion
This is the function of the TIS concerned with disseminating knowledge through networks in the innovation system. In a strong innovation system, knowledge diffusion and knowledge creation are intimately connected, although neither warranties the other.
Influence on the Direction of the Search
This is the function of the TIS concerned with motivating or pressuring actors, institutions and networks to dedicate themselves to supporting innovation in the pertinent technology. Pressures can take many forms, including regulatory, market demand, psychosocial (e.g. expectations and beliefs), and others.
Market Formation
This function relates to all activities that have a direct, tangible effect on the adoption of the technology in a given market segment and that would not happen naturally or spontaneously under established institutions. Market formation can happen in many ways, ranging from public intervention to the implementation of an ingenious market application.
Legitimation
This function of the TIS relates to activities that help make the technology accepted by the public, policymakers, and the private sector. Legitimacy is better understood on the background of established competing technologies, which are accepted by the market and supported by economic and/or political groups. Legitimacy for a technology increases when a technology is less resisted by the public and established groups of power.
Resource Mobilization
This is the TIS function concerned with allocating capital and labor toward supporting technology innovation.
Development of Positive Externalities
This is the TIS function concerned with benefits and spillovers from the technology system of interest to and from other technology systems. Such benefits can take many forms, including technological, symbolic, economic, and political.

The functions of the innovation system are interconnected. Because of the dynamic nature of innovation systems, the way in which the functions interconnect is likely to change over time and with the state of maturity of the innovation process. Innovation outcomes are largely dependent on context – as these contexts change, so too can innovation outcomes, and the networks and agents that support the innovation system (Bergek et al., 2015). For the purpose of illustration, we show in Figure 1 a schematic of the TIS functions and a *subset* of the connections between TIS functions that we would hypothesize for a relatively early stage of the market. This particular subset of connections proposes a closed loop in which the testing of new ideas can result in new knowledge, which in turn supports the dissemination of knowledge, which props the legitimation of the new technology, which encourages the dedication of resources to support the technology, which in turn feeds further experimentation. The strength of the functions determines the energy of this cycle, and one weak function could result in the entire cycle to becoming dysfunctional. For example, if new knowledge is not effectively disseminated (weak knowledge diffusion), legitimation will suffer which can have very negative effects on technology adoption.

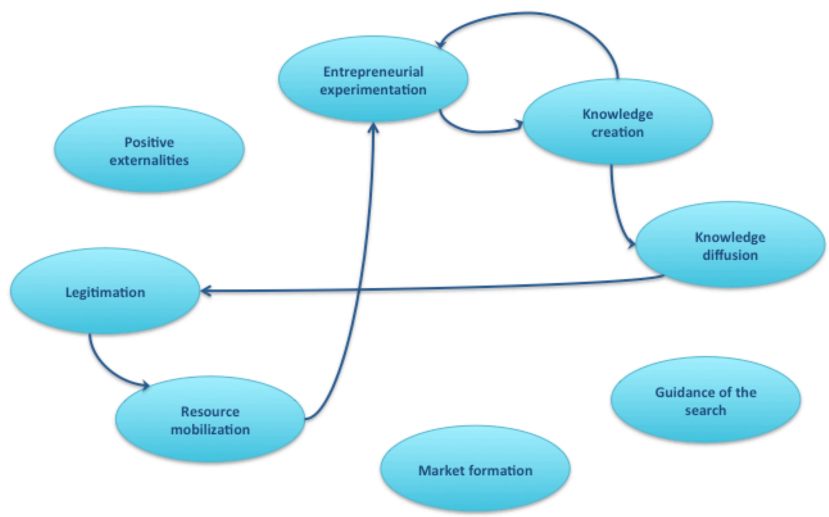

Figure 1. Subset of possible interconnections between TIS functions

As we noted earlier, TIS is still an evolving framework. During the course of this study, we felt there was value in proposing contributions to the further conceptualization of two TIS functions, namely entrepreneurial experimentation and the development of positive externalities. While these discussions may be helpful to some readers, they are also rather theoretical, and for this reason we have included them in the Appendix at the end of the report.

Research Design

Using a snowball sampling methodology and contacts established through the Zero Emission Market Acceleration Partnership at UC Davis, we were able to assemble a list of important and relevant actors in the PEV innovation space for states we were interested in. We set up several informational communications with these contacts. The purpose of these communications was to understand in as much depth as possible the innovation system, including actors, networks, and institutions, that promote or detract from the deployment of battery electric and plug-in hybrid electric vehicles. We communicated with actors from a variety of different organizations, including dealerships, state and local governments, non-profit groups, car companies, utilities, infrastructure companies, and research institutions. Communications were requested and agreed upon on the premise of confidentiality, and therefore we do not disclose the names or associations of the individuals with whom we spoke. For this phase of the research we did studies of the entire innovation systems for the states of Massachusetts and Washington, and we did a deep-dive study of one specific sector of the innovation system, namely the new vehicle retail space, for the state of Georgia.

Building upon collaborative networks that we have in these states, we sent an email to point people, requesting that they filled out a form with a list of actors associated with specific types of organization. We asked these point people to provide actors that they deemed to be particularly relevant for contributing to electric vehicle uptake within the state. An example of the form we used is shown in Figure 2.

Entry #	Stakeholder category	First Name	Last Name	Email Address	Affilitation	Strength of contact	Other Notes
Example		John	Smith	example@example.com	EV Motor Corp	5 - Know this individual well or have worked with them	This is an example field
1	State government						
2	Local/regional government						
3	Car company						
4	Electric utility						
5	Non-profit organization						
6	Research institution						
7	New car dealership						
8	Infrastructure company						
9	Technology company						
10	Other						

Figure 2. Form used to collect possible stakeholders for communications

We then contacted by email the individuals listed in the forms to request a meeting in person or phone call. The response rate for our requests was greater than 95%.

We developed a list of information items around PEV innovation to guide our informational meetings, and ensured that information was collected about each of the functions of the TIS (Bergek et al., 2008; Carlsson and Stankiewicz, 1991). We asked stakeholders for objective information, excluding personal opinions, about the items shown in Table 3.

Table 3. Guidance Protocol Used in Informational Communications

Resource Mobilization

- Please describe the resources (funding, personnel and dedicated roles) that are allocated to supporting PEV deployment in your state by each of the following
  - Your organization
  - Local governments in your state
  - Your state's government
  - The federal government
- What are the main sources of uncertainty on whether resources will be allocated now and in the future?
- What role is the Governor's Office playing on PEV discussions in your state?

Market Formation

- Does your state, or local governments in your state, offer incentives or take any other steps to help users and fleets adopt PEVs?
  - What impact have these steps had?
  - If incentives: How was its magnitude and structure decided upon?
  - If no incentives: Are there plans to implement one?
- Do governmental or private organizations subsidize or otherwise support the deployment or use of charging equipment?
  - What impact have these measures had?
- Is there, or has there been, a marketing campaign targeted to generate interest in PEVs in the public? If so, which organizations led it/them? (e.g. car companies, government, etc.)

Legitimation

- How informed is the general public in your state about plug-in vehicles?
- Is the general public opinion about PEVs positive or negative?
- Which are the primary market segments that purchase PEV in your state?
- Are there important stakeholders in your state who are antagonistic toward PEVs in your state?
- What is the most common line of argument against PEVs in your state?
- Are there estimates of the market demand for PEVs in your state?
- Are there advocacy groups actively supporting PEVs?
- Is political leadership generally supportive of PEVs?

Knowledge Development and Diffusion

- What are the more critical factors that drive/deter the market adoption of PEV in your state? Include factors of any sort: technological, economic, societal, political, legal/regulatory, knowledge, or other.
- How do stakeholders in your state learn about the fact that these factors are critical? Examples may include research, experimentation, stakeholder discussions, conferences, learning from other regions, consulting with industry, or other
- With the factors you just mentioned in mind,
  - Are most stakeholders likely to agree on the importance of these factors?
  - How well developed is the state of technology or knowledge related to each of these factors? Is there still a lot of learning or technological development to be done?
- What is being done in your state to learn more about or develop technology related to the factors you mentioned?

Influence on the Direction of Search

- How do existing state/local actions influence activities to support plug-in vehicle adoption?
    a. Are there specific regulations that support PEV adoption?
- Are there any laws, regulations, competing technologies, or organizations that prevent PEV from getting more support from stakeholders?
- Has the state and/or cities/counties in the state adopted a PEV action plan or similar strategy?
- What are the key elements of this plan/strategy?
- What is the state of implementation of this plan/strategy?
- What lessons have you learned so far?
- Have your state or cities in your state adopted any requirements on automakers or fleets for the adoption of PEVs?
- Have there been clear statements or expression in support of vehicle electrification from the political leadership in your state?

Entrepreneurial Experimentation

- Are there any companies in your state that supply parts, services or technology for the production of PEV or PEV charging infrastructure? Examples may include batteries, software for battery energy management, other.
- Are there exceptional PEV champions in your state?
- Can you cite innovative ideas that were proposed and tested in your state, to support PEV markets? This can include ideas of any sort: technology demonstrations/pilots, policy, education & outreach, or other.
- Are there companies or organizations in your state that are developing or testing new technologies or services intended to support the use of plug-in vehicles?
- Are you familiar with the startup community in this space?

Development of Positive Externalities

- Do PEVs generate jobs in your state?
- Do PEVs generate economic growth in your state?
- Are PEVs beneficial to the environment in your state?
- Could PEVs benefit any stakeholders in your state?
    a. Politically? Who and how?
    b. Administratively? Who and how?
    c. Economically? Who and how?
- Are there industries in your state that can help and/or be helped by the growth of PEV markets?

Over a period of two months in the year 2015, we consulted with 40 individuals across the three states. We conducted consultations with a duration of 45 to 60 minutes using our thematic protocol as guidance. Time available would not have allowed for the coverage of each and all the items in the protocol, and we narrowed conversations around themes to which the particular stakeholder seemed more familiar or more comfortable speaking. We recorded data by hand and these notes have been used to inform our technology innovation narrative for each state. All obtained information is anonymous and we designed all communications with stakeholders to not collect personal, subjective or confidential information. We asked participants to in turn suggest other stakeholders who they deemed to be important in the PEV space within the state and who we should contact for the purpose of collecting information. Most of the names suggested were already in our list of participants for the first round of conversations.

We use the information collected from these meetings to assess commonalities and differences between the two states. This facilitates better assessment of factors in place that promote or detract from PEV adoption. As suggested in Figure 3, PEV adoptions have followed different dynamics in Washington, Massachusetts and Georgia. While overall market trends are upward, the case is more or less clear depending on the state. While TIS is generally not well suited to make strong inferences from data of this sort, we show them to help provide context to the relative state of the markets.

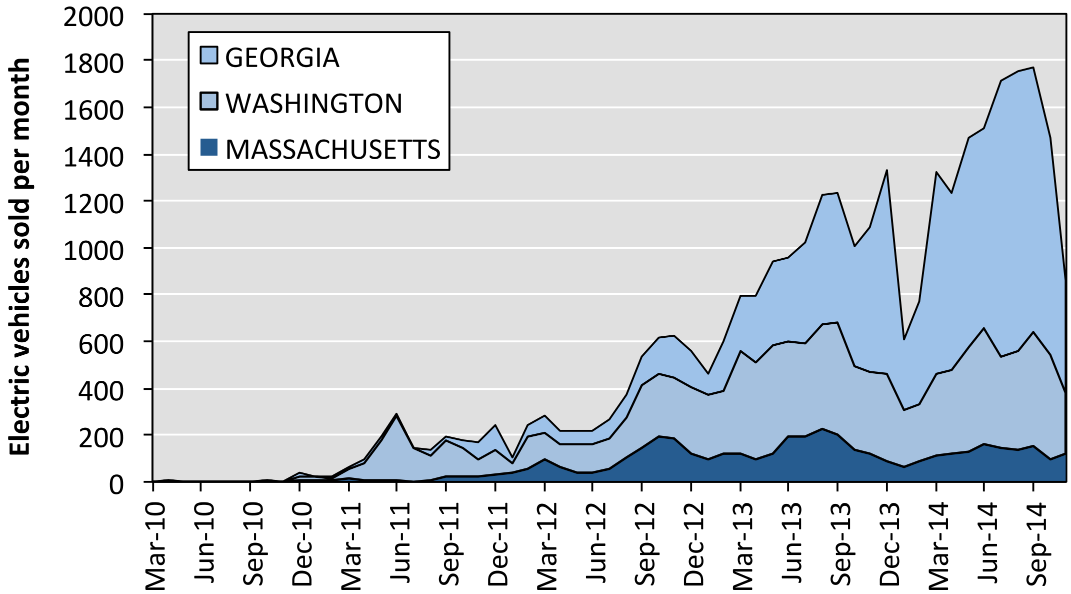

Figure 3. Plug-in vehicle sales per capita in the states included in this study and California

While we rely on our informational meetings as the main source of data to assess innovation patterns and trends in the states of interest, we used textual media (primarily newspaper articles) from across the United States to capture references to the TIS functions in the states of interest. These references can be interpreted as salient elements of the TIS functions and will help us validate qualitatively and identify potential gaps in our analyses. To extract useful data points from this very large semantic dataset, we use computational linguistics techniques. Building off of the LexisNexis database, we conducted a high-level search for all English-language news stories associated with electric vehicles. From LexisNexis indexing meta data, we identified the newspaper articles that were relevant to electric vehicles in the three states of our study. To further extract information from the large data set, we used a supervised-learning approach. Supervised learning requires manual, human-classification on a smaller subset of data that is then used as input into a statistical model. This is known as the “training set.” We trained machine-learning algorithms to analyze each articles and categorize articles into one or more of the TIS functions. More specific details on this methodology can be found in Kessler (2015).

Results

Using the trained model to classify articles into TIS functions for the entire dataset of articles for all states in the United States, we generated a *national* trend for EV innovation. The trends are shown in Figure 4.

