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Evolution of Plug-In Electric Vehicle Demand: Assessing Consumer Perceptions and Intent to Purchase over Time

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Abstract

The diffusion of plug-in electric vehicles (PEV) is a topic that has received substantial attention in recent years. In part, this heightened interest reflects rapid concurrent developments in policy, technology, and industry strategies designed to spur the uptake of this radical, emerging technology. Governments from all levels are enacting various monetary and non-monetary incentives to encourage PEV adoption; developments in battery technology are likening the performance of PEVs to conventional vehicles; and all major vehicle manufacturers now have a PEV offering. Ultimately, however, the effect of these developments is contingent upon consumer interest. Thus, in this paper we study whether, alongside technology and market developments, consumer interest in PEVs has changed over time. To answer this question, we evaluate the degree to which intent to purchase or lease a battery electric vehicle and plug-in hybrid electric vehicle, respectively, has changed between 2011 and 2017, and how the factors that explain variation in such intent have also changed over time. Our data come from two national surveys of potential car buyers in the 21 largest American cities. Among the key findings that we derive from the analysis are that, among survey respondents, intent to purchase a PEV has increased between 2011 and 2017, and perceptions about the the trialability, observability, network effects, and policies explain an increasing share of the variation in intent to purchase as time evolves.

Keywords: plug-in electric vehicle, consumer, intent to purchase, technology diffusion

Classification codes: O33, R41, L91, Q42

1. Introduction

Plug-in electric vehicles (PEV), if deployed widely, offer the opportunity to reduce greenhouse gas emissions and other forms of air pollution in both the transport sector and overall (Nordelöf et al., 2014; Hawkins et al., 2013; Woo et al., 2017). Although this emerging technology holds potential societal promise, one should not expect rapid deployment. The PEV must compete with a well-established technology, the internal combustion engine (ICE), that is firmly established from decades of “lock-in” (Unruh 2000). Not only does the ICE traditionally benefit from consumer, producer, and public policy use and support, it also is marked by significant economies of scale and positive network externalities. Additionally, adopting a PEV requires its owner to make behavioral adjustments, ranging from as minor of adjustments as plugging in the vehicle at home at night or at work during the day, to as major as rerouting road trips to correspond with charging stations or subscribing to a car-share program to have a back-up vehicle for longer distance travel (Rezvani et al., 2015).

This emerging radical technology is similar in many regards to other technologies that have come before it, such as the compact fluorescent lamp (Menanteau & Lefebvre, 2000), residential solar energy, or passenger jet aircraft. All seek to serve the same purpose as an established, competing technology, but to do so through different means that require substantial new producer investments and consumer acceptance. Even when such technologies offer potential improvements in societal welfare or environmental performance, such advantages may go unappreciated in the market, and adoption may be slow (Menanteau & Lefebvre, 2000; Bohnsack et al., 2014) if not stall out and meet the so-called “valley of death”.

Early evidence suggests, however, that the PEV has at least some market potential. Several trends support this assertion. First, since the first modern PEVs were introduced to the

U.S. automobile market in 2010 with the release of the Chevy Volt and the Nissan Leaf, all major vehicle manufacturers have released at least one PEV option. Figure 1 presents a timeline of all PEV releases to U.S. markets. Battery electric vehicles (BEVs), which run exclusively on a battery, are on the top of the timeline. Plug-in hybrid electric (PHEV), which have a dual battery and combustion engine configuration, are on the bottom of the timeline. This figure suggests that automobile manufacturers have invested significant resources into developing PEV options. As of 2018, there are 45 separate PEV—30 PHEVs and 15 BEVs—options available in U.S. markets (Auto Alliance 2018). Automobile manufacturers have additionally announced plans to release over 60 PEV options over the next several years.

[Insert Figure 1]

Second, sales of PEVs continue to climb. Figure 2 graphs BEV and PHEV sales from 2011 to 2017. This graph shows that sales have risen steadily over time. Third, although the percentage of market share is still small, the share has increased much faster than hybrid electric vehicles in the first few years of technology availability, which suggests that the PEV may eventually become a market competitor on equal, if not better, footing than the hybrid (Graham et al., 2014).

[Insert Figure 2]

While these trends suggest that PEVs are gaining at least some market traction, they do not reveal any nuance about how consumer perceptions of these vehicles are evolving over time as this technology and its market matures. Such insights, however, can be especially important because it is ultimately developments in consumer interest that will determine the fate of PEVs in the automobile marketplace. Thus, in the present analysis, we ask how has consumer interest in PEVs changed over time?

We answer this question with a unique longitudinal survey dataset of the car consumer population in the 21 largest American cities. We evaluate the degree to which intent to purchase or lease a BEV or PHEV, respectively, has changed between 2011 and 2017, and how the factors that influence such intent have also changed over time. We draw hypotheses from both the technology diffusion and the applied electric vehicle literature, but also root our analysis in real-world PEV market conditions. Our results show that intent to purchase or lease a PEV continues to rise, and that consumers are increasingly influenced by perceptions of 1) PEV compatibility and relative advantage, 2) the trialability of the technology, 3) observability and social influence, 4) charging station availability, and 5) public policies.

We believe this analysis provides three distinct contributions. First, as Rogers (2003) pointed out, the innovation and technology diffusion literature tends to perpetuate a pro-innovation bias, in which only successful innovation cases are analyzed, and generally after they have already proven successful. Rogers argues that one way to overcome this bias is for scholars to study innovations at multiple points in time, as we do here (for earlier, informative PEV articles that also incorporated a time dimension, see Jensen et al., 2013; Jensen et al., 2014; and Gould & Golob, 1998). Second, and relatedly, the extant literature on electric vehicles, particularly that which employs consumer surveys, tends to focus predominantly on early adopter characteristics and proclivities, and to use cross-sectional samples. Thus, there is presently available a rich body of literature on consumer characteristics that correlate with intent to adopt (see, e.g., Coffman et al., 2017 for a review of this literature up through 2017), which inform the present study. What is largely absent from this literature is an analysis that considers how the PEV market is maturing over time, and how consumer perceptions evolve simultaneously. Tran et al., (2012) previously published a review article that studied the intersection between behavior and technology maturity from an integrated perspective to evaluate PEV diffusion. We build on these findings with an empirical assessment using longitudinal data, and with an evaluation of both consumer and market trends over time, beginning in a year in which PEVs were first introduced and still in their infancy, and ending six years later, after PEVs have been made available by most automobile manufacturers. Finally, this article has practical importance as well. As automobile manufacturers continue to invest in new PEV models—and seek to overcome the functional drawbacks of PEV ownership with new designs and business models, and also meet state mandates that compel the production of zero-emissions vehicles—it will be necessary to continue to monitor consumer perceptions of PEVs.

2. Technology Diffusion

The PEV is an emerging technology, which serves the same purpose as a pre-existing, competitive good or service, in this case the ICE, but through an entirely different process or principle (Rotolo et al., 2015).[1] Thus, our expectations for PEV diffusion, and the role of consumer perceptions along its diffusion path, is informed by both the applied electric vehicle literature as well as the technology diffusion literature that explores the process through which emerging technologies gain market acceptance.

[1] Arguably, the PEV is also a radical and sustainable innovation that challenges incumbent businesses and their business practices, and may require some new business strategies entirely (Bohnsack et al., 2014).

At the most general level, this latter literature suggests that emerging technologies will enter a consumer market slowly and, assuming the technology is of interest to consumers, eventually experience an accelerated rate of adoption. This acceleration happens as the consumer population moves from niche and early adopter consumer segments to more mainstream segments. Even before moving to the mainstream population, however, one should expect some acceleration in the speed of adoption due to producers improving the technology and more consumers becoming familiar and comfortable with it (Hall & Khan, 2003). Based on these broad insights from the literature and simple observation of publicly available data, we can easily conclude that consumer interest in PEVs has increased over time. The really interesting question, however, and the one that we are primarily concerned with in this study is exactly which factors have led to such an increase?

The larger literature on technology diffusion can help us to develop specific hypotheses about the factors that influence consumers to adopt a novel product (Rogers, 2003). We will discuss each of these individual in the context of PEV and PHEV below but, generally speaking, that work suggests that compatibility, or the degree to which a new item is perceived to comport, with the values or habits of a consumer (Lee, 2004), and relative advantage, or the perceived benefits of a novel product relative to the status quo (Agarwal and Prasad, 1998), are key drivers of adoption. Governments can play an important role signaling the acceptability of new products by encouraging adoption of them through public policy, or by directly influencing the relative benefits through incentives for the commodity itself or complementary goods. Also related to these perceptions, as well as having a direct influence on adoption decisions, are observability, or ability of a consumer to see others' experience with a new product (Kolodinsky et al., 2004) and trialability, or the ability to experiment with a new product firsthand (see, e.g., Lee and Lee, 2003). Finally, the literature on technology diffusion, as well as related bodies of literature, suggests that marketing and social networks influence perceptions of new products, and ultimately influence the willingness of individual consumers to adopt them.

2.1. Adoption Barriers, Relative Advantage, and Compatibility

For an innovation to be viable in the marketplace, it must appeal to a consumer such that the perceived benefits of using the innovation are enough to compensate for or justify the perceived disadvantages of using it. Both the costs and benefits are, at least to some degree, uncertain, and must be weighed as the consumer decides whether to take the risk of adopting the technology (Hall & Khan, 2003; Adner 2002). For instance, if an individual is especially concerned about the range of a PEV—either due to actual range limitations such as long daily commutes or just perceived limitations—there may be no benefit to a PEV that could override his or her concern about driving range. Over time, however, manufacturers may work to mitigate these concerns by expanding the range that PEVs can drive on a single charge. This consumer may also learn more over time about the driving range of a PEV, and come to decide that this disadvantage is not as severe for his or her personal lifestyle as previously thought. At this point, the consumer's potential interest in buying a PEV may increase.

When PEVs were introduced to consumer markets in 2010, their various barriers—perceived and real—were readily apparent. One of the primary drawbacks is the driving range of a PEV battery on a single charge (see e.g., Egbue & Long, 2012; Carley et al., 2013; Coffman et al., 2017 for discussion of range perceptions). Other primary adoption barriers include the price of the vehicle (Dumortier et al., 2015), the time that it takes to charge the battery (Hardman et al., 2018), the placement of chargers (Coffman et al., 2017; Hardman et al., 2018; Egbue &

Long, 2012), and the features that a PEV contains—or, rather, does not contain—relative to one's ideal vehicle attributes. One study recently pointed out that consumers are generally not willing to sacrifice specific vehicle features that matter to them (Tran et al., 2012). Since PEVs are not commonly offered in sports utility vehicle (SUV) or cross-over models—exceptions include the Tesla Model X, the Kia Niro, and the Jaguar I-PACE—and tend to be lighter so as to accommodate a heavy battery, one example of an attribute that PEV consumers must forego is cargo capacity and overall vehicle size.

Over time, automobile manufactures, as well as other PEV stakeholders, have worked to reduce these adoption barriers. Although the diffusion of an innovation is ultimately an issue of whether consumers adopt it based on their perceptions and interests, producers affect the benefits and costs of an innovation (Hall & Khan, 2003). Producers work to reduce barriers with new business models and practices that improve the economic and other appeal of the technology.

Examples of incentives offered by both incumbent and entrepreneurial firms to facilitate PEV adoption and usage that have been introduced since 2010 include car sharing memberships for PEV owners, free rental car availability, and battery swapping programs (Bohnsack et al., 2014); declining purchase price of vehicle (Coffman et al., 2017); and expanded placement of charging stations (Egbue & Long, 2012). Even more specific examples include Porsche PEV owners' access to its own proprietary fast chargers around the country; and Nissan's efforts to give dealers specialized training on how to address consumer hesitancy about PEVs as well as how to service them appropriately. Examples of a technology related option offered by an incumbent firm to encourage PEV adoption is BMWs offering of a small gasoline engine in its PEVs, which serves as a range extender. Similarly, Chevrolet offers its own version of an extended range BEV, the Chevy Bolt. Entrepreneurial companies like Tesla have also led the industry toward extended range BEVs, with high performance and fast acceleration luxury vehicle offerings (Bohnsack et al., 2014). Despite these efforts, and many more, PEVs still have functional drawbacks, either perceived or real. For example, most PEV models still cost a premium over comparable ICE models and most batteries still cannot compete with an ICE on range (Krupa et al., 2014).

On the consumer side, adoption decisions are not based solely on the actual, functional drawbacks of PEVs, but also, if not more so, on the perceptions they have about the functional drawbacks, the technology's compatibility with their lifestyles and behaviors, and their own personal assessments of the trade-offs between the benefits and barriers of the technology (Adner, 2002; Jensen et al., 2013; Jensen et al., 2014). Consider again the range of a PEV as an example. The actual range of a PEV may be less important to the consumer than his/her perceptions and concerns about the PEV's range. In fact, others have pointed out that one of the main reasons for range anxiety is due to a mismatch between facts and perceptions about the PEV range (Li et al., 2017b; Jensen et al., 2013; Krause et al., 2013).

However, one should expect these perceptions about PEV barriers to decline, as the actual functionality of the technology improves, but also as consumers are exposed through social, industry, and policy related channels to more information about the technology and how it works. A growing sense of compatibility is important as well, where compatibility is the degree to which the technology is perceived as appropriately matched with an individual's habits, behaviors, experiences, and needs (Rogers 2003). As comfortability and familiarity with a technology rises, consumers should be more likely to adopt it (Hall & Khan, 2003). Similarly, as the relative advantage of a technology—a ratio of expected benefits and costs of adoption

(Rogers 2003)—increases for an individual, his or her interest in technology adoption will likely rise as well. These insights are reflected in hypothesis H1.

H1: Over time, the perceived adoption barriers to PEVs should decline in salience and perceptions about the relative advantage and compatibility of PEVs should increase. Additionally, we expect that, as relative advantage becomes more cemented in the minds of consumers, this factor should become an increasingly important factor in shaping one's interest in PEV purchases.

2.2. Trialability

Trialability is the degree to which one can gain experiences and try out an innovation (Rogers, 2003). Although Rogers' (2003) notion of trialability is based on a limited basis timeframe, one could expand this notion to include any previous experience with the innovation, either short-term or long-term. Avenues through which trialability of a PEV can occur include: previous ownership or lease of a PEV or a similar vehicle such as a hybrid; PEV car rentals; borrowing a friend's PEV; driving a PEV fleet vehicle; and test driving experiences at community events, conventions, or other social gatherings.

Experiencing an innovation first-hand has the potential to lead to greater acceptance of it, as an individual learns more about how it works, whether perceived drawbacks and benefits are real, and how to incorporate it into his/her lifestyle. Previous studies have confirmed the importance of trialability of PEVs, either through an improvement in stated preferences for the vehicle or actual purchase decisions (Jensen et al., 2013; Jensen et al., 2014; Burgess et al., 2013;

Li et al., 2017b; Carley et al., 2013; Egbue & Long, 2012; Jensen et al., 2013; Peters & Dütschke, 2014; Rezvani et al., 2015; Bunce et al., 2014).

Given that few PEV models were available in 2011, the first year of our study period, and the number of PEVs on the road were also limited, the opportunity for trialability was likely small in that year. Over time, however, the opportunity for trialability has increased. Also, as producers have improved their PEV offerings and worked to diminish PEV drawbacks, one should also expect personal experiences to carry greater weight in one's acceptance of a new technology. We therefore hypothesize that:

H2: Prior PEV experience will grow in importance in shaping preferences toward PEVs over time.

2.3. Observability, Social Interactions, and Communication Channels.

In the present analysis, we combine the notion of observability and communication channels to collectively represent social and external influence. Observability refers to the degree to which others' experiences with an innovation are visible or relayed in some other way. Communication channels include both social interactions and interpersonal influence from neighbors, friends, family, and other peers (Axsen & Kurani, 2011; Coffman et al., 2017) as well as mass media (Rogers 2003). According to Rogers (2003), greater amounts of observability should increase interest in a technology. For example, friends may share reflections with each other about their PEV experiences; a colleague may transport an individual to a meeting in his/her PEV; or a neighbor may drive a PEV and neighbors can observe it on the street. All of these forms of social interaction and observability may make an individual more inclined to consider a PEV in a future car purchase.

Previous PEV studies confirm the importance of these social interactions and observability opportunities in influencing interest in PEVs (Axsen et al., 2013; Axsen & Kurani, 2011; Coffman et al., 2017). Research on other energy innovations, such as residential photovoltaic panels, also underscore the importance of peer effects and observability on innovation adoption (Bollinger & Gillingham, 2012; Graziano & Gillingham, 2014; Rai et al., 2016).

There may be temporal dimensions to observability as well. Rogers (2003) argues that one should expect mass media to play a larger role in the early stages of knowledge generation about a technology, although it could persist through later stages as well, when an individual forms perceptions about the attributes of an innovation (Rogers 2003). Inter-personal interactions are likely more persuasive in the latter stage, after one already knows about an innovation but is still forming impressions about its attributes and functionality (Rogers 2003). For the present analysis, we simply hypothesize H3.

H3: The importance of observability will grow over time.