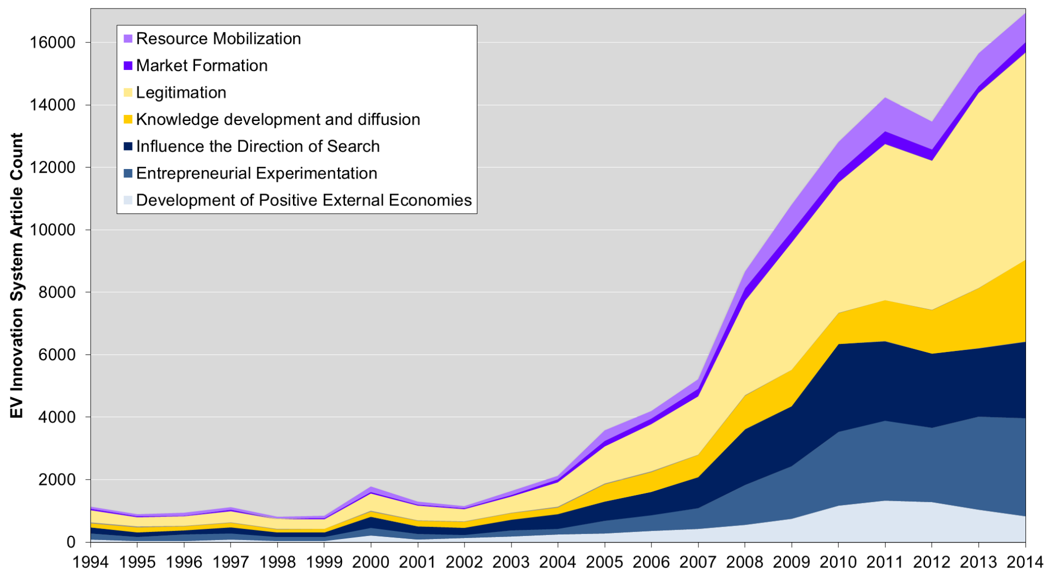

Figure 4. National trends in the plug-in electric vehicle innovation system, as given by classified articles relevant to electric vehicle innovation in the United States.

Our article classification shows that steep increases in media articles related to PEV started even before the commercialization of the Nissan LEAF and the Chevy Volt in 2009-10. Earlier coverage increases coincide with a number of other events, including Tesla's announcement that it would produce the Roadster model and oil price spikes starting in 2007 to name two. These results suggest also that there has been steady growth across most innovation functions, with a recent surge in the perceived legitimacy of the PEV. Some functions, however, show signs of stagnation and even weakening.

To derive further meaning from the article count analysis, we are interested in whether the counts for a given state are significantly different from counts in other states. To do this, we use a fixed-effects model for panel count data; in particular, we use a negative binomial general linear model. This model assumes that state and year fixed effects account for a majority of the variation in media portrayal of PEV innovation in each state and each month. We include a state: year fixed effect to account for differences that occur in a state in a given year. If this effect is significant, it indicates that something unique happened in that state in that year compared to the expected trend.

It is from this perspective of increasing electric vehicle legitimacy, and a maturing technology innovation system that we hope to gain insight into how to further foster and support this system. We now turn to the study of the individual states.

We provide qualitative empirical analysis of the PEV technology innovation systems in our sample of states. Additional, textual media relevant to electric vehicles has been captured for all 50 states (and D.C.) from 1994 through 2014. The content from each document has been classified through computational, machine-learning methods and each corresponds to one or more of the technology innovation system functions (Kessler, 2015). The innovation systems, as documented through this method for Washington and Massachusetts are tracked over time. Support for each function, and how this support changes, can be quantitatively compared to other states.

The State of Washington

Washington is often included alongside California and Oregon during discussions of environmental policy and regulatory action. The state has attempted to adopt policies and approaches similar to those in California to deal with greenhouse gas emissions. Most recently, Washington had plans to adopt and implement a Clean Fuel Standard, similar to the California Low Carbon Fuel Standard (Witcover, Kessler, Eggert, and Yeh, 2015). These implementation attempts, however, have recently been derailed (64th Washington Legislature, 2015). The state has adopted the California vehicle emission standards and has considered over time adopting the Zero Emission Vehicle (ZEV) program (Collantes and Sperling, 2008), but implementation of the ZEV program remains unlikely given that it needs to be approved by a State Legislature unsupportive to the idea. In this respect, the state of Washington offers an important difference in the policy landscape when compared to Oregon or California.

Despite the absence of a sales mandate, per-capita PEV market uptake in Washington has been among the top in the United States, considerably exceeding that in most ZEV states. Looking at article count trends for Washington, we also see that the TIS mirrors the national EV TIS in terms of strong support increasing overtime. Remarkably, however, there is stagnation in media reporting followed by a sudden drop in support in Washington in 2011 and 2012 that did not occur for other states.

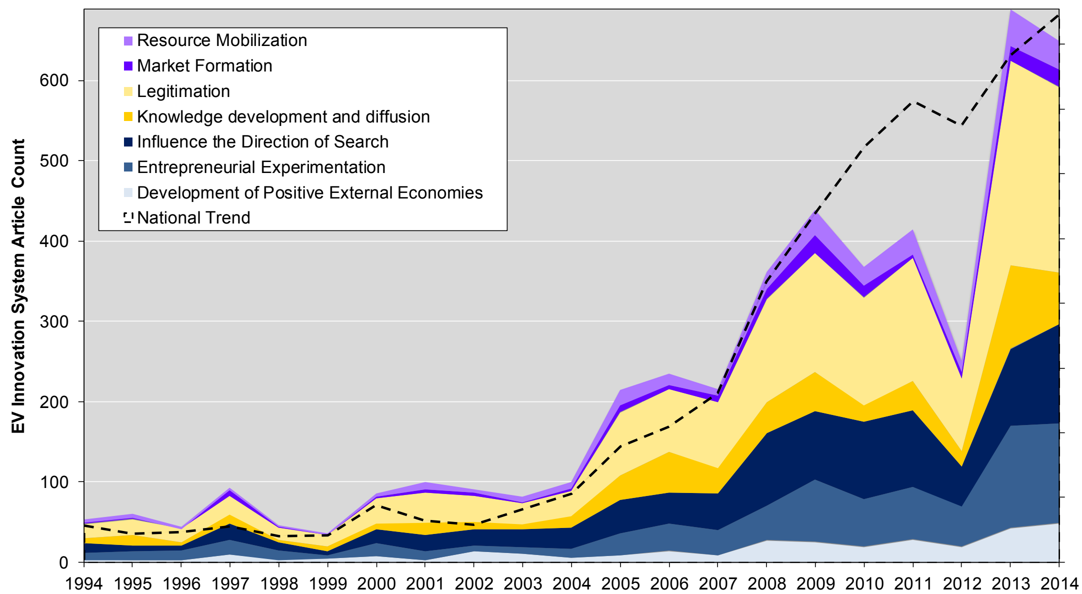

Figure 5. Visual mapping of the different functions of the plug-in electric vehicle innovation system in the state of Washington. The overall national trend is shown for comparison.

To better understand why the TIS leveled out and then declined in 2012, we examined word clouds for all articles associated with electric vehicles in Washington for each year. Starting in 2012, a number of new PEV models emerged that captured significant interest in the Washington market (like the Tesla Model S). At the same time, discussion of PEVs suddenly shifted from dealing with a future technology ("PEVs *will* be entering the market"), to a current technology ("The Tesla Model S is available"). As is often the case with new technology, media hype can exist (Melton and Axsen, 2015). Hype occurs when users expect performance from the technology to exceed the technology's existing capabilities. It is the availability of new, hyped PEV models and the lead-up to their entry from 2012 to 2013, with a corresponding shift in media reporting from a future event to a current occurrence (hype correction), alongside PEV supply shortages for electric vehicles like the Nissan Leaf, that is responsible for this stark contrast between the 2011 and 2013 TIS in Washington. Other states that did not have such strong anticipation or hype for future PEV models do not show a corresponding "correction" in TIS support.

In this section we explore the TIS functions as portrayed through informational meetings, and we try to identify the critical factors driving market performance, as well as factors deterring from an even stronger market uptake for electric vehicles. We also investigate how the results from the TIS article-modeling approach compare.

Entrepreneurial Experimentation

Stakeholders did not identify companies in Washington that supply parts, services or technology for the production of PEV or PEV charging infrastructure. The exception is MC

Electric Vehicles, a small PEV producer, which could not be directly linked to the production of plug-in vehicles for the larger scale market. We were intrigued by the fact that stakeholders did not identify the joint venture by BMW and SGL as an important presence in the state, contributing to the supply chain of electric vehicle production. These companies had invested about $100 million to deploy a carbon fiber plant in Moses Lake in Central Washington, and have announced a second stage investment of $200 million to triple the plant's capacity to 9,000 tons per year. Carbon fiber produced in the plant is used in the production of the body of the BMW i-series plug-in models in Germany.

The state has seen strong support for vehicle electrification from the state executive office, first with Governor Christine Gregoire (2005-2013) and then with Governor Jay Inslee (2013 - present). State agencies have also played a significant role in supporting vehicle electrification, with a number of individuals that stakeholders recognize as champions, particularly in the departments of Transportation and Commerce. These agencies collaborated in the pioneering implementation of a regional network of fast charging infrastructure corridors. The state Department of Transportation took an instrumental role in moving this project toward completion and publicizing it. The Sustainability Office of the largest city in the state, the City of Seattle, has been strongly engaged in activities to support vehicle electrification, and in convening working groups to coordinate statewide activities. The Western Washington Clean Cities Coalition was also referenced by stakeholders as an important champion and a key source of information about EVs for cities.

A small number of non-profits were also highlighted as champions. Among local non-profits, the Seattle Electric Vehicle Association has been the most prominent in terms of EV support in the policy space. Plug-in America, a non-profit of national scope but with a strong presence in Washington, has been identified as a strong champion as well. The level of engagement that the auto company Nissan showed in supporting EV markets led some stakeholders to identify them as champions. We also identified the presence of "champion" Nissan new-vehicle dealers, who pursued aggressive marketing and sales of Nissan Leafs. The Nissan dealership immediately outside of Seattle bolstered the strongest Nissan Leaf sales of any dealers in the U.S. for several consecutive quarters. Unique among states, the state of Washington has a Legislature EV Caucus. The strong support for EV that this body has demonstrated earned them the champion label in the minds of some stakeholders. The engagement of Nissan and the EV Caucus was instrumental on resurrecting the PEV sales tax exemption.

Prominent among absentees in the list of champions are electric utilities. Stakeholders recognized that utilities are starting to show stronger interest in vehicle electrification, but indicated that there was still substantial uncertainty with how utilities will best be able to integrate in the market, and that utilities are cautious to experiment due to regulatory concerns.

We emphasize that the concept of champion is generally attributed to individuals rather than organizations. Clearly, organizations deserve recognition to the extent that they enable individuals in them to become champions, but for each of the organizations mentioned above there have been one or more individuals that effectively played that role with personal creativity and results-oriented commitment. We do not mention the names of these individuals to maintain the focus of this report on the structural factors rather than on individuals. We are also aware that there may have been champions in organizations that were not mentioned above, but the list included here is a representation of those who were readily identified by stakeholders.

Washington has often been at the forefront of experimentation to support electric vehicles. As one of the states that took earliest action to support EVs, it often found itself in uncharted territory. A collaborative effort of the Puget Sound Regional Council and the state's Department of Commerce led a multi-stakeholder process to develop the first model ordinance, development regulation and guidance for the installation of EV charging infrastructure in the nation in 2010. This document has been very helpful in several fronts, helping local governments start thinking about these questions. As mentioned above, the Department of Transportation in collaboration with the Department of Commerce planned and implemented the first regional network of fast charging stations in the nation, connecting communities north to south along Interstate 5, as well as along U.S. Highway 2 and Interstate 90, connecting western with central Washington. One critical outcome from these projects has been the engagement of communities in areas that were not initial PEV targeted markets, helping them become familiar with the technology and its benefits. This represents a nice example of a connection between the entrepreneurial experimentation and legitimation functions. One final area of experimentation at the state level that is worth noting is the use of revenue collected through the annual "road fees" that PEV owners pay to compensate for the gasoline taxes that would otherwise be collected from a conventional vehicle. This "road fee" is directed toward investment in charging infrastructure.

King County, the county with the largest population and the strongest economy, started experimenting with the use of plug-in vehicles for its vanpool program even before the launch of commercial-scale vehicles in 2010. Their experimentation expanded to the testing of the Nissan Leaf in the vanpool program and to Proterra electric buses for their transit system.

Beyond the experimentation that has taken place, stakeholders identified a number of ideas that could be good candidates for experimentation, reflecting an active experimentation mindset among the PEV policy community. Such ideas included the donation of PEVs to driving schools to increase familiarity with the technology among the pre-car-ownership population. We learned that ideas were being discussed to link PEVs to low-income families to tap into markets that may be attracted by the low operating costs of these vehicles.

We were not able to identify many companies or organizations in Washington that have been developing or testing new technologies or services intended to support the use of plug-in vehicles. Stakeholders in general were not aware of players in the startup community in this space in the state.

Analysis from TIS modeling results indicate that Entrepreneurial Experimentation is the only function captured that shows significantly better support in Washington than elsewhere in the nation. Modeling results indicate that this function has been well supported since 2009. This corroborates the account of considerable interest in EVs from the private sector and private industry for experimenting with the release of EV models in Washington. In 2009, Nissan began to prime select North American markets for their release of the Leaf, including stopping in 22 cities including Seattle and other key markets on the West Coast.

Knowledge Creation & Diffusion

The State of Washington has implemented one of the very few exemptions on the sales tax for electric vehicles in the nation. This policy originally applied to battery electric vehicles only and more recently, as its expiration date approached, was extended and amended to include plug-in hybrid electric vehicles contingent on a minimum requirement on the size of the battery. Stakeholders point to this policy as a key driver of the PEV market in the state. The level of certainty about the degree of effectiveness of the tax incentive varied somewhat across stakeholders from complete certainty to more cautious confidence. Some stakeholders based their belief about the effectiveness of this incentive on the findings of a study commissioned by the Legislature's Joint Transportation Committee. This study, which was actually criticized by some stakeholders, was concerned with the exploration of business models for charging infrastructure, and did not do any analysis of the effectiveness of vehicle incentives. This misperception or misunderstanding of the findings of the study funded by the legislature suggests weaknesses in the process of policy knowledge creation and diffusion.

A few stakeholders argued that plug-in electric vehicles help consumers think about vehicle economics in terms of total cost of ownership, instead of solely from an upfront expenditure point of view. Some stakeholders still believe that without these incentives PEVs are more expensive since prorating costs is "a luxury to higher income" segments. State agencies have developed estimates showing that the Nissan Leaf enables savings in the order of $6,500 over the ownership of the vehicle, although they expressed concern that this type of information is not yet well disseminated and consumers remain relatively uninformed in this respect. Furthermore, the level of these savings can substantially diminish during periods of low gasoline prices, bringing uncertainty to the true value of the purchase. Experience from PEVs operated in the state fleet shows that PEVs do offer cost savings provided that they are driven a sufficient number of miles. It was suggested that the upfront cost is not a real barrier given the competitive leasing plans currently offered by some manufacturers, particularly Nissan, but that the perception of PEVs being more expensive is still prevalent.

The sales tax exemption also applies to electric vehicle support equipment (EVSE). Some stakeholders also believe that the availability of public EVSE has been instrumental in supporting the market penetration of PEV. One stakeholder referenced the case of Kansas City, where PEV adoption reportedly grew with the number of charging stations, accompanied by a drop in the cost of installation. Funding from the America Recovery and Reinvestment Act provided a significant boost to the deployment of a network of charging stations in Washington starting in 2009-2010.