2.4. Network Effects and Charging Stations

Especially in the case of a radical technology, the value of an innovation to one consumer should increase with the number of users within the network (Hall & Khan, 2003). PEVs are especially assisted by indirect network effects, which is where the consumer experiences increased utility not necessarily from the expanded network itself, but from the wider availability of a complementary good (Hall & Khan, 2003) such as charging stations.

Previous literature has already revealed that charging stations are one of the most important factors in PEV development and deployment (Tran et al., 2012; Hardman et al., 2018; Li et al., 2017a; Hall & Lutsey, 2017; Zambrano-Gutierrez et al., 2018; Sierzchula et al., 2014), on equal footing, if not more important, than PEV purchase incentives and other factors. For the consumer, what should matter is availability, or at the least perceived availability, of chargers within one's community and along travel routes. We therefore hypothesize H4.

H4: Perceptions of charging station availability have increased over time and such perceptions are important predictors of intent to purchase.

2.5. PEV Policies

Governments play an important role in incentivizing new innovations generally, and more specifically in helping to improve PEVs' perceived relative advantage, encouraging network effects through infrastructure development (Hall & Khan, 2003), and sponsoring a technology through direct government purchases or niche markets (Menanteau & Lefebvre, 2000). Although the literature is not entirely conclusive about the importance of policy in PEV adoption (Coffman et al., 2017), much of the empirical evidence confirms the efficacy of state incentives for PEV purchases (Wee et al., 2018; Li et al., 2017a; Zambrano-Gutierrez et al., 2018; Krupa et al., 2014; Hardman et al., 2017), national and regional incentives in Norway (Mersky et al., 2016), and HOV lane access (Sheldon & DeShazo, 2016), among other policy incentives. Some find policies to be important drivers of PEV diffusion on their own, but especially important when combined with charging infrastructure availability (Li et al., 2017a; Zambrano-Gutierrez et al., 2018). While the majority of previous studies reaffirm the importance of PEV support policies, it is not clear how important policy is to PEV diffusion vis-à-vis other factors, nor whether the importance of policy changes over time as a technology matures. We thus posit a more limited hypothesis regarding the role of policies in PEV diffusion.

H5: Policy incentives will play a role in PEV interest.

3. Research Design

This analysis is based on longitudinal survey data that were gathered at two points in time. The first survey was conducted in the fall of 2011, in the early years of PEV availability. The survey was administered to a sample of 2,302 individuals residing in the 21 largest American cities, with between 99 and 120 respondents per city. The second survey was administered in the fall of 2017, to a sample of 2,119 individuals in the same 21 cities, with between 103 and 120 respondents per city. The 2011 and 2017 respondent samples had minor overlap; a total of 250 respondents took the survey in both years. In the supporting information, we confirm that this overlap in sample did not introduce testing bias into our results.

GfK (formerly Knowledge Networks in 2011) administered the survey online to a random and representative sample of individuals that were 18 or older and had a valid driver's license. GfK recruits participants into their KnowledgePanel, which is a probability-based web panel that is constructed through random digit dialing and address-based sampling. KnowledgePanel participants receive monthly compensation for their participation in GfK surveys. The KnowledgePanel is thus both based on random sampling and can be used to pull representative samples.

The 2011 and 2017 survey instruments were very similar. All questions used to generate variables in the present analysis were identical, with the exception of three new questions that we added to the 2017 survey instrument to capture interpersonal communication channels, as discussed more below. The 2011 instrument also contained some additional questions, but we use none of them in the present analysis.

To begin to answer our hypotheses, we first present a series of descriptive statistics. We then estimate an ordinary least squares regression for both the 2011 and the 2017 samples, and for both the BEV and PHEV, respectively, since we are interested in the results for each of these time cuts and types of PEV.[2] We cluster the standard errors at the city level in the regressions and apply demographic post-stratifications weights that are unique to each sample period. Weights were produced by GfK using a proportional fitting procedure so that all screened respondents from each city are weighted to reflect their city-specific demographics, with trimming of outliers at the extreme upper and lower ends of the weight distribution. Weights were also produced so that all screened respondents from all cities combined are weighted to reflect the demographics of the combined cities.

Following the regression results, we also present R-squared decomposition estimates with bootstrapped confidence intervals based on 2,000 repetitions. R-squared decomposition is a measure of the share of explained variance that each user-specified group of variables generates, based on Shapley and Owen values (Huettner & Sunder, 2012). These values estimate the marginal contribution to the main R-squared from adding any single variable (Shapley value) or

[2] A Wooldridge test and visual analysis of the distribution confirm that the data are normally distributed.

group of variables (Owen value) to the model, weighted by the number of regression permutations that can be calculated using the set of independent variables or specified groups of variables (see Huettner & Sunder, 2012, for a full derivation of the Shapley and Owen values). By comparing R-squared decomposition values for different groups of variables between 2011 and 2017, we can observe whether different explanatory factors have gained or lost importance in explaining the variation in intent to purchase or lease.[3]

3.1. Variables

The dependent variable is a respondent's stated intent to purchase or lease (hereafter referred to as "intent to purchase") a BEV and PHEV, respectively. We asked respondents to think about their next vehicle purchase or lease, and then indicate how likely they are to purchase/lease each type of PEV on a scale from 1 (not at all likely) to 10 (very likely). The resulting measure is a discrete variable.

It is important to note that this measure, stated intent, is not the same thing as actual purchase behavior. While the latter is obviously a better measure (Coffman et al., 2017), one can still gain valuable insights from a perceptual study of intent about consumer reactions to and acceptance of a commodity. Nonetheless, we encourage caution in the interpretation of results, and discourage readers from inferring strong behavioral implications.

We are especially interested in the influence of perceptions about relative advantage, trialability, observability, network effects, and policies on PEV intent to purchase. To measure

[3] This is different than a change in the impact of any independent variable on the predicted value of the dependent variable between time points, which would be tested using individual interaction terms between those independent variables and year fixed effects. Because we are interested in any changes in the degree to which variables and groups of variables contribute to the explanatory power of our intent to purchase model, the regression decomposition approach is the most appropriate.

relative advantage, we used the following formula, which is an average of all benefit perceptions divided by all barrier perceptions:

$$\frac{1}{n}\sum_{i=1}^{n} BN_i \Big/ \frac{1}{n}\sum_{i=1}^{n} BR_i, \tag{1}$$

where *BN* represents all benefit variables and *BR* represents all barrier variables. Benefit and barrier variables are all presented in the descriptive statistics table (Table 1) below, and account for possible range, charge time, price, and vehicle feature limitations; and environmental concern, environmental imaging, gasoline savings, and innovation benefits. These barriers and benefits were presented in random order in the survey instrument, following the prompt: "There are also several possible benefits to [concerns about] plug-in electric vehicles. Considering **your personal** lifestyle, preferences, needs, and abilities, please tell me how large a benefit [barrier] each of the following would be to your decision whether or not to purchase or lease a plug-in electric vehicle." Likert scale response options ranged from 1 (not a benefit or barrier) to 4 (major benefit or barrier). The primary regression model uses this relative advantage variable. We also include a second model, however, in which we include each of the eight benefits and barriers separately as dichotomous variables.

To represent trialability, we include a measure of whether the respondent currently owns or leases a PEV.[4] For observability, we include a variable that is equal to one if the respondent has seen television or other kind of advertisements about the PEV. As noted above, we included a set of variables in the 2017 on peer effects that we did not include in the 2011 survey. The

[4] It is a limitation of this analysis that we do not consider whether a respondent owns a different type of alternative-fueled vehicle, such as a hybrid or a fuel cell vehicle. A second limitation is the lack of inclusion of an alternative measure of experience based on non-ownership trialability. For example, respondents may have test driven a PEV, which our measure would not capture.

survey question first asks whether the respondent knows anyone personally that owns or leases a PEV. If the respondent replies "yes" he or she is then asked whether the personal connection is with a neighbor, relative, or friend. We use these questions to generate three additional dichotomous variables that are exclusive to the 2017 sample but, we believe, still worthy of inclusion in this study given that these variables are three potentially important avenues through which one could experience peer effects. These variables equal one if the respondent shares one of these personal connections with a PEV owner or leaser, and zero otherwise. For network effects, we use a measure of whether a respondent has seen charging stations in his or her community in the last three months.

We include a set of state- and city-level policy variables, respectively, as gathered from publicly available datasets. The state-level policies include: 1) the dollar amount that a state offers in rebates for the purchase of a PEV; 2) whether a state offers access to high occupancy vehicle (HOV) lanes for PEVs, regardless of the number of passengers in the vehicle; 3) whether the state has adopted a zero emissions vehicle (ZEV) mandate[5]; and 4) state efforts to increase public charging stations by reducing administrative burden of installations or requiring charging stations at interstate highway rest areas or elsewhere. The city-level policies include: whether the city or a major utility within the city offers PEV purchase incentives; and whether the city or a major utility within the city offers electric vehicle supply equipment incentives. State-level data were sourced from a dataset provided in Zambrano-Gutierrez et al., (2018), which were

[5] ZEV states abide by a mandate that, by 2025, 15.4 percent of all vehicles distributed for sale by a manufacturer per year must be zero emitting, which functionally includes BEVs and fuel cell vehicles. PHEVs count for partial ZEV credit. The ZEV mandate was first adopted by California and nine other states have since adopted the program wholesale, using authority granted in the Clean Air Act. Despite this mandate, no study to date has identified a causal connection between the ZEV program and PEV deployment, but this is likely because the ZEV program does not require state-specific ZEV sales until 2021 due to travel provisions (up through 2017) and pooling provisions (up through 2021) (Carley et al., 2017). There is no evidence, however, that states or cities that abide by ZEV are more prepared, on average, to significantly ramp up PEV deployment (Clark-Sutton et al., 2016).

originally extracted from state legislative statutes within LexisNexus State Capital. City-level data were collected and cross-referenced from a variety of sources including the American Council for an Energy-Efficient Economy's (ACEEE) State and Local Policy Database (2017), an ACEEE report (Ribeiro et al., 2015), and an International Council on Clean Transportation report (Lutsey et al., 2015).

Besides the primary variables of interest, we also include several control variables that have been used in consumer adoption or intent to purchase studies in the past (see, e.g., Krupa et al., 2014; Carley et al., 2013; Li et al., 2017b). We include measures of travel and vehicle purchase behavior, views on climate change and the environment[6], and a standard set of demographics (see Coffman et al., 2017 for a review of findings in the literature about demographics). Although less common, we also include a political leaning variable in the set of demographics, since anecdotal evidence suggests that PEVs have become more of a political issue over time.[7]

We present additional robustness checks in the supporting information in which we: 1) include a set of respondent-reported preferred vehicle attributes as additional regressors to account for the possibility that one's vehicles preferences dictate one's support for different types of vehicles; 2) include a variable that measures whether a respondent was already familiar with PEVs before taking our survey, to rule out the possibility that results are exclusively driven by those that are highly familiar with PEVs; and 3) remove those respondents that took the

[6] The literature confirms that those concerned about climate change and are pro-environmentally oriented have greater odds of considering PEV adoption (Krupa et al., 2014), and tend to more frequently engage in environmentally conscious behavior (Li et al., 2017b).
[7] One previous study (Krupa et al., 2014) has found that those that are left of center are more likely to consider purchasing a PHEV than those with other political affiliations.

survey in both 2011 and 2017, so as to eliminate the possibility of testing bias. As we show, these modifications do not substantively change the results.

[Insert Table 1]

4. Results

We begin with an analysis of basic trends in the data over time. Table 2 presents descriptive statistics for all variables in both years, as well as corresponding variable definitions. These data show that intent to purchase has increased for both types of PEVs over time. The average response, although statistically different between time periods ($P<0.0000$ for the BEV and $P<0.0003$ for the PHEV), still remains fairly low by 2017; this variable is measured on a scale from 0 to 10 and the average response is less than 4 for both the BEV and PHEV. Figure 3 reveals that intent to purchase increased for both the BEV and the PHEV across all 21 cities in our study sample, with the exception of PHEV interest in Charlotte, Chicago, and San Francisco. Cities with the greatest interest in BEVs by 2017 include San Francisco, San Diego, and Chicago; PHEVs are relatively popular by 2017 in Los Angeles, San Francisco, and Baltimore.

[Insert Figure 3]

The descriptive statistics also demonstrate that perceptions of the drawbacks to PEVs have all declined over time. The two features that were considered most worrisome in 2011, price and range, both declined in magnitude but remain the most worrisome in 2017. Perceptions of benefits do not all trend together. The perceived benefit of gas savings and demonstrating to others that one cares about the environment both declined in magnitude, while PEVs lessening one's impact on the environment and being on the cutting edge of innovation have both increased in magnitude.

We present regression results across three tables. In Tables 2 and 4, the model includes the relative advantage variable. In Table 3, we replace the relative advantage variable with a vector of ordinal benefit and barrier variables. Table 4 includes additional peer influence variables: whether the respondent knows a neighbor, relative, or friend that owns a PEV. Because these variables were sourced from survey questions that were only included in the 2017 sample, Table 4 only presents 2017 results. In each table, results are presented side-by-side for the BEV and PHEV.

[Insert Tables 2, 3, and 4]

In Table 2, we observe that intent to purchase is strongly associated with the perceived relative advantage of owning a PEV in both 2011 and 2017. For each one unit increase in the ratio of benefits to barriers, one's intent to purchase a BEV increases by 2.2 points in both 2011 and 2017 on a ten-point scale; and intent to purchase a PHEV increases by 1.7 in 2011 and 1.8 in 2017, holding all else constant. Table 3 gives a more nuanced perspective on the importance of specific advantages and barriers. Range anxiety, for example, remains a statistically significant predictor of intent to purchase a BEV in both 2011 and 2017, whereas such concerns appear to influence intent to purchase PHEVs in 2011 but no longer by 2017. These trends are corroborated by findings by Lane et al., (2018) that range concerns are no longer an inhibiter, on average, to PHEV consumption. Concerns about purchase price and PEVs not having attractive vehicle features, respectively, pertain to both BEVs and PHEVs, and are persistent over both time periods. The time that it takes to recharge one's battery is statistically associated with intent to purchase for both the BEV and the PHEV in 2011, but loses statistical significance by 2017, which suggests that potential PEV consumers are less concerned about recharge time in recent years.

The benefit of PEVs being at the cutting edge of innovation is an important factor in one's intent to purchase both in 2011 and 2017. While the perceived advantage of PEVs lessening one's impact on the environment was statistically associated with PHEV intent to purchase in 2011, this effect is no longer present by 2017. The perceived benefit of PEVs demonstrating to others that one cares about the environment, on the other hand, is not a predictor of BEV or PHEV intent to purchase in 2011 but is a strong predictor in 2017. Taken together, these last two findings suggest that there is a growing interest in the social implications of PEVs, in which consumers are motivated by the cues that they can give to their social networks about their own values and beliefs, such as their views on the environment. This result is consistent with findings by Lee & Sintov, (2017) that environmental symbolism is one of the most important predictors of PEV adoption intentions.

For trialability, as discussed previously, we use a variable that measures whether an individual already owns a PEV. The results reveal that this factor is statistically significant in 2017 for the PHEV. Those that have already owned a PEV by 2017 are, on average, around 1.2 (Table 2) to 1.4 (Table 3) points higher in their stated intend to purchase a PHEV. Although, in Table 5, the effect of owning a PEV disappears when we control for a more complete set of observability factors.

Observability through advertisements predicts intent to purchase a BEV in 2011 and a PHEV across both time periods. In Table 5, we include three other measures of observability and find that peer influence from neighbors and relatives that own PEVs also drives intent to purchase in both periods, holding all else constant. Specifically, we find that having a neighbor who owns a PEV increases intent to purchase in both time periods, increasing intent to purchase by more than 0.9 in 2017. Having a relative who owns one of these vehicles was not a significant predictor of expressed intent in 2011, but is significantly correlated with the dependent variable in 2017. Finally, the results suggest that having a friend with a PEV significantly increases intent to purchase in both periods, though the substantive impact appears to be relatively small.

Network effects have no statistical correlation with intent to purchase a PEV in 2011 but a strong correlation—statistically significant at the 1 percent significance threshold—in 2017. Not only has the availability of charging infrastructure grown between the early roll-out of PEVs to present (Levinson & West, 2018), but this result reveals that so too has the connection between observation of charging stations and intent to purchase.

The relationship between PEV policies and intent to purchase is more complicated. The availability of state-level BEV rebates is an important factor in one's intent to purchase. Those that reside in ZEV states, controlling for all other PEV policies and other factors, are less likely to want to purchase or lease a BEV in 2017. This result may seem counter-intuitive, yet one may recall that ZEV mandates do not actually force consumers to purchase PEVs. A ZEV mandate is imposed on the producer and, through 2017, was not yet geographically-binding. The negative association, however, remains unexplained.

Control variables yield results that are consistent with expectations. The number of cars that one owns is positively associated with intent to purchase a PEV, which reaffirms a study from Norway that found that consumers typically do not own only a PEV but, rather, they tend to own several different vehicles, each of which serves different travel purposes (Holtsmark & Skonhoft, 2014). In the case number of miles and the BEV, the negative relationship that is present in 2011, albeit at just a 10 percent statistical significance, disappears by 2017. Demographics are important predictors of intent to purchase and there is variation in demographic importance across the two types of PEV models, as others have found previously (Lane et al., 2018).