Some stakeholders said that the multi-stakeholder collaboration mentioned above that resulted in the development of guidance and zoning documents for the installation of charging infrastructure was an important knowledge creation milestone in that it forced stakeholders from all sectors to think about and document answers to key questions, as well as in getting municipalities to understand their role in supporting the market deployment of these vehicles. Because municipalities were required by law to adopt development regulations for charging infrastructure based on the report of this process, knowledge diffusion within the state was strong. The resulting document also served as a model to many jurisdictions around the country, which extended the influence of this pioneering collaboration beyond the borders of Washington.

There are factors that we would call *native*, or underlying characteristics of a geographical region, that can be favorable or unfavorable to innovation in a given technology. Among native factors that may be present in the state of Washington, stakeholders mentioned pro-environment, outdoorsy, and technology-loving attitudes among significant segments of the population. It is generally believed that a market with these characteristics is likely to have positive attitudes about a new and clean technology such as plug-in vehicles. Native factors do not help explain innovation in a given state, as these are relatively stable over time and are an indication of the baseline of the initial market. As such, these factors cannot be affected much by policy. Native factors do help explain differences in market dynamics across states. They are carefully evaluated by industry when they develop their market deployment strategies, and it is no coincidence that Nissan and General Motors chose the Seattle metropolitan area as one of their launch markets in the United States.

Stakeholders also identified a number of deterrents for broader adoption of PEV in the state. The need for further technology evolution and limited consumer information were among the most frequently mentioned deterrents. From a technology standpoint, stakeholders generally believe that vehicle electric range still is a significant barrier and that this barrier is stronger for one-car families. They also believe that additional electric vehicle models are also needed to appeal to a broader base of the market. King County has been experimenting with electric vehicles in their vanpool services, but find that the current models are not well suited for the drive cycle encountered in this type of operations. State representatives indicated that electric vehicles in the current state of technology could replace about 350 of the existing units in state vehicle fleets when retired. If the electric range increased to 200 miles, this potential could expand six fold to 2,000 vehicles. While in general stakeholders are committed to helping create the best possible conditions for PEV adoption, they universally believe that the most effective way to grow the market at this point is to see further technological improvements, predominantly increases in vehicle range.

The need for more effective communication with motorists about PEVs was almost universally recognized as a weakness in the innovation system and that needs to be resolved to see stronger market uptake. While many consumers are familiar with the technology, many more still need to better understand the technology. For example, experience with state fleets suggests that many people have some "emotional apprehension" toward the new technology. There is no clear vision among stakeholders on how to improve consumer awareness and education. Some stakeholders believe that new car dealers have not, in general, actively marketed to or informed the public about plug-in vehicles. The reasons for this are not well understood though there is a sense that dealers' low motivation may be linked to PEV having lower profit margins compared to conventional vehicles as well as a higher risk associated with customer satisfaction. A decades-long line of research on the dynamics of innovations says that peer-to-peer and social networks provide an important platform for the diffusion of knowledge about a new technology (e.g. Aral, Muchnik, and Sundararajan, 2009; Bollinger and Gillingham, 2012; Katona, Zubcsek, and Sarvary, 2011; Moretti, 2011; Valente, 1996). There is no reason to believe this would not apply to PEV. A number of factors however act against the natural diffusion of information about PEV. First, it is more difficult to change established beliefs than to help develop new ones. The technology had to rid itself of historical stigmas, such as the image of electric vehicles as golf carts. Second, perceptions about plug-in vehicles have been negatively affected by campaigns and media reports from different sectors including car companies. With this context in mind, interventions to help with the dissemination of information about plug-in vehicles are warranted. In Washington, non-profit organizations such as Plug-in America and the Seattle Electric Vehicle Association have organized events to connect PEV owners with regular consumers, to foster peer-to-peer information diffusion.

While charging infrastructure, particularly in the workplace and along regional corridors, is recognized among stakeholders as an important driver for PEV adoption, the state, like every other state, faces important challenges around the financing of this infrastructure. Federal funding has been critical to jump start investments but now limited public funding and private investments are challenges to the expansion of this infrastructure. We found that governmental organizations struggle to find or commit the funding to install charging stations at their offices. Local governments in the state started discussions about "charge for charging" to address the concern of public gifting, but paying for the use of the stations would only be a partial contribution toward financing installations.

Stakeholders shared opinions about a variety of possible issues that could be slowing the market deployment of PEV, including the complex relationship between car manufacturers and the state, the limited engagement of electric utilities, information gaps in the state legislature, and others. Overall, stakeholders recognize the need for a better understanding of the barriers; this would help them be more strategic in their efforts to support PEV.

Entrepreneurial efforts by PEV champions in the Office of Sustainability of the City of Seattle and the state Department of Commerce have helped convene stakeholders on a regular basis to exchange information and coordinate policy ideas. However, according to stakeholders, there is no concerted strategy to identify the factors that affect PEV markets and how to support them most effectively. Stakeholders still have questions about the role of charging infrastructure and how government can best help with deployments. One example is the uncertainty about the value of investments in charging infrastructure if PEV with much longer range were coming to the market in the near future. Sources of information that stakeholders use include media write-ups, the Tesla owner community, experience from other regions and countries (such as Norway and the Netherlands), data from and experiences with the use of PEV in state and municipal fleets, and the Facebook Leaf users page, though stakeholders understand that these are not rigorous sources. It is generally recognized that there is a need for more granular information on lessons learned. Limited sound data and analysis, stakeholders recognize, can lead to inefficient policy development and investments. There is also a sense that the communication with the car manufacturers could be better and that improving this communication would lead to better strategy development.

The general uncertainty associated with PEV incentive mechanisms, alongside confusion in policy efficacy and further engaging manufacturers and utilities is also reflected in the statistical analysis conducted on TIS article count data. We find that the Knowledge Development and Diffusion function has not been better supported in Washington compared to elsewhere in the United States. Despite comparatively strong PEV uptake, these results suggest that there is room to strengthen knowledge creation and diffusion efforts in Washington.

Resource Mobilization

The overall sense among stakeholders is that the resources available to support PEV market diffusion are insufficient. The state of Washington, however, has one of the most generous incentive programs for PEVs in the United States. State law grants exemptions on the state tax on the sales and leases of vehicles that "(a) are exclusively powered by a clean alternative fuel or (b) use at least one method of propulsion that is capable of being reenergized by an external source of electricity and are capable of traveling at least thirty miles using only battery power" (RCW 82.08.809, 2015). While the incentive was state law by the time of the Nissan Leaf launch, part (b) of the language was introduced in 2015, when the incentive was extended through 2019, to include plug-in vehicle models that initially did not qualify for the incentive. These tax exemptions represent savings of 6.5 and 5.9 percent of the retail price for sales and leases, respectively. The argument used to get legislative support for the extension of the incentive beyond the original sunset date (July 1, 2015) was centered on the health impacts that mobile emissions have on specific communities.

Starting in 2015, states offering PEV incentives faced increasing concerns about the socioeconomic equity of these policies. Washington was no exception. During the policy process to extend the incentives, the Legislature proposed an amendment limiting the eligibility for the tax exemption to vehicles with a retail price under $35,000. Ensuing discussions resulted in a more balanced amendment that excluded from the incentive the portion of the retail price in excess of $35,000, while the first $35,000 of the price remained eligible. This anecdote is a testament to the thoughtfulness of some of the PEV policy discussions taking place in

Washington. It is also a testament to the ability and commitment of Washington stakeholders to navigate the design and implementation of PEV incentives through the legislative process.

The state has also instituted a revolving charging infrastructure “bank” at the $1 million level. This fund, administered by the state’s department of transportation, is financed with proceeds from plug-in vehicle registration fees and is predominantly intended for investment in public access fast charging stations. A recent transportation funding package also includes an allocation of $25 million per year to cover ferry rides and tolls for electric vehicles—a sticker for ferry rides costs $250 per vehicle per year. Because of divided views in the state legislature about the importance of supporting vehicle electrification, there is some uncertainty about the stability of these resources in the long term.

At the state level there is some personnel to support PEV. The City of Seattle’s Sustainability Office has led efforts to understand market barriers and convene stakeholders. Communities associated with The King County Cities Climate Collaboration are devoting staff resources to addressing barriers to PEV and EVSE deployment.

When further assessing Resource Mobilization in Washington through article count data, we find that articles do not represent this function better for Washington than elsewhere in the United States. Given that not many other states offer comparable monetary incentives for the deployment of electric vehicles, this result may be a reflection of limited salience of the state’s incentive.

Guidance of the Search

Exercising its right under the United States Clean Air Act, the state of Washington has chosen to adopt California’s vehicle emission standards. Unlike other states that followed a similar path, the state has not adopted regulatory requirements for the sale of zero emission vehicles. During discussions about the possible adoption of the Zero Emission Vehicle Mandate, the state encountered strong opposition from politically influential new car dealers. This stakeholder group believed that such regulation would force them to take for retail from the car manufacturers zero-emission vehicles that they did not necessarily want, requiring the dealerships to invest in training a sales force that typically has high turnover rates. Some dealers also opposed on the grounds that they would have to make investments in charging infrastructure at dealership locations.

Although the ZEV mandate has not been adopted in Washington, the state has adopted goals to increase the number of PEV in state fleets, aiming to have plug-ins account for 10% of new vehicle purchases by 2018. Twenty-two state agencies signed a pledge committing to this goal. More informally, the state has a minimum goal of 50,000 plug-in vehicles on state roads by 2020. Another state-level action that supports PEV markets is an upcoming amendment for building codes, which will require parking facilities to be EVSE ready.

Government leadership at the executive level has explicitly supported vehicle electrification. Former Seattle's Mayor Greg Nickels worked to convince Nissan to choose Seattle as one of the metropolitan areas for initial launch of the Leaf as part of the EV Project, in 2009-10. Governor Jay Inslee is acutely aware of the challenges posed by climate change and has shown commitment to lower carbon emissions in the state. The Governor's Office understands the role that vehicle electrification can play in reducing carbon emissions. The state is presently working on the development and implementation of a rulemaking to establish a cap on carbon emissions.

The state's energy policy framework is centered on promoting energy efficiency. While this in itself is an important goal, it has had the effect of limiting to some extent the involvement of certain electric utilities. Actively supporting vehicle electrification can be interpreted as promoting the use of electricity.

The state has adopted one of the earliest EV action plans in the nation. The plan lays out 13 actions for the 2015-2020 timeframe, believed to help the market deployment of plug-in vehicles. Importantly, since this plan was adopted, significant progress has been achieved toward its implementation. Actions that were recommended in the plan and on which progress has been made include the further development of the state's fast charging network, the extension of the vehicle sales tax incentive, the amendment of the building codes and others.

Further strengthening the guidance of the search in the Washington innovation system, the City of Seattle has adopted a Green Fleet action plan that also has a strong focus on vehicle electrification. The city also adopted a Climate Action Plan that implies significant PEV market adoption; stakeholders believe that has to be the case if the city is to achieve the goal 81% reduction in carbon emissions by 2030 set forth in the plan.

While current efforts are underway to further promote PEV adoption in Washington, results from our article-count analysis indicate that this is a fairly recent materialization, and that further support can still manifest. Prior to 2009, modeling results indicate that Washington had been significantly worse than other states in the U.S. at guiding the search toward PEVs. Once commercial PEV models became available, however, this negative trend ended.

Legitimation

Western Washington, and particularly the Puget Sound region, has a high concentration of residents who are highly educated, interested in new technologies, environmentally minded and relatively comfortable financially. This combination, in the opinion of local stakeholders, has offered a fertile market for the first generation of plug-in vehicles. Residents are also aware of the very low cost and low carbon intensity of electricity in the state, which is important to consumers in the first and second wave of adopters (new-car dealers note that economic considerations are important to the second wave of consumers). This offers initial conditions conducive to strong legitimation of plug-in vehicles among consumers in Washington.

Consumers are relatively familiar with and informed about PEV in the Puget Sound region, though less so in more rural regions of the state. Some believe that there is misinformation about the cost of ownership and the reliability of PEV, and the state has been trying to address these questions with limited resources by posting information online. It is believed that consumers are also poorly informed about the availability of government incentives. In the absence of significant information dissemination, marketing campaigns and minimal media attention, information diffuses predominantly in a peer-to-peer fashion, mainly through the web. Organizations like the Seattle Electric Vehicle Association and the Plug-in Electric Vehicle Center have been actively disseminating information to the public. The latter, in particular, has been instrumental in bringing attention to vehicle electrification in rural areas in Central Washington. There is relative uncertainty about who could most effectively step up to inform consumers. While most believe that the auto industry would be best equipped to design an information campaign, there is a certain degree of distrust of the auto industry among some stakeholders.

Stakeholders highlighted the importance of fleets as a technology diffusion mechanism; fleets adoption of PEV helps “put butts in the seats” and help motorists gain driving experience and familiarity with the technology. Some fleet managers have been proactively providing information to employees. There is anecdotal evidence that when employees participate in training programs that focus on vehicle operation and make them familiar with the technology, they increase the use of the plug-in vehicles relative to other vehicles in the fleet. Simultaneously, fleet operators and technicians gain experience with the technology and thus become tested sources of information for peers and decision makers.

The public image of plug-in vehicles in Washington is overall positive. For a population who cares about the environment, the source of the electricity is an important element in the image of electric vehicles. Even when most of the state’s electricity comes from clean hydropower, there is still some generation from coal power plants, and some media outlets have highlighted this fact. In some circles, particular policy ones, there has been an interesting polarization of this image between the “cool” Tesla and other electric vehicles that are still sometimes erroneously associated with golf carts. The Tesla has become an icon of wealth and also a symbol of what electric vehicles *can* be. In general, the public feels that “EVs are here to stay”, as reportedly highlighted by a state legislator.

In the experience of Washington stakeholders, the main concern that consumers express about electric vehicles is a constrained vehicle range. We believe that the issue of range has become to certain degree part of the folklore of electric vehicles and that it is often generalized to plug-in hybrids, which do not suffer from range constraints. Paraphrasing a respected expert in consumer behavior, Dr. Ken Kurani, talking about range anxiety only reinforces range anxiety in consumers’ minds. This is certainly a perception that works against the legitimation of plug-in vehicles for the average consumer. As we will see in the section about Massachusetts, the issue of range takes a slightly different spin in the context of cold weather.

Consumers' ability to charge vehicle at home is also a strong determinant of legitimation. Consumers who could not plug in at or in the vicinity of their residences will likely feel that plug-in vehicles are not for them. Limited or lack of access to residential charging affects two key market segments, namely renters and condo dwellers. The City of Seattle's Office of Sustainability identified the question of "garage orphans" early on and has been actively investigating alternatives to address it.