These collective results provide insights on what influences PEV intent to purchase in each time period, but provides limited detail on how these relationships evolve over time. In our discussion thus far, we have commented on changes in statistical significance, which provides some clues, but we can assess changes over time more deeply with an evaluation of R-squared values. Here again it is important to note that we are primarily interested in the degree to which these various influences contribute to the predicted intent to purchase, at least as we have modeled it, rather than the independent differences in the impact of a unit change in an individual independent variable between time periods.

We begin by observing that, across all models, that the R-squared values rise between 2011 and 2017; in other words, the set of regressors is better at predicting intent to purchase in later years. At the same time that the overall R-squared value increases, we observe changes in the R-squared decomposition values for groups of variables. Table 5 presents these R-squared decomposition values for all groups of variables presented previously in Tables 2, 3, and 4. A higher value means that a grouping of variables explains more of the variation of the dependent variable, and vice versa. In this table, we also calculate the difference in R-squared decomposition value between 2011 and 2017, to determine whether a set of variables became more or less important in its ability to explain predicted variation in intent to purchase over time. Figure 4 visually presents the R-squared decomposition values from Table 2, with the addition of a 90 percent confidence interval, as obtained from bootstrapping with 2,000 repetitions. The table and figure not only reveal interesting trends over time that generally comport with our hypotheses, but also across PEV type.

[Insert Table 5 and Figure 4]

Perceptions about relative advantage of PEVs is the single most important factor in explaining the dependent variable in both 2011 and 2017. Interestingly, although the importance of relative advantage grows in the case of the PHEV, it actually declines in the case of the BEV. Perceptions about the barriers of PEVs decline in their explained variation of the dependent variable over time for both the BEV and the PHEV. Across both PEV types and all three tables of results, the set of PEV-related experiences—which includes trialability, observability, and network effects—increases in importance, especially in the case of the PHEV. Once we add the three peer effects variables in Table 4, the PEV experience variables collectively account for 12 and 23 percent of intent to purchase a BEV and PHEV, respectively. PEV policies account for a small, fairly steady, share of the dependent variables, with a slight increase over time. Among the control variable categories, climate and environmental beliefs generally decline in importance over time; and demographics become more important in the case of BEV intent to purchase and less in the case of the PHEV.

5. Discussion

The diffusion of innovations is not a rapid process, particular when considering a radical technology, or one that must overcome significant entrenchment of a competing technology that benefits from economies of scale, consumer appreciation, and network externalities, among other benefits (Menanteau & Lefebvre, 2000). The diffusion of such technologies is often a gradual process with regular developments assisted by learning in both the production process—to better tailor it to consumer needs—and among consumers as they modify their demands and behavior accordingly. In the present analysis, we consider the diffusion of a radical technology that has significant potential societal benefit: plug-in electric vehicles.

Much of the literature on PEV consumer adoption tends to focus on the early adopters (Coffman et al., 2017; see, e.g., Carley et al., 2013; Tran et al., 2013; Jensen et al., 2013, 2014).[8] What we add to the existing literature, however, is a study of changes as the PEV technology matures, including an evaluation of the factors that influence its increasing acceptance—or not—in mainstream markets. Here, we ask what factors are responsible for driving intent to purchase or lease a PEV, and study differences among these factors at two points in time: in the very early years of modern PEV developments, 2011; and six years later, after all vehicle manufacturers offer PEV models and PEVs are available in most states.[9]

We find that as the perceived relative advantage of an emerging technology increases, so too will intent to purchase that technology. Although respondents are, on average, far less concerned about functional drawbacks of PEVs in 2017 than they were in 2011, concerns about these drawbacks—especially the purchase price, features of a PEV, and range, the latter only in

[8] We are likely still in the early adopter phase of PEV diffusion. The next phase, consisting of what Rogers (2003) terms “early majority” adopters occurs after more than 16 percent of the population has adopted the technology.
[9] Even as recently as 2016, not all states had PEV options available at dealerships. While states such as California had as many as 22 different models of PEV available in 2016, other states such as Mississippi and South Dakota had none (UCS 2016).

the case of the BEV—are still associated with lower intent to purchase responses in 2017. Over time, respondents' perceptions of the relative advantage of a PEV explain a decreasing share of the variation in intent to purchase for the BEV but an increasing share for the PHEV. Trialability, observability through social connections and peer influence, and network effects have all grown in importance for consumer acceptance over time, as measured by the variance of intent to purchase that each regressor, or set of regressors, can explain.

Our results also reveal some differences between consumer impressions of different types of PEVs, which reaffirms findings made by Lane and colleagues (2018). Although actual sales show a fairly equal distribution between BEVs and PHEVs over time, results of our intent to purchase exercise show clearly that PHEVs are in higher demand. Interest in PHEVs appears due to, at least partially, the fact that PHEVs have overcome the functional drawback of range limitations and can therefore be more compatible with consumer lifestyles in the event that someone does not have more than one car. BEVs have improved over time as well, however, through extended range and other battery improvements. Yet, the verdict is still not out on acceptance of new extended range and less expensive BEVs such as the Chevy Bolt and the Tesla Model 3.

One of the most interesting results from our analyses concerns the lack of influence that public policies seem to have on consumers' interest in PEVs, even though the policy variables collectively explain more variation of the dependent variable over time. The literature on technology diffusion has long suggested that government actions help to make people aware and persuade them of the utility of innovations (Rogers 2003). This is assumed to be particularly true when a new product must overcome technological "lock-in," like the one created by the internal combustion engine (Unruh 2002); and studies have shown that public policies do influence PEV registrations at the aggregate level (see, e.g., Zambrano et al., 2018). In our analyses, however, only purchase rebates have a significant and positive impact on intent to purchase and only for the BEV. Other relationships between policies and PEV interest are negative in select years, which is more difficult to explain. Admittedly, our findings regarding the inefficacy of policy incentives may be due to the fact that intent is not a perfect proxy for actual purchasing behavior. It is also possible, however, that incentives provided by government are a less powerful predictor of either, once we are able to control for more proximal factors like the perceived relative advantage of the technology. Nevertheless, practical insights that policymakers can derive from our study is that purchase rebates and educational initiatives that convey the benefits of PEVs can effectively stimulate consumer demand. The latter is also relevant for car manufacturers that can engage in marketing initiatives to relay to potential car buyers the benefits of PEV ownership.

Throughout this article, we have noted several limitations of our research design, such as the use of an intent to purchase measure rather than an actual behavior measure and the use of some relatively incomplete measures to operationalize key concepts, such as trialability. Another limitation to our study in our two-time period approach, rather than a full longitudinal dataset with annual measures.

These limitations notwithstanding, the present analysis makes several contributions to the literature. Most notably, it provides a perspective on how intent to purchase a PEV is evolving over time, and how different factors shape one's intent. This time perspective allows us to test theories of diffusion for a radical technology that is experiencing market maturation in real-time. We detected important changes in consumer perceptions within the first six years of plug-in electric vehicle introduction. As more PEV models are introduced to the market—and as consumers continue to interact with these models as well as engage in discussions about them through social and media networks—scholars will have the opportunity to study how consumer perceptions continue to evolve.

Perhaps more than any other time in history, the vehicle landscape is changing rapidly. Not only are PEVs now regular market offerings, but so too are a variety of other competing technologies, such as fuel cell, natural gas, or biomass fueled vehicles. The effects of such technological progress—of which there are various, competing possibilities—on vehicle markets, as well as consumer PEV interests, are impossible to predict. The way in which vehicles are operated is evolving as well, as new designs feature automation, platooning vehicle operations, wireless charging, and vehicle to grid connections, among other advancements. Such technological developments will likely improve the economics of PEVs, reduce range anxiety, and affect consumer perceptions of the relative advantages of PEVs (Tiaebat et al., 2018).

Our study provides a theoretically informed approach for evaluating factors that shape the adoption of emerging vehicle technologies at different time periods following their introduction into mass markets. Scholars should continue to study consumer perceptions of PEVs as they diffuse—and as these other complementary and substitute markets continue to evolve—and seek to draw deeper insights about radical technological deployment in such a rapidly changing environment.

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Competing Interests

The authors declare no competing interests.

Data and Code Availability

All survey instruments, codebooks, code files, and data files needed to recreate this analysis are available at https://sourceforge.net/projects/electric-vehicle-project/files/.