On average, legitimation among lawmakers is not strong and certain misperceptions of the technology remain. While the State Legislature is perceived as being divided across party lines over the issue of vehicle electrification, there is a bipartisan EV caucus, which enables productive discussions. Part of the reluctance among some lawmakers to support EV policy has been due to equity concerns, namely transferring public funds to high-income consumers; this issue is being addressed through recent legislation, which we discussed above. Besides this political divide in the legislature, we did not identify stakeholders who are actively antagonistic toward PEV. Stakeholders however pointed to the electric utilities as a stakeholder group that should have played a stronger role in creating conditions for PEV market development in the early stage of vehicle deployments.

At the time of this study, there was no formal state coalition or task force charted with advancing vehicle electrification. At the state level, the Governor's Office, the state Department of Transportation and the Energy Office are all very supportive and play some role on coordination. The City of Seattle Sustainability Office has also led stakeholder coordination efforts.

Assessment of article counts on legitimation suggests that Washington could better support this function of the TIS. The legitimation function is not better represented in Washington compared to other states, and there is no indication that the state as a whole starts to recognize PEV as a mainstream technology. This result plays out in the recent battle over the extension of the state sales tax exemption for PEVs. Going forward, it seems that more model offerings and additional familiarity with the technology, and the institution of a recognized and resourced state collaborative or similar, may be able to change this perception, further lending legitimacy to the technology.

Market Formation

The Cleaner Energy Act of 2007 (HB 1303) requires state fleets to purchase alternative fuel vehicles, including plug-in vehicles, "to the extent practicable". The intent of the fleet provisions was to form market for new, clean transportation technologies, including plug-in vehicles. The implementation of this legislative direction, however, has been challenging and is still in progress. Part of the challenges come from confusing language used in the law, while another part comes from the financial realities facing state agencies. While the Governor has sent strong encouragement to state agencies to consider adopting PEV, limited adoption has occurred to date. This is a trend that is further corroborated by the lack of significant market formation trends in article count data.

Some of the factors affecting fleet adoption were discussed above. In general terms, there is a cost associated with the organization time needed to understand the technology and to implement administrative and infrastructure steps for their operation. While some fleet operations stakeholders indicated support for PEV stating that the overall economics of the vehicles were attractive, other stakeholders thought that PEV were only suitable for niche applications. A recurring critique associated with the use of PEV in fleets was the lack of a more powerful or more spacious PEV models, which would be required for many operations.

We discussed above the strong incentive program implemented by the state, which has market formation effects. There is general agreement on the positive effect that the current sales tax incentive program has had and is having on PEV market development. Stakeholders pointed to one study (Keybridge, 2015) that looked specifically at the effect of the PEV sales tax exemption on the state economy and arrived at the conclusion that such effects are positive.

Besides state incentives, the largest electric utility in the Puget Sound region, Puget Sound Energy (PSE), implemented a $500 rebate for the first 5,000 qualified customers to install residential electric vehicle charging equipment. PSE's main motivation is to collect data and better understand questions related to the integration of plug-in vehicles with the electricity grid.

Development of Positive Externalities

PEV supporters in Washington have been able to make strong arguments about the economic and environmental benefits that the mass adoption of these vehicles would bring to the state. Electricity in Washington is among the cleanest and most affordable in the nation. The potential for air quality benefits, particularly to disadvantaged communities, has been a strong selling point for both sides of the political spectrum. When it comes to acknowledging the benefits accruing from the lower carbon emissions of plug-in vehicles, the political divide is significantly wider.

One narrative consistent with the definition of the positive externalities function is that if the development or production of a new technology results in increases in economic prosperity (e.g. new job creation) in the state, then the state would show interest in supporting the industry players responsible for such benefits. This has not entirely been what we observed in Washington. BMW, the German auto manufacturer, invested over $200 million in the state for the deployment of a plant that manufactures carbon fibers that are then shipped to Germany for the production of the company's electric i-series. Interestingly, this investment and the associated new jobs did not generate significantly more positive political attitudes toward vehicle electrification in general or the company in particular. Indeed, BMW electric models were almost entirely left out of the state tax incentive, as the original text of the law proposed capping eligibility to $35,000. Discussions with stakeholders indicate that BMW is looking to extend the application of many of these manufacturing techniques and material advantages to their other vehicle models, making the economics for such a facility more compelling.

Despite the strong benefits that can come from PEVs, many of these benefits are not unique to Washington. As such, the Positive External Economies function was not better represented in Washington than in the rest of the U.S. in the article-count analysis.

The State of Massachusetts

Massachusetts shares some similarities with Washington and is dissimilar in several important ways. Located in the New England region in the northeast of the United States, it is subject to larger seasonal climatic swings where one-digit winter temperatures are not infrequent. Also considered a generally progressive state, Massachusetts is much smaller than the states in the west, and has a higher population density. The state has been a leader in the region in regulatory action to address mobile emissions, adopting the California emission standards as well as the ZEV regulation in the 1990's. Because of the relatively small size of most states in the northeast, these states have historically approached air quality problems collaboratively. This is still the case with the requirement of zero emission vehicle sales, which has also been adopted by the regional states of Maine, Vermont, Rhode Island, Connecticut, Maryland, New York and New Jersey (Collantes and Sperling, 2008), This collaboration is managed by the Northeast States for Coordinated Air Use and Management (NESCAUM), a non-profit organization jointly created and supported by these states.

Despite the presence of a sales mandate, PEV market uptake in Massachusetts has been relatively challenging. Furthermore, trends associated with TIS article-count analysis indicate that Massachusetts has not supported any of the TIS functions better than other states, and has supported the "Guidance of Search" function significantly worse than in the rest of the U.S. This may be due to a variety of factors that we will try to identify. The overall TIS trends as represented through relevant article counts are shown in Figure 6 Interesting to note is the recent decline in the Massachusetts PEV-TIS since a peak in 2012 – at stark contrast with Washington.

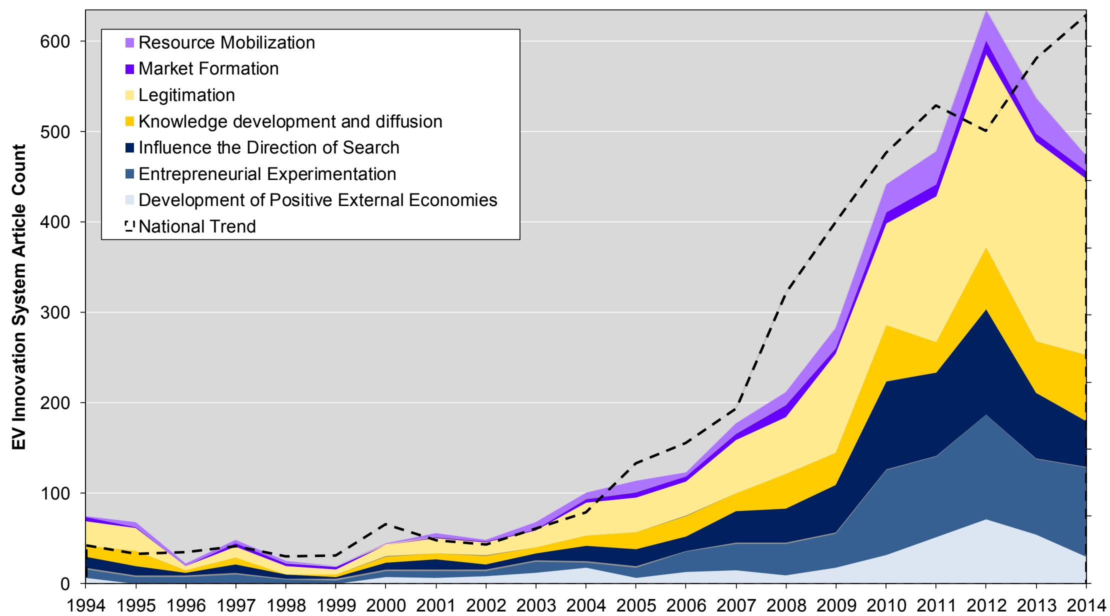

Figure 6. Visual mapping of the TIS functions for Massachusetts, along with overall national trend.

In this section we explore some of the critical factors driving the EV market dynamics in the state.

Entrepreneurial Experimentation

We did not identify companies in Massachusetts that are significant parts of the supply chain of plug-electric vehicle development and production. The company that stakeholders referenced more often is A123, a developer of lithium-ion batteries that had originally attracted significant attention of investors. A number of smaller companies, particularly in the vehicle charging space (e.g. wireless charging and traditional equipment suppliers and installers, such as EVGo. ChargePoint. Voltrek, etc.) were also mentioned. The state, and particularly the Boston metropolitan region host a vibrant startup company community, and certainly some of these have implications for electromobility. Thus, there is an innovation dialogue that is difficult to evaluate. We found some evidence that ideas from the startup and university communities may be given a place in PEV policy and strategy discussions; though we believe there is space for better communication.

We are aware of a number of champions in the state who have been committed to advance and support electromobility in Massachusetts for years. Stakeholders often referenced the state Department of Environmental Protection and the Department of Energy Resources including the Clean Cities Coalition housed in the latter. The Governor's Executive Office, which runs the recently created zero emission vehicle commission, was also identified as an active champion. The value of these champions was characterized as coordinating stakeholder activities and pushing policies such as financial incentives. While active and influential, some of the stakeholders with whom we spoke were not able to identify champions. This may suggest that their reach could be expanded to include stakeholders and groups that are not directly engaged in policy and planning discussions.

Some of the municipalities, such as Boston and Bedford, were identified as champions, leading the adoption of plug-in vehicles in their fleets. Other champions included the top new car dealers and the Acadia Center, a non-profit organization.

Stakeholders in general think that there is little experimentation with new ideas to support PEV markets. There is general agreement that ride and drive events are effective, as they expose consumers to the vehicle and help them get over mental barrier. The state recently started a program to support workplace charging, which can be considered a good example of experimentation. However, at the time of our research this program was fairly new so some stakeholders were not aware of it.

New ideas from the private sector include the use of electric vehicle by car sharing companies, which also helps consumers experience the vehicles (likely a more immersive experience than a ride and drive), and also may help with providing some public-access charging infrastructure. The company Charge Point implemented relatively innovative infrastructure financing for multi-unit dwellings whereby owners retain the ability to take the charging equipment with them if and when they move. Some dealerships started offering extended test drives, letting consumers take the vehicle for several days before buying the vehicle.

The electric utility EverSource was referenced as a progressive organization with customers in the states of Massachusetts and Connecticut that has been working on ideas to support PEV deployment. It instituted residential PEV rates structured as an access fee tied to a flat energy rate. In Massachusetts, they used a $3 access fee and a ¢0.23 per kWh rate. In Connecticut, they used an access fee of $16 and an energy rate of ¢0.15 per kWh. According to stakeholders, the testing of new ideas, such as dedicated rates, is sometimes challenging as they are faced with complaints from different stakeholder groups. For instance, social justice groups may tend to focus on the high part of the rate (the access fee in Connecticut and the rate in Massachusetts) and argue against the exclusion of lower income sectors. Conservation groups, on the other hand, may be uncomfortable with ideas that promote the use of energy. To avoid public criticism and perception that they may not be acting in the best interest of conservation or lower income customers, risk-averse utilities may prefer to do nothing.

A company based in Watertown, MA, is developing wireless charging systems that could be installed in vehicles in factory or as retrofits. These systems are achieving technological maturity and could help improve consumers charging experience. First generation applications of these systems will be stationary, located in places such as parking lots, while second generation applications could be distributed, such as in bus stops.

Knowledge Creation & Diffusion

As we saw above, PEV sales in Massachusetts have followed a slower upward trend than in other states. We consulted with stakeholders about possible factors that may be acting in support of and deterring from stronger sales. One reason that stakeholders put forth is that industry is not delivering a wider variety of models, and as the early-adopter market segment is saturated, other consumers look for other model options.

While stakeholders believe that plug-in vehicles offer a range of benefits that should be appealing to consumers, such as a good driving experience and lower operation and maintenance costs, many stakeholders agreed that consumers are not well aware of these aspects of the technology. Stakeholders also pointed out that currently the PEV marketplace is confusing to consumers. Consumers are told about BEV vs. PHEV vs. PHEV40, or level 2 vs. level 1 vs. DC Fast charging, which is often too technical and hard to absorb. For consumers, gasoline is much easier to understand. Thus, there seems to be a need to simplify the way that PEV are communicated to the market.

From information we received, the car companies have not done much marketing, for reasons that are not too clear to stakeholders, although some ventured that industry is not showing much interest. They also pointed to differences in attitudes across automakers: some have chosen not to make plug-in models available, while others have. Some stakeholders indicated that the ZEV regulation has been the main motivation for industry to bring plug-in models to the market. There is no robust education campaign from other stakeholder group either and in general there seems to be uncertainty as to how to best fill the consumer education gap. Some believe that in the end, to effectively inform the public, industry will need to get involved, but that they are driven by profit and currently have very limited budgets to support vehicle electrification.

Some stakeholders believe that the economics of PEV ownership are compelling, particularly after the state implemented financial incentives. Some stakeholders referred to survey research that suggests that capital cost and limited model availability are key obstacles to consumer acceptance. The Tesla Model S has demonstrated that PEV can be attractive and exciting, and that other models with attractive design would help attract other market segments. While objectively plug-in vehicles would save consumers money on fuel, some stakeholders question whether this enters consumers calculations as strongly as the higher capital cost.

Stakeholders gave the availability of public-access charging infrastructure various degrees of importance as a market-driving factor. Some stakeholders say it is critical to have a robust charging network, and some further emphasized the importance of a strong network of DC Fast charging stations (at the time of this research, there were 30 such stations in the state, which some stakeholders considered insufficient). Other stakeholder, however, pointed to survey research that suggests that public access charging is not an important factor to drive sales at this point. In this context, some stakeholders commented that even though no viable financial model has been identified for public access charging stations, this is not a significant factor in explaining PEV market uptake in the state.

The “garage orphan” issue was also identified as an obstacle for PEV adoption in inner Boston. Stakeholders believe that multi-unit dwellers would be an important adopter population if they had access to charging. This is consistent with earlier studies suggesting that charging stations at commercial centers in the Boston area were used at night by nearby PEV-owner residents (Transportation and Climate Initiative, 2013). Stakeholders indicated that condo associations are not yet familiar or comfortable with questions relating to charging access. There are no established programs to address this.

Massachusetts’ consumers currently can benefit from federal income tax incentives and state rebates supporting the adoption of plug-in vehicles. While stakeholders universally agree that such mechanisms are critical to help the market in the early stages, some indicated that, according to available evidence, incentives are most effective when implemented at the point of sale. In fact, some stakeholders identified the lack of a point-of-sale incentive as a factor that slows down sales. Others suggested that fuel taxation would be equally incentivizing of the market. Higher oil prices in 2007-08 influenced the renewed consumer and policy interest in vehicle electrification, which helped create favorable conditions for the introduction of electric models such as the Nissan Leaf and public-private partnerships on manufacturing capacity investments, such as the Nissan battery factory in Tennessee and the expansion of Tesla’s facilities. The recent downward trends in oil and gas prices are re-creating market conditions conducive to fossil fuel consumption.

Stakeholders across the board suggested that the electric range limitations in most PEV models currently in the market are a critical impediment to broader market acceptance. This, in conjunction with the longer times needed to recharge the vehicles encourage the perception that battery electric vehicles are best suited to be the second vehicle in the household. Some stakeholders believe that electric ranges in the order of 200 miles or more would significantly help spur the market. The cold winters in the Northeast and the heavy toll that the use of heating tends to have on onboard batteries are believed to significantly deteriorate the electric range of plug-in vehicles. Stakeholders shared anecdotal evidence from interactions with numerous PEV owners that confirms this cold weather effect on electric range and that it frustrates many PEV owners, it prevents them from being more enthusiastic about the cars and from passing on to their peers positive “reviews”. This would negatively affect the peer-to-peer effect, one of the key mechanisms for new technology diffusion.

It was argued by some stakeholders that the batteries are not sized for the winter and that the narrative that “we drive less than 40 miles a day” is less compelling in the context of harsh winters. In general we found that stakeholders tend to focus on battery size as the solution to the electric range concerns, and much less attention is given to other strategies, such as advances in cabin heating systems or better integration of workplace or public charging infrastructure into user charging behavior (as noted above, some stakeholders do not see nonresidential infrastructure as an important driver in adoption). To most stakeholders with whom we spoke, improvements in vehicle technology are more important at this point than policy and planning to see improvements in market uptake.

From a policy perspective, as discussed above, stakeholders agree that financial mechanisms such as rebates and tax incentives are effective at moving the market. Some stakeholders however believe that policy discussions in the state are often too complicated and broad. Discussions “get stuck” on questions such as regulatory treatment of public access stations, which some stakeholders believe are not too important at this point and distracts stakeholders and policymakers from more important questions. Some stakeholders believe that the breadth that policy discussions take is the result of a limited understanding of the key issues.

Car dealerships were seldom mentioned in our conversations with stakeholders. From the limited information we received, it appears that there is a diversity of attitudes and willingness to promote plug-in vehicles among dealers. The reasons for this are apparently diverse. It appears that better stakeholder knowledge of this critical area may be beneficial.

Some stakeholders said that they or other stakeholders were still unclear as to the net environmental effects of plug-in vehicles in the state. They cited as examples the unclear understanding of the connection between plug-in vehicles and the attainment of climate goals, questions about the so-called “long tailpipe” (the impact that PEV might have on upstream emissions from coal electricity generation), and environmental questions related to battery recycling. These uncertainties weaken the pro-environment narrative to support PEV deployment among some stakeholders in the state.

How Do Stakeholders Inform Themselves?

The State of Massachusetts has a long history of collaboration with other states that adopted the ZEV regulation. When the ZEV states signed a memorandum of understanding committing to take decisive action to support the deployment of zero emission vehicles, one of their first steps was to develop an action plan. The result was a document describing 11 actions that they identified as critical to support zero emission vehicle markets. In the process of developing this document and to deepen their understanding of what was needed to implement it, the ZEV states convened a number of activities to elicit input from a wide variety of stakeholders. The state and the city of Boston also joined an initiative called Zero Emission MAP that convened government jurisdictions in North America interested in incorporating the latest research to inform their zero emission mobility strategies. At the state level, however, there had not been a formal forum for stakeholders to share learned lessons, coordinate activities and inform strategies related to plug-in vehicles. The ZEV Commission, formalized recently, is expected to play this important role and support knowledge sharing and diffusion. Some stakeholders told us that the commission has already been valuable to discuss what works and what doesn’t.

The Massachusetts Clean Cities Coalition is perceived as a leader among Coalitions in the Northeast and is active in convening stakeholders in specific sectors to share information and experiences. Similar to the California model, the state implemented a survey that consumers who receive the state PEV rebate need to complete—the responses to the survey have become an important source of information for regulators. A few stakeholders were familiar with research evidence and experiences in other jurisdictions, although not all of them were directly involved in discussions to inform state strategy.

Most stakeholders with whom we spoke said that they try to gather information from a variety of sources, tapping on relationships, collecting anecdotal evidence and reading public reports. One stakeholder described this information gather process as "being out and about, listening to people".

What Knowledge is Needed?

As mentioned earlier, some stakeholders are interested in a narrower policy discussion that focused on very few actions. One stakeholder summarized this perspective as "the rest is noise". Their perspective is that the ZEV action plan contains too many recommendations, it prevents key stakeholders to focus on any one of the action items, and that there is a need for prioritization. This group of stakeholders believes that the breadth of the policy discussion is a result of not having a "mature understanding of the issues".

Some stakeholders emphasized that supporting further technology improvements is more critical than aggressive policy. Policy needs to keep sight of the state of technology and not try to force the markets excessively. It may be counterproductive to sell a technology that they are not sure consumers will love. On the technology front, stakeholders generally believe that electric range suffers in the harsh winters of the Northeast and that industry needs to develop solutions. For example, stakeholders suggested that specific plug-in models need more efficient heating systems. Stakeholders in general also believe that PEV market uptake would increase if industry supplied more plug-in models.

Stakeholders also highlighted the importance of getting a better understanding of the policy levers that can be effective at moving the market and what would lure consumers to consider plug-in vehicles. They indicated that there is not sufficient information based on serious market research. Stakeholders have opinions or beliefs about what is needed to appeal to a broader consumer base, but these opinions and beliefs, they admit, are often not grounded on hard evidence. One example cited by stakeholders is the need to better understand where to locate charging stations.

Stakeholders suggested the need for more experimentation in areas such as charging rates and consumer information. The state was conducting a pilot to price DC Fast charging on an energy basis. Regulators are interested in doing something in this space but more experimentation may be needed to see what is more effective to support the market. For example, one question that was raised was weather time-of-use rate systems would be more effective than testing new technologies for the control of charging. To address the information gap, stakeholders suggested the need to find mechanisms to engage with the car dealerships, to understand how to get more buy-in and get them to better educate prospective buyers. Stakeholders recognized that Nissan has been in general more proactive in working with their dealerships to support PEV sales.

Resource Mobilization

Stakeholders in general said that the state has come a long way to allocating resources to support PEV market. For example, the ZEV commission was established and a PEV sales rebate program was implemented. Resources for the most part come from the state; the main metropolitan areas have allocated very limited resources and do not have strong programs.

While the funds for the vehicle rebate are replenished every year, some stakeholders expressed concerns about the stability of that program and the need for a long-term funding strategy to support various aspects of PEV readiness. Vehicle electrification has received support from the Governor's Office. Even after the change in administration in 2014, the Governor convened the ZEV Commission, supported incentives and staying as signatory of the ZEV MOU.

Guidance of the Search

When consulted about possible statutory or regulatory elements that could be slowing down PEV adoption, stakeholders often pointed to issues related to the installation of charging infrastructure. Installations in multi-unit dwellings are apparently problematic, as PEV owners depend on approval from condo associations. The processing of installation permits often takes long and some stakeholders mentioned institutional elements that may deter from the electrification of parking lots. More generally, stakeholders pointed to the need to update the building code to account for charging infrastructure.

While some stakeholders indicated that further deployment of fast charging infrastructure would be critical, they generally expressed concerns about the current demand charges being too high (the second in the country) which is an obstacle to materialize that deployment.

With the adoption of the ZEV regulation and the signing of the ZEV MOU, the state is sending a clear signal about its commitment to vehicle electrification. Until 2017, however, the regulated auto manufacturers can meet their ZEV obligations in Massachusetts (and any other ZEV state) counting sales of qualified vehicles in California, after applying specific proportionality rules (CCR 1962.1(d)(5)(E)). This compliance flexibility, commonly known as the *travel provision*, may be having the effect of temporarily weakening or confusing market signals for Massachusetts barring other clear incentives for PEV adoption. The adoption of an action plan along with other ZEV states provides direction regarding the areas that will be prioritized. Additionally, the ZEV commission has developed an action plan and submitted it for approval by the commissioners. The City of Boston has not adopted strong signals to drive PEV adoption. The city, one of the major hubs of innovation in the country, released an update to its climate action plan, Greenovate Boston, in 2014, which contained no specific directions or goals related to plug-in vehicles.

In Massachusetts, stakeholders often expressed the need for PEV technology to mature before policy could be more effective. Given this, and uncertainty about continued policy support and resources, signals to pursue PEV development and deployment in this region are weakened. Uncertainties and lack of guidance toward PEV technologies were also evidenced by the statistical analysis we conducted on PEV TIS article counts. The results suggested that Massachusetts was significantly worse than other states at influencing the direction of search toward PEV technology.

Legitimation

Stakeholders universally agreed that consumers in Massachusetts are either unaware of plug-in vehicles or unfamiliar with the technology and its environmental benefits. This is apparently backed by results from consumer surveys. We received disparate information about the degree of awareness among policymakers, from mostly unaware to aware. The information gap among consumers is a result of limited investments in marketing by industry and other key stakeholders. Massachusetts' electric utilities are effective at disseminating information about incentives and energy efficiency, though they are not engaging significantly on informing the public about plug-in vehicles. Some stakeholders said that the limited involvement of electric utilities is a missed opportunity. As a possible example to follow, they referred to the case of Southern California Edison, one of the largest electric utilities in California, which seeded 100 plug-in vehicles in the communities it serves, loaning these cars for two weeks to increase consumer exposure to the technology.

Does the Public Have a Positive Opinion of PEVs?

Because public awareness of PEV is low, it seems fair to assume that only a relatively small segment of the public would have an opinion about them. Stakeholders could not agree on how positive such opinions were. While that segment of the public sees PEV generally as a green technology, there may still be questions about the "long tailpipe" still remain among not just the public but also among some stakeholders and policy makers. The result is a yet unclear understanding among certain sectors of the connection between PEV and climate policy. One stakeholder said that there are no policymakers who are "passionate" about plug-in vehicles.

The Tesla Model S has been more publicized and more people are aware of it than other models. The Model S, according to stakeholders, has been successful at demonstrating the benefits of plug-in vehicles, beating the competition in its category in all metrics. Tesla shows consumers that the electric vehicle is not exotic or impractical. A stakeholder described the Tesla as an "aspirational product".

While stakeholders generally see the Tesla as a success story and a few car companies are actively supporting PEV markets, other car companies are publicly expressing skepticism about the market for PEV in the region. In this context, non-profit organizations are trying to play an advocacy role. Stakeholders identified Acadia, the Sierra Club and the Conservation Law Foundation as the key advocates in the non-profit sector. They have had some success at bringing awareness about the PEV-climate connection to key decision makers.

Market Formation

The state has implemented a PEV rebate in mid 2014. The rebate program, named MOR-EV and funded with proceeds from the Regional Greenhouse Gas Initiative, offers $2,500 and $1,500 to buyers or lessees of battery electric vehicles (BEV) and plug-n hybrid electric vehicles (PHEV) respectively. PEV buyers and lessees with leases of at least 36 months can apply for the rebate and could expect to be issued the rebate within two and half months, contingent on approval and available funding. In the first 18 months the program had issued almost 1,600 rebates, with over 65 percent of the applications received from BEV buyers/lessees. By then about $4 million had been allocated to consumers.

While stakeholders believe that MOR-EV is important to drive markets, they are debating the role that it ought to play in sales of higher-end vehicle models. The Tesla Model S represented about 430 rebate applications, or over 25 percent of the total. Higher-end models are eligible for the same incentive as more affordable models. Just like in other states, this is sparking a debate about the role of the program in helping wealthier consumers. Some stakeholders have argued for the exclusion from the program all models with a retail price over a certain level. Others support a tiered incentive structure that includes all models. The rationale for the latter is that higher-end models, particularly the Model S in stakeholders opinion, are important to bring awareness to the public about PEV and about the fact that BEV can be a product with strong market appeal, which would help with acceptance (or legitimation, as we discuss later) of the technology.

On Earth Day 2013, the state also implemented Mass EVIP, a program administered by the Massachusetts Department of Environmental Protection, to offer financial support for the adoption of plug-in vehicles in municipal and state fleets, pubic colleges and universities. By the end of 2015, the program had awarded almost $700,000 for 93 BEV ($7,500 per vehicle), $165,000 for 33 PHEV ($5,000 per vehicle), and $444,000 for 43 charging stations (over $10,000 on average per charging station).

There have been efforts to increase public awareness of plug-in vehicles, including a website administered by the multi state ZEV Task Force, numerous events to expose the public to vehicles organized by state agencies and non-profit organizations. There has not been however coordinated marketing or communications campaigns in the state aimed at creating public awareness and interest. As discussed above, stakeholders believe that consumers' information and awareness about plug-in vehicles is relatively low and that it is important to bridge that information gap. Stakeholders acknowledge the value of government outreach efforts, but in general believe that marketing and information should be lead by industry so that the different companies can bring their marketing expertise and tailor their message to the specifics of their product offering. Some stakeholders have the view that, because of existing regulatory requirements emanating from the ZEV program, that the burden to continue improving and marketing the product is on the car companies. In their view there is much more that industry can do to educate the market, including direct advertising and send signals to consumers that legitimate plug-in vehicles. For example, when a company announces that it will cap production of their plug-in models, that action may send a signal in the opposite direction of what is needed to develop the market.

Despite the recent forays into market forming policies, our statistical analysis of article-count data does not indicate that there had been a significant rise in the Market Formation function in Massachusetts compared to other states. This may reflect that there was limited information portrayed that related to the incentive in 2014, or that even with the additional incentive Massachusetts has not significantly changed the innovation trajectory for PEVs in the state.

Development of Positive Externalities

Stakeholders indicated that plug-in vehicles bring benefits to the state in the form of lower carbon emissions, improved air quality and lower urban noise levels. When inquired about the possible impact of electricity from coal-fired power plants on the greenhouse gas emissions attributable to plug-in vehicles, stakeholders generally indicated that the state produces much of its electricity from natural gas and renewable sources. A report by the Massachusetts Executive Office of Energy and Environmental Affairs suggested that deploying 300,000 electric vehicles in the state would result in net lifecycle greenhouse gas emissions savings of over 800,000 short tons.