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Figure 1. BEV (above the axis) and PHEV (below the axis) Model Releases Timeline, 2010-2018

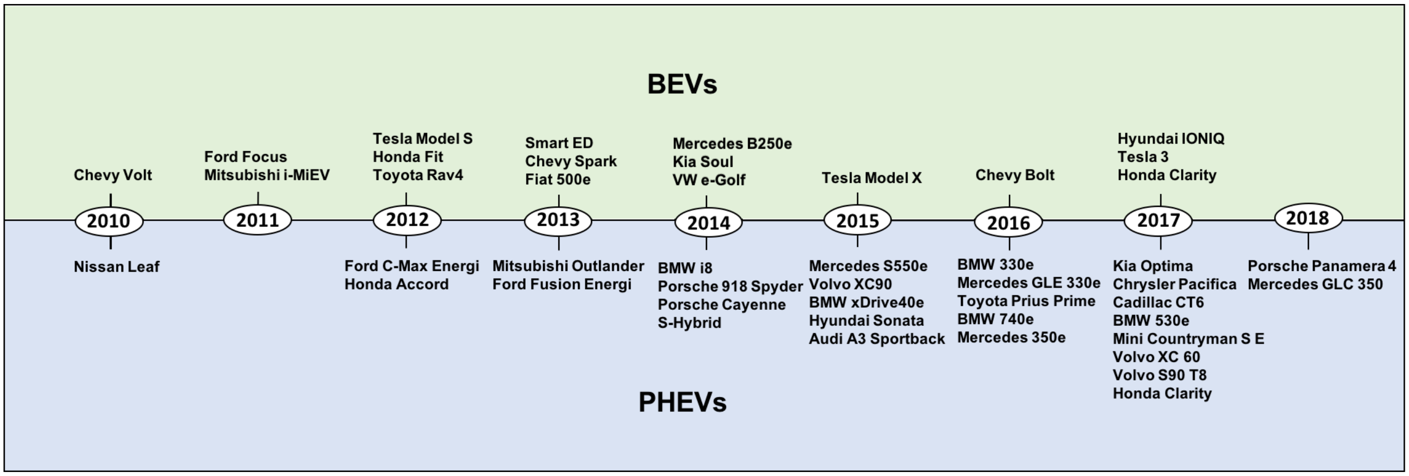
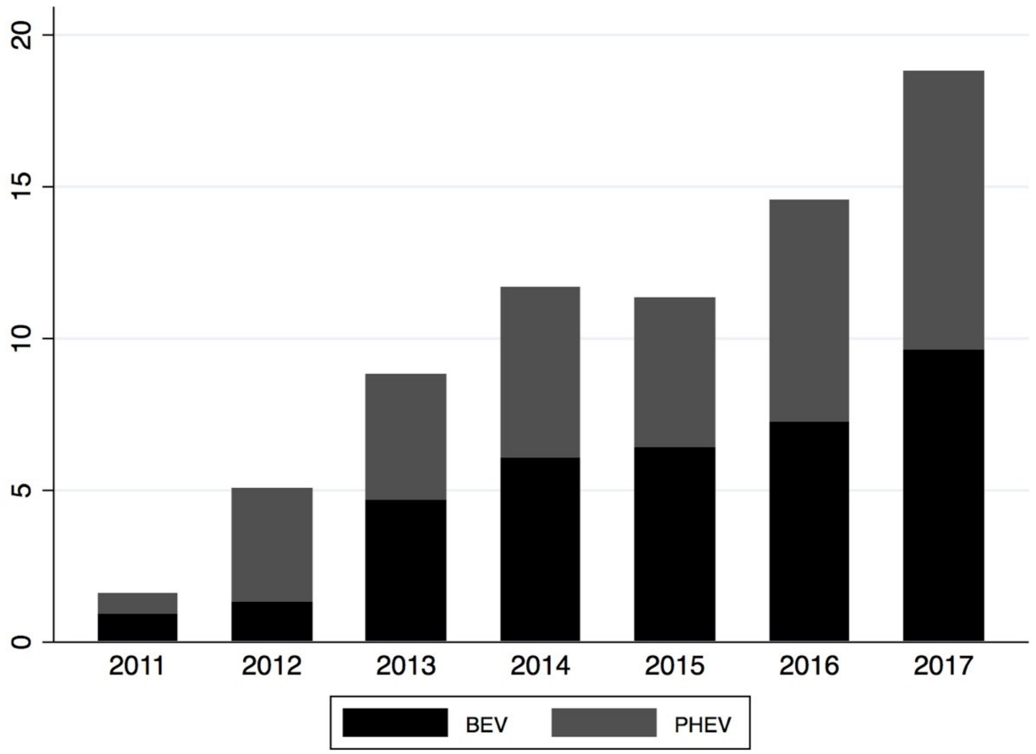


Figure 2. BEV and PHEV sales in counts of 10,000, between 2011-2017



Source of data: (Auto Alliance 2018)