Stakeholders were in general unsure about the impact of vehicle electrification on jobs in the state. Some pointed to the jobs created with the growth of the charging station network, suggesting that 3-4 people are paid to install a station

State of Georgia: A Case Study of the PEV Retail Subsystem

In this section we take an in-depth look at one part of the PEV innovation system, namely the new vehicle retail subsystem. Retail practices have been the focus of much interest among PEV actors given the critical role dealerships play, as the nexus between the technology and the market. A number of interacting stakeholders (actors) and regulations (institutions) converge in this space, which makes the denomination of subsystem appropriate. By looking at a subsystem we are able to uncover and discuss processes at a more granular level, including specifics of actors and networks behaviors and institutions' roles.

As a case study we selected the state of Georgia, which drew the attention of PEV stakeholders when it emerged as one of the fastest growing PEV markets in the United States. In 2014, sales of PEVs in the state of Georgia grew seven-fold over the previous year, catapulting Georgia to second, behind California, in the list of top PEV markets in the United States (Pratt, 2015). At one time, Georgia was the fastest growing market for PEVs in the nation, adding 600 vehicles every month to its tally of 12,000 registered PEVs (Francis, 2014). The state's capital, Atlanta, was also the number one metro market for the Nissan LEAF, historically the nation's most popular all-electric PEV until Tesla's Model S outsold the LEAF in 2015.

Many observers attribute the state's PEV sales success to the former $5,000 state tax credit. The evidence lends support to this argument: Shortly after enactment of House Bill 170, which repealed this long-standing incentive for low- and zero-emission vehicles in early 2015, PEV sales plummeted. While the impact of the state's tax incentive seems apparent, it is likely that other factors were at play in Georgia's remarkable growth in PEV sales.

The selection of PEVs sold at a substantial premium compared to similarly equipped conventional vehicles. Like other states in which PEVs are sold, carmakers can "bake in" a federal income tax credit for PEVs worth up to $7,500 through lease programs that yield competitive monthly payments. Some carmakers offer additional incentives. Nissan, for example, offers special pricing for corporate campuses and universities.

A number of states offer additional benefits to decrease the price premium for PEVs. California, for instance, offers a $1,500 rebate check for buyers of plug-in hybrid vehicles (PHEV) and a $2,500 rebate check for all-electric PEV buyers. Unlike California, Georgia residents could capture the state tax credit on PEV leases for lease terms as short as two years (though California recently reduced its minimum ownership requirement to 30 months from 36 months). Notably, unlike the federal tax credit, buyers must wait to claim the credit through their individual tax filings rather than through the lease contract at the time of purchase. In addition, both Georgia and California grant access to HOV/HOT lanes for single occupancy PEVs.

Empirical Findings

Georgia's tax credit for zero-emission vehicles, combined with targeted marketing led by Nissan, appear to have been a key driver of the state's PEV sales. Since plug-in hybrids did not qualify for the state's tax credit, the incentive clearly favored battery electric vehicles. Perhaps unsurprisingly, BEVs comprised the vast majority of Georgia's PEV sales. During the study period, only four BEVs were available in the state of Georgia: The Nissan Leaf, Ford Focus EV, Tesla Model S and the BMW i3. Georgia's franchise laws cap sales made directly by auto manufacturers at 150 units annually, imposing an upper limit on sales of Tesla's Model S. BMW's i3 did not arrive until spring of 2014 but made inroads shortly thereafter.

Nissan Motors, proving to be the most aggressive of the PEV manufacturers in this regard, led competitive lease pricing. Based on feedback received from lead EV dealers in early markets like California's San Francisco Bay Area, Nissan North America was the first to capitalize on the ability to roll the full $7,500 federal tax credit into a lease agreement. This dramatically lowered the monthly payment and increased EV affordability. To remain competitive, other carmakers followed suit with their own aggressive lease programs.

Because the Georgia tax credit could be claimed on leases as short as 24 months, the monthly payments required to lease the Leaf were effectively brought to zero. Factoring initial costs associated with the transaction and including approximate gas savings, the cost of PEV ownership landed in the neighborhood of $50 per month, for a total biennial ownership cost of just over $1,100 (see Figure 7).

24 month Lease

$199 x 24	=	$4776
Down Payment	=	$1499
Disposition Fee	=	$395
Total		$6670
Ad Valorem Tax		$2116
ZEV Tax Credit		($5000)
Total		$3786
Fuel Savings		
$1325/year x 2	=	($2650)
2 year Total Cost	=	$1136

Figure 7. Example customer cost calculation for a two-year PEV lease, along with a Nissan LEAF ad from the Atlanta area.

BEVs available for sale in Georgia include the Nissan LEAF, BMW i3, Tesla Model S and Ford Focus electric. Kia's Soul electric only more recently debuted in the Atlanta region. The Nissan LEAF was a clear leader in PEV sales. This suggests that understanding the market success of PEVs in Atlanta requires a better understanding of how Nissan differentiated its strategic marketing and/or PEV product in the regional context.

While there is every reason to believe that price was the key determinant of success, pricing is just one piece of the puzzle. Dealers (among other stakeholders) often described the sudden takeoff of PEV sales in the Atlanta area from 2013 to early 2015 as a "perfect storm" of factors that, when taken together, yielded a compelling value proposition for local motorists. These factors included:

- Aggressive and innovative marketing by Nissan
- The federal tax credit
- Unique structure of the state income tax credit
- Single-occupant HOV/HOT lane access for PEVs
- A handful of "champion" dealers that aggressively embraced PEV sales
- Discounted electricity rates and rebates for homes and businesses that install PEV chargers
- Heavy rush-hour traffic
- Moderate commute distances
- A high number of corporate campuses that qualified for special PEV pricing

Many of these factors, however, are not unique to Georgia. While Atlanta ranks in the top tier of U.S. cities with the worst traffic, several other cities in states with EV-friendly policy

environments rank higher, including: Portland, Oregon (No. 10), Seattle, Washington (No. 5) and Honolulu, Hawaii (No. 3) (Bowerman, 2015).
Atlanta also recorded the longest average commute distance among all U.S. metropolitan areas in 2015, at 12.8 miles each way, beating out Houston, Detroit and Los Angeles (Kneebone and Holmes, 2015). Yet, according to a FHA-funded report, Atlanta was absent among cities with the most HOV/HOT lane facilities (Booz Allen Hamilton, 2008). The Twin Cities region tops the list with 83, followed by the San Francisco Bay Area (47), Puget Sound (Seattle-Tacoma, 40), Los Angeles (23) and Houston (21). Absent data on HOV utilization by EV buyers, it is difficult to pinpoint whether access to HOV/HOT lanes played a defining role in driving sales of EVs in the greater Atlanta metro region. Nevertheless, stakeholders cited HOV/HOT access in Atlanta's high congestion, long commute environment as a compelling explanatory factor in the region's affinity for EVs.

Time series data on the deployment of DC fast charge stations using ChaDeMo connectors (the standard compatible with the Nissan LEAF) shows that the rapid uptake of PEVs precedes increases in this type of infrastructure. This suggests that DC fast charging infrastructure was not a major cause of strong increases in PEV sales. Instead, rapid deployment of Level 1 and 2 charging infrastructure, particularly at workplace locations, may have played a greater role. As discussed above, deployment of workplace chargers, particularly at major corporations and institutions, helps legitimize EV technology. We speculate that charging at work is particularly supportive of EV legitimation in localities with long commute distances, such as Atlanta. Table 4 shows that Level 2 charging infrastructure grew at a rapid clip alongside PEV sales over the same period.

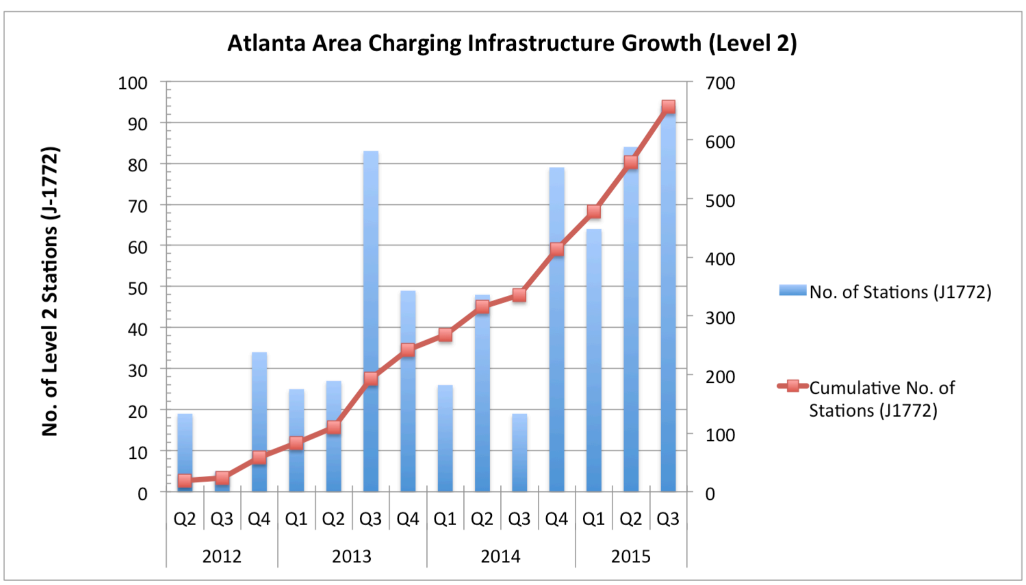

Table 4. Level 2 EVSE (charger) deployment in the Atlanta metro region (Source: Plugshare)

<u>Entrepreneurial experimentation at dealerships: Novel marketing and sales approaches</u>

Only specially certified dealers sell PEVs. Nissan was the first manufacturer to levy certification requirements on dealers wishing to sell PEVs. Of note, state franchise laws require that automakers sell all new vehicles, PEVs included, through independent franchised dealers (Cahill, 2015; Crane, 2015). While these laws may vary to some extent from state to state, in general, they stipulate that automakers must in principal provide dealers equal opportunity to sell its products. Dealers ultimately decide which vehicle lines they sell and, in turn, how vehicles are retailed to end customers (within the constricts of franchise agreements and a large body of consumer protection laws). In turn, automakers may set requirements for dealers selling particular products or technologies. The burden of proof, however, rests with automakers to justify that such requirements pass the test of “reasonableness” in the courts (Crane, 2015; Marx, 1985).

Dealers interested in selling the Nissan LEAF must first earn designation as a LEAF-certified dealer. Certification typically requires up-front dealer investment in PEV-specific assets including equipment, facility upgrades and training. Examples include purchase and installation of a minimum of two Level 2 chargers (one for the lot and one for the service bay), a service lift capable of accommodating access to the vehicle’s high-voltage battery pack and training of at least one member of the sales team and one service technician. Nissan also encourages dealers to install DC fast chargers and to make them available to the public. The decision to do so, however, rests with the dealer.

Though a later entrant to the Atlanta market, BMW implemented a similar certification program for BMW dealers interested in selling its initial EV models through its “i” sub-brand. This sub-brand is intended to showcase BMW’s cutting edge technologies such as the use of lightweight unibody construction made with carbon-fibers manufactured in the State of Washington, as we discussed in the section on that state. Unlike BMW’s Mini sub-brand, in which its signature Mini Cooper and other “Mini” nameplate models are sold through separate “Mini”-branded facilities, i-branded models are sold alongside conventional vehicles on BMW dealers’ lots.[2] Like Nissan, BMW dealers must invest in a minimum of EV-specific equipment, facility upgrades and training for members of the sales team and service technician pool.

Trainees undergo four days of instruction at BMW’s Bay Area facilities to immerse “i”-certified sales advisors in the history, philosophy and technology that underpin BMW’s “i” product line. BMW motivates its students to pass the “final exam” for i certification by granting those that achieve a passing score the opportunity to drive BMW’s i8 flagship supercar. The company also encourages graduates to share the experience via social media.

Though students spend just one-half day behind the wheel of the i3, each is given the opportunity to buy or lease this PEV at reduced employee pricing. BMW’s purpose is to place more “i” sales advisors in a position to gain real-world experience behind the wheel of an i3 PEV. Doing so may aid in speeding sales advisors up the considerably steeper learning curve

[2] BMW has launched separate “i” branded dealer facilities in California.

associated with selling PEV technology (Cahill, 2015). Dealers may also be more prepared to expertly address the sophisticated questions posed by prospective PEV customers and to craft messages and anecdotes that more effectively convey the unique value of driving a PEV to customers. Real world EV driving experience also positions sales advisors to better determine whether a customer is a good fit for the technology. We see dealer training as contributing to strengthening various function of the TIS, including knowledge creation, knowledge diffusion and legitimation.

Of the carmakers with PEVs to sell, Nissan embarked on one of the more comprehensive marketing campaigns intended to introduce customers in key markets to the LEAF PEV. Their campaign included participation in ride-and-drive events such as National Drive Electric Week sponsored by third parties such as the local Electric Auto Association. The campaign also featured Nissan-led road-shows that showcased the Nissan LEAF at various auto shows and venues in targeted PEV markets across the nation (Figure 8). In the greater Atlanta area, Nissan specifically targeted potential PEV customers at large corporate campuses like Coca-Cola, UPS, and Georgia Power. It also targeted university campuses in the Atlanta region, including Georgia Tech and Emory University.

Figure 8. 2011 Drive Electric Nissan tour stops at Atlanta Station in midtown Atlanta

Nissan distinguishes its marketing efforts from other automakers by actively targeting and engaging potential PEV customers at locations away from dealer facilities. Company representatives noted that franchised dealers are best situated to sell familiar products in markets where demand already exists. Conversely, dealers are much less equipped to sell new and unfamiliar technologies in an early market where low initial demand is anticipated. Given these distinctions, the automaker acknowledged that PEVs need a different retail approach.

Nissan conceded that the role of marketing PEVs starts with vehicle manufacturers. One company representative noted that dealers are set up to facilitate vehicle sales in relatively high volumes; it is up to the manufacturer to ensure that customers arrive at dealerships primed for a purchase. In light of this, the company's marketing efforts for the LEAF departed from customary model launches in that they provide additional support to dealers. This takes the form of ride-and-drive events intended to expose customers to the technology in a neutral setting and to complement dealer core expertise. Dealers can then do what dealers do best: transact the sale once the customer arrives on the lot.

To do this, not only did Nissan package the LEAF at a compelling price point (essentially free once fuel savings are accounted for) but also targeted customers who needed to solve a particular problem, namely, a difficult commute. Nissan regional managers concentrated their outreach efforts on corporate and university campuses. As one manager put it, "Rather than looking for a needle in a haystack, we go to the needle factory." Typically, this involved coordinating a no-cost (to the sponsor) ride-and-drive event during lunchtime hours, often orchestrated through campus sustainability managers. Corporate and university campuses housed the most likely customers for PEV technology: Well-educated, upper income professionals from a diversity of backgrounds who face a daily commute. Moreover, the company positioned subject matter experts capable of addressing the wide array of questions customers threw at them. Topics included the ins and outs of not only the LEAF PEV, but also related charging equipment and options, electricity rates, and myriad public incentives and benefits. Nissan invited area LEAF-certified dealers to send a representative sales member to assist with offering test drives for interested customers. In return, sales representatives earned the opportunity to generate potential leads and to establish themselves as the "go-to" salesperson should the customer decide to buy.

Nissan Vehicle Preferred Pricing (VPP) combined several elements into an enticing package built around a two or three-year subsidized lease option. As mentioned previously, the lease instrument allowed NMAC to reduce the monthly payments by applying the full $7,500 federal tax credit to the lease amount. Over a 36- month lease term, this amounted to a reduction of $208 in the customer's monthly payment. Nissan, which maintains its own captive credit agency (NMAC), was also fairly generous in further subsidizing the lease and by setting the LEAF's residual value relatively high so as to further reduce the monthly lease payment.

A two-year lease option proved even more enticing for two primary reasons. First, the $7,500 federal credit is concentrated over a shorter term, reducing monthly payments by $312 (compared to $208 on a three-year lease). This magnifies the credit's impact. Second, Nissan dealers emphasized to customers that the state's $5,000 tax credit would effectively reduce the monthly payment by an additional $208. Unlike the federal tax credit, the manufacturer's finance arm could not use the state tax credit to reduce the capital cost of the vehicle through the lease instrument. Regardless, dealers expressed few reservations about sharing this incentive with prospective customers. With a VPP lease payment of just $199 a month, customers could essentially get a new car for free. As it turned out, the promise of a “free car” proved a powerful enticement for attracting customers.

Knowledge and information diffusion

Not surprisingly, word of a “free car” can spread fast. By many accounts, this potent phrase likely served as the kindling that ignited the fire of LEAF sales, starting with water cooler conversations at corporate and university campuses in the Atlanta region. Several stakeholders shared that the LEAF was particularly popular in the Indian/Pakistani immigrant community. Aside from the LEAF’s attractive economics, rationale for the PEV’s appeal with this particular sub-group included the community’s relatively large footprint in the technical professions targeted by Nissan.

Other automakers like BMW did witness some success with PEV sales. BMW dealers, however, suggested that the i3’s“polarizing” design, which eschewed BMW’s traditional design aesthetic in favor of a much more distinct profile, limited its sales potential. According to salespeople at these dealers, the i3 PEV had minimal appeal with typical BMW buyers. As a result, the model likely ended up competing for the same pool of customers as the Nissan LEAF. With customers accustomed to the “virtually free” price point of the LEAF, BMW dealers found it that much more difficult to interest customers in the higher priced BMW i3.

Ironically, the “free car” moniker may have played as much a role in precipitating the ultimate demise of the state’s alternative fuel tax credit as it did in goosing EV sales to record levels. Word of a state-subsidized “free car” soon reached the state’s capitol in Athens, Georgia. There, the credit fanned opposition to its continuation, with positions generally divided across party lines. As in other states, including California, dissenters pointed to equity concerns, among other general arguments. At the end of the first quarter of 2014, just five of the state’s 159 counties comprised 80% of Georgia’s EV registrations (Figure 9). All five were generally concentrated in the more affluent Atlanta metro area. This lead to the perception that PEVs were being disproportionately subsidized by less affluent counties in the state.

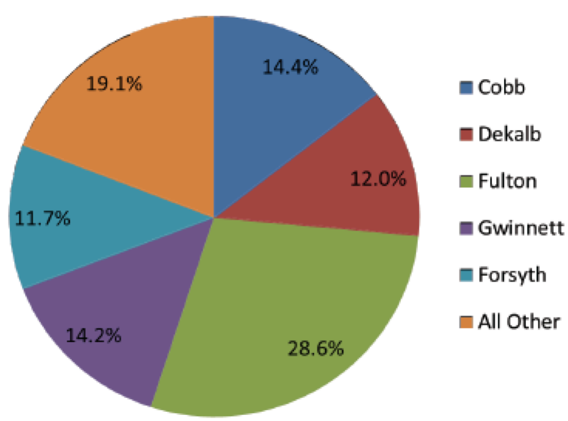

Figure 9. 80% of the plug-in vehicle sales in Georgia were concentrated in five counties in the Atlanta region

Despite such headwinds, the credit had withstood previous challenges. Advocates expected a renewed challenge to the credit in the 2015 legislative session. They were prepared to head off this latest challenge with a number of arguments highlighting the economic benefits to the state in preserving the long-standing incentive. A relatively diverse, though not very broad, coalition emerged to save the credit that included Nissan, Georgia Power, the Sierra Club, the Atlanta Clean Cities Coalition, as well as a number of other stakeholders.

This time, however, the credit's renewal accompanied debate over the state's transportation bill, which was due to close a growing shortfall for upkeep of the state's deteriorating road and highway infrastructure. In the end, opponents prevailed and the credit expired on June 30, 2015. In its place, the state imposed a $200 annual road use fee on PEV buyers. In a matter of weeks, the state pivoted from having the strongest PEV incentive in the nation to the weakest.

Area Nissan and BMW dealers reported to us that since Georgia's tax credit expired on June 30, sales have collapsed by as much as 90%. Absent a cohesive post-credit transition strategy, automakers and their dealers may be hard-pressed to restore PEV sales to their former heights.

Discussion and Recommendations

Large-scale market deployment of zero-emission vehicles is critical for achieving deep reductions in greenhouse gas emission from transport. Most public support for plug-in electric vehicles has been justified on these grounds. This has placed plug-in vehicles in the middle of complicated policy processes at the state level, with political groups divided over their positions regarding climate change and the need for policy intervention. Legitimation of the technology at the government level is low. This in turn negatively affects resource mobilization and market formation, which negatively affects other functions of the TIS.

The electrification of transportation is a challenge of enormous proportions. As such, it demands great commitment and mobilization of resources, as well as expert planning, coordination and implementation. In spite of extraordinary efforts by important stakeholder sectors, the PEV innovation systems in the states that we examined remain underdeveloped. Given that Massachusetts and Washington represent two of the more aggressive states in support of PEV markets, we believe it is fair to expect, though this would have to be verified, that PEV innovation systems are underdeveloped in most other states as well.

Methodology

We used the TIS framework in response to the need for holistic, system-level approaches to understand many aspects of plug-in electric vehicle innovation. We had observed that earlier TIS studies have used the framework for post-hoc descriptions of the development of innovation in certain technologies. We were thus interested in better understanding whether TIS could help us also draw inferences of prescriptive value, which could then inform strategy and policy.

We found that TIS is helpful in disaggregating the research into a more manageable set of focus areas. This disaggregation through the TIS methodology not only makes the research more replicable, but also facilitates technology innovation system comparisons across different geographical or administrative jurisdictions. At the same time, we recognize that TIS is still under development. While the functions appear comprehensive in terms of their reach to all aspects of the innovation system, we found the precise meaning and scope of the functions themselves at times to be subject to interpretation. For example, if a state legislature approves a financial incentive to support sales of plug-in electric vehicles, this clearly has implications for the resource mobilization function, but it can also be interpreted as affecting the market formation and legitimation functions. It could even be interpreted as affecting policy actors' entrepreneurial experimentation, to the extent that the incentive program is evaluated only after implementation (if at all), and possibly amended to incorporate new information. These questions motivated us to set clear definitions for each of the functions as they were used in our study, and it is a practice that we recommend to researchers using TIS. They also motivated us to dedicate some space to expanding upon our understanding of the meaning of two functions, namely entrepreneurial experimentation and the development of positive externalities.

Findings

Earlier we described innovation as including both the processes of technology development and of technology adoption/diffusion. While our analysis reveals that all functions of the innovation system, particularly Knowledge Diffusion, are underdeveloped, our study shows that presently the main detractor for accelerated market adoption is the early state of technology development. There are distinct differences in mindset and product strategy by new entrant (namely, Tesla) and incumbent automakers. From a design perspective, Tesla has sought a vehicle with universal appeal (no sacrifices) but is pursuing a niche strategy that builds legitimacy for the technology and the brand through a top-down approach featuring entry at a much higher price point in the luxury market and moving down-market. Conversely, the major automakers have, from a vehicle design standpoint, fielded vehicles with explicit compromises (in range, performance or utility) at a much lower price point via a bottom-up introduction strategy. We find that, while resulting in a more affordable product, these compromises not only limit the market but also affect negatively the Legitimation and Knowledge Diffusion TIS functions. Across the board, stakeholders surmise that the best way to increase market acceptance of PEVs is for industry as a whole to deliver product lines that appeals to a broader consumer base.

In this light, we see the case of sudden PEV uptake in the Atlanta metro not so much as a success story, but rather as evidence of the limited market appeal of PEV offerings. Rather than emphasizing the comparably large number of PEVs sold in that region, we instead ponder why vehicle sales were not larger, especially given that consumers were essentially offered a "free car" after factoring in various private and public sector incentives. The difference between Tesla and the incumbent manufacturers extends beyond the technology to encompass a number of social and institutional factors that magnify their differences. Important among these factors is a weak Guidance of the Search function. Except for Tesla, whose very existence and corporate structure rides solely on the success of electric platforms, incumbent auto manufacturers arguably are less prepared and face a different set of pressures (shareholders and the market) to invest more aggressively on plug-in models and to market more aggressively their existing product lineup. We found evidence that the degree of engagement has varied across the incumbent automakers, with Nissan being the leader.

Additionally, actors and networks have not developed the knowledge needed to design and implement the most effective and consistent strategies and policies. Despite the successful implementation of policies and programs to support market adoption, policy learning has been slow. In great part, this has been due to the absence of resources dedicated to rigorous program design and program evaluation.

Political divides about the support for vehicle electrification further weakens the Guidance of the Search function. The transformation of the transportation sector to electromobility needs supportive policymaking, which is difficult to achieve while state legislatures remain polarized on the subject. Even when a number of states have been able to pass legislative or regulatory programs to support PEV innovation, the political disagreements about these programs create a climate of uncertainty that discourages innovation. The Mobilization of Resources function, most notably in the form of government financial incentives, whose effectiveness depends upon long-term stability, is instead exposed to uncertain political cycles. The state of Georgia served as a good illustration of this instability. The climate of uncertainty affects predominantly actors and networks in the supply chains in the innovation system. The car manufacturers' ability to engage in aggressive PEV product planning and marketing is negatively affected, while new car dealers' confidence to plan marketing, inventory and sales strategies is also degraded.

In spite of the resources dedicated to supporting PEV innovation, PEV are still competing in a system that is friendly to petroleum fuels. We also find this to be an important structural weakness in the PEV innovation system. There are a host of institutional factors that directly or indirectly favor the incumbent internal combustion vehicle. Lack of internalization of the social cost of burning fossil fuels, weak enforcement of speed limits, land use planning that encourages long trip distances, tax breaks for oil companies, and other factors, all combine into what amounts to a large subsidy to conventional vehicles. It is critical to understand the difference between two aspects of innovation policy, namely fostering a socially beneficial technology during its development stage, and leveling the competitive playing field. Addressing both aspects of innovation policy is critical in technology innovation systems for consumer products, where the new technology competes with an incumbent technology with different consumer experience. To use an example, a PEV financial incentive is *not* a replacement to a fee on vehicle carbon emissions. The former is predominantly intended to help with the higher costs typical of technologies in their early stage; the latter is predominantly intended to internalize the social carbon cost of driving and thus level the competitive playing field across vehicle technologies.

Financial incentives have been the primary instrument used by state governments to encourage the market adoption of plug-in vehicles. We found that the effectiveness and efficiency of these programs are strongly dependent on the way that the incentives are structured. We suggest that if incentives are at the consumer level (e.g. rebates), their structure needs to be simple and easy to understand. Increasing the complexity of these incentives decrease their effectiveness, as they increase the cognitive burden on consumers.

While simplicity supports incentive effectiveness, it does not necessarily support program efficiency. Incentives often followed two-tier structure à la California intended for simplicity and to push sales.[3] Such structures send sub-optimal innovation signals and thus make a mixed contribution to the Guidance of the Search TIS function. Some PEV models contribute more to innovation (and are more socially beneficial) than others, and thus an incentive structure that reflected more closely these differences would make more efficient use of public funds toward public goals. Incentives that have more efficient (and more complex) structures can work better at the level of the manufacturer or the dealer, who are able to integrate them into pricing strategies that can best serve their customers. However, as we indicated above, if applied at the level of the consumer, more complex structures can be confusing and detrimental to adoption.

The tax rebate in the state of Georgia constituted an example of an incentive with a more sophisticated structure, which provided dealers with flexibility to integrate it into their pricing and marketing strategy, reducing the burden for consumers to figure out the math on their own. The ability to apply the incentive to leased vehicles, where consumers were able to effectively "test" the car over the duration of the lease served to reduce adoption risk for consumers. While the incentive ultimately delegitimized support for PEV at the political level, it accelerated knowledge diffusion of the technology across some consumer markets. Georgia's incentive had the effect of a steep increase in PEV leases in the Atlanta metropolitan area, a location with a "champion" dealer. Although PEV usage increased dramatically, the incentive may have been overly generous. It encouraged a consumer word-of-mouth narrative centered on the idea of a "free car", with much lower attention to the value of the technology. In our assessment, this works against the development of a lasting Legitimation function. Consistent with modern marketing practices, it may be better innovation policy to place the product in the hands of consumers who can become ambassadors and support broader consumer acceptance for the right reasons, and to provide mechanisms that serve to reduce the risk for individuals interested in "trying" the technology. Equally important, the structure of the incentive (and subsequent spike in sales) encouraged a quick political opposition that eventually resulted in phasing out the program.

The simplicity of some incentive programs has eventually run into concerns among stakeholder groups concerned with their equity impacts. Concerns such as these often lead to

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[3] Two-tier rebate programs generally offer a set amount for battery electric vehicle transactions and a lower amount for plug-in hybrid electric vehicle transactions.

regulatory/legislative review/amendment processes that result in uncertainties around the programs. While these bumps in the road can be considered part of the Entrepreneurial Experimentation function, it is important that lessons be distilled and incorporated into program structures in other jurisdictions. We heard from stakeholders, however, that policy learning across states has been slow. Thus there are opportunities to strengthen interstate collaboration.

Beyond incentives and incentive structure, we also found that the Legitimation function is still weak and that this weakness manifests itself at the actor, network and institutional levels. While segments of the public are aware of plug-in electric vehicles, there has been only limited progress on the implementation of effective large-scale strategies/campaigns to increase awareness among consumers. Stakeholders are in general aware of this gap, but they struggle to identify solutions.

We have found that dealerships can play an essential role in the promotion and deployment of electric vehicles. Given their proximity to local markets and personal interaction with customers, dealers can act as a source of information to assuage consumer uncertainty related to PEV technology and infrastructure. The extent to which customers trust dealer as an objective source, however, remains an important barrier to dealer effectiveness in this role. Consequently, automakers or other entities may be better suited to these activities. Conversely, dealers may be better positioned to ensure that a PEV is a good fit for customers arriving at the dealer intending to buy. In this way, the dealer acts as a final check to ensure the customer's needs are met before the customer has committed to a purchase.

We recognize the potential for endogeneity, as dealer champions may be more likely to be present in communities that are receptive of plug-in vehicles in the first place. We did not try to assess this potential in the present study. Selling a PEV to a customer who will not be satisfied is counterproductive for the dealer and for the broader innovation system (deters diffusion by contagion). So:

- Dealers are concerned with making the customer happy, which motivates them to place PEV judiciously in the right hands (which is good), or to continue with BAU and focus on conventional cars (which is not good);
- Policy needs to be careful not to push dealers to the point where the incentive of selling a PEV exceeds the incentive of placing PEVs in the hands of those best able to realize their value.

To accelerate PEV sales and technology innovation, dealers with substantial knowledge about the technology and the range limitations or charging caveats associated with its use may be better able to inform potential customers about the technology, furthering legitimacy and knowledge diffusion in the TIS. In turn, informed dealers may have a better sense of technology weaknesses and the consumer markets best suited for adoption of PEVs. As such, dealers that champion PEVs help support the innovation system and policy incentive system to better align technology development with consumer demand.

Modern marketing strategies require a type of expertise generally beyond the scope of the public sector. It would also be extremely difficult to articulate an effective marketing campaign without the participation of the auto industry. In the end, we believe, this brings us back to the value that consumers currently see in the technology. Awareness becomes viral when the product is compelling, as illustrated by Tesla and by the distinction that stakeholders often make between Tesla and other models. Having acknowledged the importance of product value proposition, there is more that networks and institutions can do to further the legitimization of the PEV technology. We observed varying degrees of commitments to support PEV among stakeholders. There are leaders and champions in government that work very hard to mobilize markets for PEV. However, the government institutions where these leaders and champions reside do not necessarily regard PEV as a high priority. The reasons for limited institutional legitimation can be complex, but in our assessment one important reason is the limited understanding of the connection between PEV and attaining deep reductions in carbon emissions in the transportation sector.

To summarize our conclusions related to incentive policy, we believe the PEV TIS is still in search of incentive structures that strike a balance between effectiveness and efficiency. The work done across jurisdictions can be considered part of the fulfillment of the Entrepreneurial Experimentation function and has been extremely valuable to learn lessons. Moving forward, we recommend that states allocate resources to the careful design of their incentives' structures. This would typically involve engaging experts and stakeholders who can work with regulators and policymakers to identify solutions that are both efficient and practicable. Best practices based on experience include:

- Make incentives available at the point of sale;
- Empower dealers and automakers to integrate incentives in their marketing and sales plans;
- Exempt consumers from the need to do the math or even to be aware of the incentive program;
- Provide long-term certainty for technology developers;
- Create signals that encourage innovation,
- Reduce the risk for consumers to gain experience or knowledge about the technology, and
- Incentive programs are not a substitute for programs that can level the competitive playing field.

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Appendix

Entrepreneurial Experimentation

Uncertainty and risk are natural elements of the innovation process and as such they should be embraced and accepted. A way to deal with uncertainty is to foster experimentation. Vibrant experimentation is a sign that the TIS understands that technological pathways are uncertain (and cannot be predicted), and that intensive exploration of ideas is needed as part of the innovation strategy. Indeed, a TIS that doesn't embrace uncertainty, or one that doesn't foster experimentation or that prescribes the path of innovation, is a TIS that stifles innovation.

Earlier TIS studies have generally understood *Entrepreneurial Experimentation* as the probing of new technologies and applications. With this perspective, the central actors of this function are in industry. While we maintain the perspective that experimentation around technology is a fundamental building block for technology innovation, we give the *Entrepreneurial Experimentation* function a broader meaning. In our view, this function embraces a number of activities and associated institutions, which include the probing of new:

- Technologies;
- Methods or ways to apply technologies; and
- Institutional mechanisms to foster the adoption and use of these technologies.

Low barriers of entry for new firms and institutions, and diversification of existing ones are signs of healthy conditions for experimentation.

Scope of Experimentation

The concept of experimentation can be interpreted both as a scientific process whereby a series of steps are performed in a controlled environment to discover or test an effect, and more loosely as referring to informal testing of how well something works. As applied to innovation systems, scientific experimentation is more common in research and technology development, while other less technical areas will see more informal experimentation. In any case, experimentation for its own sake is not necessarily a sign of a healthy innovation system. Experimentation needs to be intertwined with knowledge creation and diffusion in a way such that experimentation a) builds upon and is guided by existing knowledge (whenever available), and b) results in new knowledge that can be disseminated and used. The last point is important: experimentation needs to integrate mechanisms to transform findings into documented or accepted knowledge. For example, experimentation with a new state program to support consumer adoption of plug-in vehicles should build upon any existing pertinent evidence and should include mechanisms to test and interpret the extent of its effectiveness.

The Scope of Entrepreneurship

Does the term entrepreneur embody actors whose mission is not specifically related to technology development? Theories of the policy process have used this term to refer to actors that bring attention to policy problems and/or propose policy solutions to these problems. Public entrepreneurship is the process of introducing innovation into the public sector. The concept of policy entrepreneurship has been used in earlier studies in a relatively loose manner to help explain policy change. The concept plays a central role in the Multiple Stream framework for the study of policy change (Kingdon and Thurber, 1984). Mintrom and Norman (2009) propose a way to integrate policy entrepreneurship more formally into theories of the policy process and policy change. On describing policy entrepreneurs, Kingdon and Thurber (1984) say that they can "*be in or out of government, in elected or appointed positions, in interest groups or research organizations. But their defining characteristic, much as in the case of a business entrepreneur, is their willingness to invest their resources—time, energy, reputation, and sometimes money—in the hope of a future return*" (p.122). Mintrom and Norman (2009) offer a crisp perspective on what distinguishes a policy entrepreneur: "*Many actors and organizations participate in policymaking or seek to influence decision makers. Most of these participants are comfortable working within established institutional arrangements; doing their bit to achieve improved outcomes for themselves and their supporters without upsetting the status quo. Policy entrepreneurs distinguish themselves through their desire to significantly change current ways of doing things in their area of interest*" (p.650). Kirzner (1978) defines entrepreneurship as the facility of awareness or alertness to profit from opportunities existing in a world of disequilibrium. Shane (2000) articulates entrepreneurial behavior as "a situation in which a person can create a new means-end framework for recombining resources that the entrepreneur believes will yield a profit" (p.18). These conceptualizations can be directly adapted for our purposes to the case of public entrepreneurs, by substituting *profit* with *public benefit*.

In the case of PEV innovation systems, institutional experimentation is critical. This in itself is a broad area, so we attempt to analyze it in categories:

- Government program development and evaluation,
- Stakeholder program development and evaluation,
- The strength of education programs that create the necessary skilled workforce,
- The vitality of research programs at academic and research institutions, that create new ideas;
- Data collection, an activity that is critical to addressing uncertainties; without data, program evaluation and technology progress and acceptance are virtually impossible.

For technology-related experimentation, we look at two main components: the diversity and fluidity of technology firms, and technological diversity.

Diversity and fluidity of technology firms

This is concerned with the ability of new firms and startups to develop and test new ideas. This ability depends on the removal of unwarranted capital and institutional constraints.

Capital Constraints

Researching and experimenting with new technologies and methods requires access to capital that is fairly risk-tolerant. For higher-risk social-return experimentation, government investments are warranted. For early stage market formation, funding should support a diverse array of ideas and market players, such as universities, startups and small businesses. Narrower portfolios are acceptable once technology probing has shown clear directions for investment. The influence of capital translates into a direct relationship between the *Resource Mobilization* and *Entrepreneurial Experimentation* functions in the technology system. We expect states that allocate resources more effectively to support entrepreneurial experimentation will help advance ideas and foster knowledge creation in the technology, methods or institutional fronts. In turn, the accumulation of knowledge enables knowledge diffusion and legitimation of the technology.

Institutional Constraints

Experimentation can also be hindered by incompatible existing rules and regulations, market power by the economic establishment, prescriptive early government action, and the weakness, weak coordination, or absence of institutional networks that support innovation. For a TIS to foster entrepreneurial experimentation, it is necessary to review existing regulations and rules to understand and address such possible obstacles. Examples include the implementation of development regulations for the installation of charging infrastructure, addressing condominium association covenants that hinder the installation of charging equipment at residential buildings, addressing liability questions for prospective hosts of public-access charging equipment, deregulation, as appropriate, of electricity rates and other market elements that could be internalized through third-party innovative ideas, poorly designed incentive programs, etc.

The market power of established economic players may promote the belief that it is the dominant sector that will lead the generation of innovations and social change needed for the market success of the new technology. Disruptive innovation generally needs new rules and practices that the establishment is not directly setup to provide or for which it cannot adjust fast enough. At least two areas deserve close attention: new car dealership franchise laws and the role of electric utilities. The question of dealership franchise laws is complex and a discussion of it lies outside of the scope of this study. The appropriate role of electric utilities in PEV innovation, while it has not been studied in depth, to a large degree relates to the question of vehicle-grid integration. It is critical not to assume, so early in the innovation process, that it will be this sector that will drive the innovations needed toward the integration of plug-in vehicles with the grid. The innovation system ought to provide a healthy environment for experimentation that is open to established players as well as new entrants into the market.

To foster experimentation, government activity needs to avoid being too narrow such that it prescribes the exact outcomes that private sector innovation should achieve. Such government activity should also incorporate mechanisms that allow learning and activity re-adjustment based on outcomes. The California ZEV regulation, as an example, constantly strives to find a balance that maximizes innovation. Not pushing enough may loosen incentives on the industry to innovate, while prescribing too much may restrict experimentation. The current debate over the allocation of ZEV credits based on vehicle electric miles driven (eVMT) is an illustrative example. Granting eVMT credits suggests an opportunity for experimentation, and could simultaneously reduce incentives to innovate on larger-battery vehicle platforms. Government programs, while generally well intended, often do not include evaluation elements, which limits opportunities for learning, which in turn cripples the value of experimentation, and hampers the ability to apply successful programs to other jurisdictions.

Operationalization of Entrepreneurial Experimentation

Given the preceding discussion, a wide range of possible ways to operationalize arises for entrepreneurial experimentations. These could include the presence of strong PEV champions in the state, the existence of working groups recognized by government, dedicated to the advancement of PEV, the development of a state and/or city action plans or similar document, the number of entrepreneurs in the PEV space, the number of PEV-related RD&D programs, the number of PEV-related pilot programs, the number of PEV-related startup companies, the development and adoption of metrics, the participation of dealerships, patent filings, scientific research related to PEV, measured for example as the number of peer-reviewed publications, the number of PEV dedicated models in the market by OEM, the number of PEV models offered in the state, among others. Given the time constraints on our informational meetings, we synthesized these into the following smaller set of areas to help with the identification of entrepreneurial experimentation in a given state:

- Presence of companies in the state that supply parts, services or technology for the production of plug-in vehicles or plug-in vehicle charging infrastructure (e.g. battery production inputs, energy management software, etc.)
- The presence of exceptional PEV champions in the state
- Innovative ideas proposed and tested in the state with the goal of supporting PEV markets. These could be ideas of any sort, including technology demonstrations/pilots, policy, education & outreach, or other.
- The presence in the state of companies (including startups) or organizations that are developing or testing new technologies or services intended to support the use of plug-in vehicles.

Development of Positive Externalities

Innovation processes and policy are generally thought of as taking place within the realm of a firm or an industry. An appropriate definition of the boundaries of the innovation system is important to attain an understanding of the processes occurring (or that could occur) at different scales. The decision of where to place the boundaries of the system for any given study will depend on aspects of the study and the preferences of the analyst. The choice of boundaries should nonetheless be consistent with the objectives of the study as it enables (preclude) the analyst to (from) study (studying) innovation processes at the desired scale. Narrowly defined systems simplify the study and may be the right choice in some cases. Expanding the system however may unveil important interactions between different socio-technical systems and subsystems that can help strengthen or weaken the prospects of growth for the new technology.

To help clarify what we mean by all this, imagine expanding our system to include a more established techno-economic system, such as that of wind energy. If there were subsystems within the wind energy system that benefited from the growth of the plug-in vehicle technology system, these would represent positive externalities that would in turn benefit the PEV technology system. For example, PEVs could reduce the cost of grid integration for wind energy through increased reliability by making use of idle battery storage capacity in PEVs. Similarly, negative externalities could result if PEV innovation were contrary to the interests of established socio-technical systems. This could result in the affected systems dedicating resources to counter the threat posed by the PEV technology system.

Positive or negative externalities can take different forms, including economic, symbolic, technological, policy or other. For this reason, we believe that the use of the term externality to conceptualize these processes is confusing, as it is commonly used in the economic literature to describe processes that can be similar but are not necessarily identical to the ones in which TIS scholars are interested.

Externality dynamics become particularly important as we recognize the finiteness of public sector resources. There is a long history of emerging energy technologies in the transportation sector that have been affected by negative externalities. Alternative fuel stakeholders, such as technology developers and producers, have often been pitted against each other, competing for the attention of public sector funding for research, development, demonstration and deployment. Specifically in the realm of vehicle electrification, there are ongoing struggles between proponents of hybrid electric vehicles, plug-in electric vehicles and hydrogen fuel cell vehicles. These are predominantly rhetorical competitions for the legitimization of a particular vehicle fuel platform in the eyes of the public and government; often at the expense of competing platforms. From a technology perspective, advances in each of these electric drive platforms have produced spillovers (positive externalities), including technology development and maturation, production learning and economies of scale. Many of the involved technologies are developed within the firm and generally remain proprietary; this includes, for example, energy and power management systems as well as electrochemical storage technologies and production know how.

There are also geographic areas where externalities occur. For instance, external firms supply certain inputs for the production of lithium-ion batteries. Cobalt electrodes, for example, are the single most expensive component of lithium-ion batteries and are supplied by a small number of producers, predominantly in South Korea. As production of lithium-ion batteries increases, so does demand for these electrodes, enabling higher production, with the consequent gains in economies of scale. In this sense, the market growth of plug-in vehicles, which is entirely based on lithium-ion technology, likely produced positive externalities to hybrid electric vehicle producers as they shifted from nickel metal hydride (NiMH) to lithium-ion when the production cost of the latter came down.