Figure 3. Intent to Purchase or Lease by City, 2011 and 2017

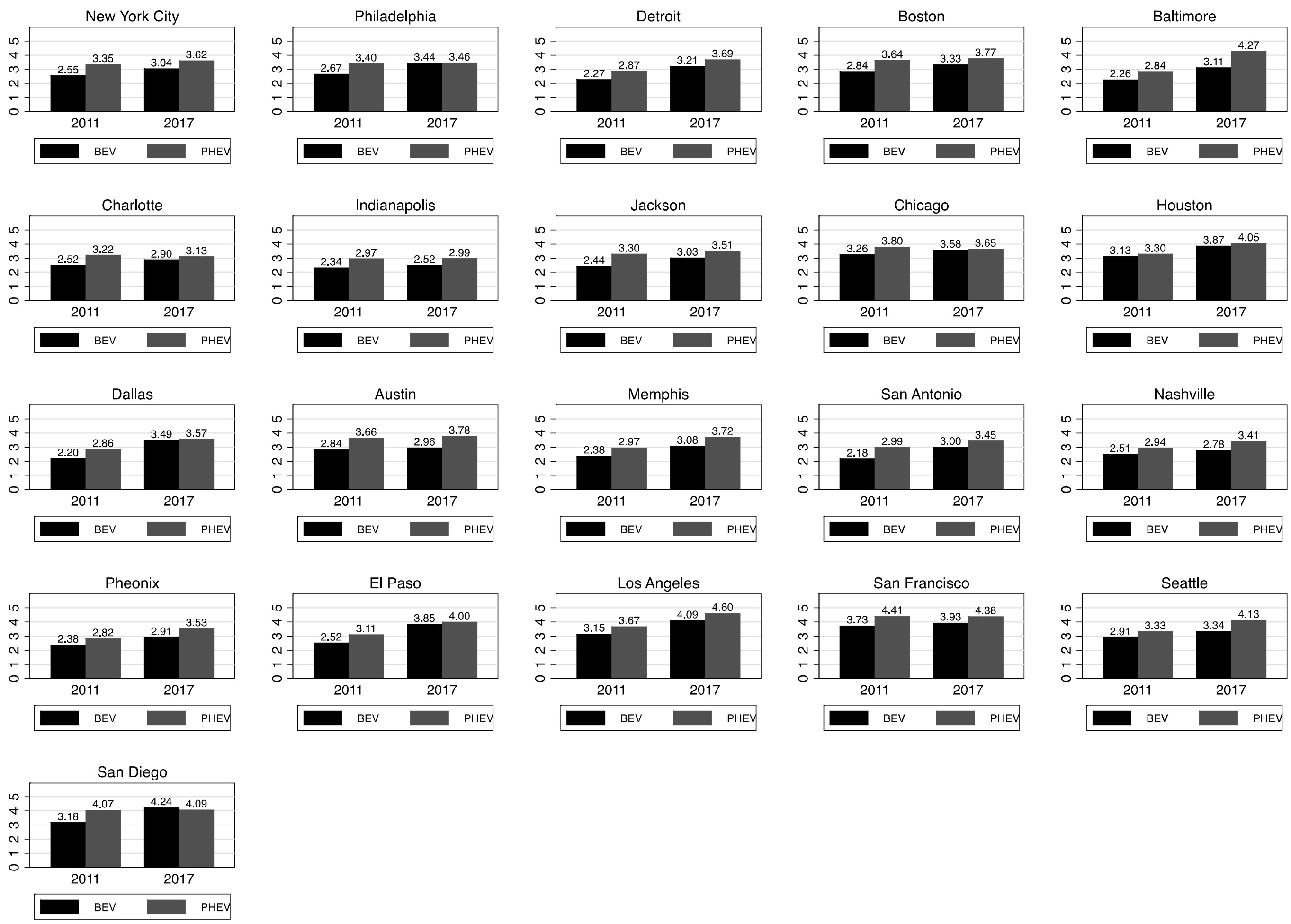


Table 1. Variable Definitions and Descriptive Statistics

Variable	Operational Definition	2011 Mean	2011 Std Error	2017 Mean	2017 Std Error
BEV Intent Purchase/Lease	Intent to purchase or lease a BEV, from 1 (least)-10 (most)	2.79	0.0728	3.43	0.0806
PHEV Intent Purchase/Lease	Intent to purchase or lease a PHEV, from 1 (least)-10 (most)	3.42	0.0788	3.84	0.0787
Barriers and Benefits					
Relative Advantage	Average response to barriers divided by average response to benefits	0.913	0.0131	3.84	0.0787
Range barrier	Response to "The range of a plug-in electric vehicle is too short" on 1-5 Likert scale	3.10	0.0330	0.975	0.0137
Price barrier	Response to "The prices of plug-in electric vehicles are too high to buy or to lease" on 1-5 Likert scale	3.36	0.0285	2.90	0.0299
Recharge time barrier	Response to "It takes too long to recharge a plug-in electric vehicle" on 1-5 Likert scale	2.86	0.0313	3.01	0.0298
PEV features barrier	Response to "Plug-in electric vehicles do not offer the features I want in a car (size, horsepower, speed, etc.)" on 1-5 Likert scale	2.73	0.0351	2.72	0.0301
Saved gasoline money benefit	Response to "A plug-in electric vehicle will save me money on gasoline" on 1-5 Likert scale	3.14	0.0287	2.59	0.0334
Demonstrate care for environment benefit	Response to "Owning a plug-in electric vehicle will demonstrate to others that I care about the environment" on 1-5 Likert scale	2.13	0.0338	2.96	0.0295
Lessen impact on environment benefit	Response to "Changing from a gasoline powered vehicle to a plug-in electric will lessen my impact on the environment" on 1-5 Likert scale	2.65	0.0322	2.00	0.0301
Cutting edge of technology benefit	Response to "Plug-in electric vehicles are at the cutting edge of technological transport innovation" on 1-5 Likert scale	2.20	0.0313	2.70	0.0303
PEV-Related Experiences					
Own PEV	Respondent currently owns or leases a PEV, binary variable	0.00286	0.00123	0.0211	0.00456
Ads	Respondent has seen TV or other advertisements about PEVs, binary variable	0.673	0.0155	0.551	0.0153
See charger	Respondent has seen charging stations in his/her community in the last three months	0.174	0.0185	0.910	0.0285
Neighbor	Respondent has a neighbor with a PEV, binary variable	-	-	0.0511	0.00724
Relative	Respondent has a relative with a PEV, binary variable	-	-	0.0549	0.00678
Friend	Respondent has a friend with a PEV, binary variable	-	-	0.140	0.0106
PEV Policies					
PEV state purchase rebate	Dollar amount that the state offers in rebates for the purchase of a PEV	363.94	19.88	1625.20	44.84
HOV lane access	State offers access to high occupancy vehicle lanes for PEVs, binary variable	0.319	0.00959	0.358	0.00682
ZEV state	State has adopted a zero emission vehicle mandate, binary variable	0.509	0.00963	0.480	0.00714
Public charger state policies	State has efforts to increase public charging stations by reducing administrative burdens or requiring stations at highway rest areas, binary variable	0.0522	0.00366	0.365	0.00697
PEV city-level incentive	A city or major utility in the state offers PEV purchase incentives, binary variable	0.0212	0.00200	0.0898	0.00430
Electric vehicle supply equipment city-level incentive	A city or major utility in the state offers vehicle supply equipment incentives, binary variable	0.263	0.00905	0.224	0.00639

Transport Preferences/Behavior					
Number of cars	Number of cars that respondents' household owns	1.90	0.0320	2.14	0.0369
Number of miles	Approximate number of miles that respondent drives on average day	27.77	0.860	31.59	1.452
Climate/Environmental Views					
Environmental lifestyle	Agreement with the statement that "People need to change their lifestyles to protect the environment" on 1-5 Likert scale	1.94	0.0238	1.98	0.0238
Climate Change is a problem	Agreement with the statement that "Climate change is a serious problem" on 1-5 Likert scale	2.05	0.0277	1.89	0.0275
Demographics					
Age	Age of respondent	46.99	0.533	48.26	0.506
Male	Respondent identifies as male	0.487	0.0163	0.490	0.0155
Education	Ordinal variable measuring highest completed education level of respondent	3.13	0.0435	3.14	0.0423
Income	Ordinal variable measuring approximate household income	2.99	0.0354	2.88	0.0413
Political leaning	Ordinal variable measuring respondents' self-reported political party affiliation from 1 (very conservative) to 7 (very liberal)	4.41	0.0642	4.52	0.0601
Suburban	Respondent lives in suburban setting, binary variable	0.553	0.0162	0.579	0.0153
Rural	Respondent lives in rural setting, binary variable	0.201	0.0117	0.179	0.0105
Additional Variables for Supporting Information					
Familiarity with PEVs	Respondent reports being somewhat or highly familiar with PEVs, binary variable	0.879	0.0115	0.868	0.0109
Size	The size of a vehicle is an important factor that influences vehicle purchase decisions, binary variable	0.204	0.0123	0.230	0.0122
Cost	The cost of a vehicle is an important factor that influences vehicle purchase decisions, binary variable	0.561	0.0162	0.563	0.0154
Appearance	The appearance of a vehicle is an important factor that influences vehicle purchase decisions, binary variable	0.200	0.0141	0.216	0.0141
Fuel Economy	The fuel economy of a vehicle is an important factor that influences vehicle purchase decisions, binary variable	0.580	0.0175	0.493	0.0166

Table 2. Main Model Results, where Dependent Variable is Intent to Purchase or Lease a BEV or PHEV, 2011 and 2017

	Model 1 BEV 2011	Model 2 BEV 2017	Model 3 PHEV 2011	Model 4 PHEV 2017
Barriers and Benefits				
Relative Advantage (Benefit / Barrier)	2.175***	2.247***	1.715***	1.845***
	(0.189)	(0.192)	(0.208)	(0.184)
PEV-Related Experiences				
Own PEV	0.770	-0.175	-0.535	1.223**
	(0.780)	(0.538)	(0.671)	(0.521)
Ads	0.294**	0.0505	0.357**	0.408***
	(0.125)	(0.140)	(0.159)	(0.148)
See charger	0.126	0.304***	0.285	0.299***
	(0.144)	(0.081)	(0.179)	(0.0845)
PEV Policies				
PEV purchase rebate at state-level	0.000123*	0.000223***	0.0000587	0.00000790
	(0.0000696)	(0.0000628)	(0.0000708)	(0.0000671)
HOV lane access	0.263*	-0.0714	0.101	0.105
	(0.153)	(0.145)	(0.182)	(0.164)
ZEV state	-0.0684	-0.484***	0.0371	-0.0782
	(0.147)	(0.179)	(0.178)	(0.190)
Public charger state policies	0.144	-0.411	-0.0654	0.121
	(0.257)	(0.258)	(0.282)	(0.279)
PEV city-level incentive	-0.183	0.450	0.348	-0.126
	(0.294)	(0.331)	(0.375)	(0.343)
Electric vehicle supply equipment city-level incentive	-0.277*	-0.270	-0.358**	0.361
	(0.143)	(0.245)	(0.165)	(0.276)
Transport Preferences/Behavior				
Number of cars	0.170**	0.138**	0.207***	0.142**
	(0.0662)	(0.0574)	(0.0692)	(0.0669)
Number of miles	-0.00376*	0.00259	-0.00231	0.0000641
	(0.00196)	(0.00228)	(0.00243)	(0.00202)
Climate and Environmental Factors				
Environmental lifestyle	-0.185	-0.121	-0.127	-0.127
	(0.120)	(0.131)	(0.132)	(0.135)
Climate Change is a problem	-0.0720	0.0181	-0.236*	-0.0482
	(0.107)	(0.106)	(0.122)	(0.114)
Demographics				
Age	-0.0107***	-0.0205***	-0.00315	-0.0105**
	(0.00371)	(0.00439)	(0.00416)	(0.00480)
Male	0.273**	0.396***	0.166	0.044
	(0.126)	(0.144)	(0.145)	(0.155)
Education	0.0929*	0.0724	0.110	0.00567
	(0.0555)	(0.0614)	(0.0680)	(0.0699)
Income	0.0854	-0.0916*	0.171**	-0.0244
	(0.0682)	(0.0519)	(0.0766)	(0.0514)
Political leaning	0.0688**	0.0871**	0.0842**	0.0771*
	(0.0342)	(0.0414)	(0.0416)	(0.0416)
Suburban	-0.131	-0.553***	0.0430	-0.230
	(0.167)	(0.188)	(0.185)	(0.197)
Rural	-0.436**	-0.468**	-0.467**	-0.296
	(0.184)	(0.217)	(0.208)	(0.224)
Constant	0.472	1.647***	0.828	1.795***
	(0.475)	(0.578)	(0.591)	(0.624)
N	2,102	1,945	2,095	1,945
R^2	0.3078	0.3311	0.220	0.2488

Standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01

Table 3. Main Model Results with Barriers and Benefits included Separately, where Dependent Variable is Intent to Purchase or Lease a BEV or PHEV, 2011 and 2017

	Model 1 BEV 2011	Model 2 BEV 2017	Model 3 PHEV 2011	Model 4 PHEV 2017
Barriers and Benefits				
Range barrier	-0.147*	-0.415***	0.188**	-0.089
	(0.0852)	(0.0986)	(0.0936)	(0.0991)
Price barrier	-0.169*	-0.238**	-0.234**	-0.319***
	(0.0955)	(0.0922)	(0.112)	(0.0933)
Recharge time barrier	-0.232***	-0.101	-0.339***	-0.148
	(0.0838)	(0.0899)	(0.0942)	(0.0960)
PEV features barrier	-0.381***	-0.434***	-0.456***	-0.437***
	(0.0698)	(0.0794)	(0.0818)	(0.0919)
Saved gasoline money benefit	0.0791	0.112	0.0935	0.172*
	(0.0743)	(0.0876)	(0.0881)	(0.0977)
Demonstrate care for environment benefit	-0.0122	0.314***	-0.0345	0.229**
	(0.102)	(0.104)	(0.109)	(0.111)
Lessen impact on environment benefit	0.145	-0.0174	0.280**	-0.0133
	(0.0913)	(0.100)	(0.112)	(0.110)
Cutting edge of technology benefit	0.448***	0.381***	0.253**	0.348***
	(0.0992)	(0.0980)	(0.107)	(0.106)
PEV-Related Experiences				
Own PEV	1.294	0.260	-0.0752	1.358***
	(0.838)	(0.428)	(0.695)	(0.506)
Ads	0.209*	0.0104	0.273*	0.376**
	(0.126)	(0.139)	(0.155)	(0.148)
See charger	0.156	0.302***	0.280	0.277***
	(0.154)	(0.0785)	(0.189)	(0.0838)
PEV Policies				
PEV purchase rebate at state-level	0.000112*	0.000237***	0.000041	0.0000508
	(0.0000675)	(0.0000617)	(0.0000683)	(0.0000665)
HOV lane access	0.257*	-0.066	0.00799	0.0658
	(0.155)	(0.142)	(0.178)	(0.166)
ZEV state	-0.136	-0.551***	-0.0228	-0.111
	(0.145)	(0.175)	(0.175)	(0.186)
Public charger state policies	0.0761	-0.524**	-0.174	-0.0286
	(0.266)	(0.247)	(0.280)	(0.278)
PEV city-level incentive	-0.00381	0.558*	0.409	0.024
	(0.363)	(0.318)	(0.407)	(0.333)
Electric vehicle supply equipment city-level incentive	-0.234	-0.263	-0.256	0.245
	(0.143)	(0.245)	(0.161)	(0.257)
Transport Preferences/Behavior				
Number of cars	0.172***	0.135**	0.213***	0.142**
	(0.0648)	(0.0591)	(0.0649)	(0.069)
Number of miles	-0.00320	0.00311	-0.00352	-0.0000720
	(0.00207)	(0.00203)	(0.00257)	(0.00208)
Climate and Environmental Factors				
Environmental lifestyle	-0.151	-0.128	-0.0107	-0.173
	(0.123)	(0.129)	(0.136)	(0.135)
Climate Change is a problem	-0.0999	-0.0132	-0.233*	-0.00735
	(0.106)	(0.106)	(0.128)	(0.115)
Demographics				
Age	-0.0102***	-0.0162***	-0.00401	-0.00713
	(0.00376)	(0.00438)	(0.00410)	(0.00469)
Male	0.220*	0.392***	0.0795	-0.0261
	(0.126)	(0.143)	(0.144)	(0.159)
Education	0.104*	0.0573	0.0940	-0.0408
	(0.0559)	(0.0625)	(0.0654)	(0.0715)
Income	0.0743	-0.0952*	0.133*	-0.0395
	(0.0697)	(0.0494)	(0.0766)	(0.0518)

Political leaning	0.0648*	0.0836**	0.0715*	0.0715*
	(0.0344)	(0.0393)	(0.0417)	(0.0413)
Suburban	-0.148	-0.480***	0.00879	-0.100
	(0.173)	(0.183)	(0.187)	(0.196)
Rural	-0.457**	-0.397*	-0.522**	-0.185
	(0.192)	(0.213)	(0.204)	(0.225)
Constant	3.684***	5.309***	3.521***	4.709***
	(0.704)	(0.728)	(0.816)	(0.776)
N	2,038	1,849	2,030	1,849
R^2	0.3257	0.3743	0.2659	0.2825

Standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01

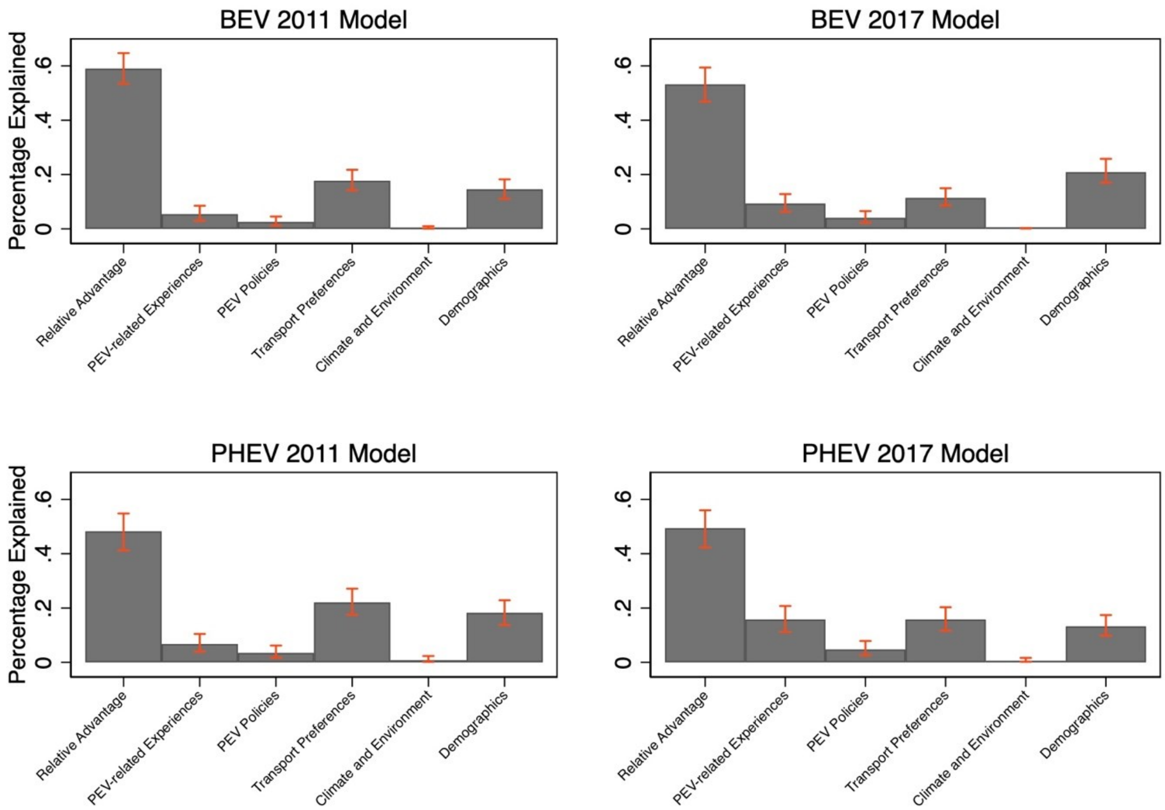
Table 4. Main Model Results with Additional Social Influence Variables, where Dependent Variable is Intent to Purchase or Lease a BEV or PHEV, 2017

	Model 1 BEV 2017	Model 2 PHEV 2017
Barriers and Benefits		
Relative Advantage (Benefit / Barrier)	2.201***	1.783***
	(0.192)	(0.182)
PEV-Related Experiences		
Own PEV	-0.414	0.805
	(0.540)	(0.507)
Ads	0.0189	0.367**
	(0.140)	(0.147)
See charger	0.253***	0.227***
	(0.0807)	(0.0836)
Neighbor	0.516*	0.914***
	(0.311)	(0.284)
Relative	0.333	0.725**
	(0.278)	(0.297)
Friend	0.416*	0.398*
	(0.233)	(0.218)
PEV Policies		
PEV purchase rebate at state-level	0.000220***	0.00000680
	(0.0000618)	(0.0000651)
HOV lane access	-0.0675	0.116
	(0.143)	(0.163)
ZEV state	-0.486***	-0.0769
	(0.179)	(0.188)
Public charger state policies	-0.458*	0.0509
	(0.254)	(0.270)
PEV city-level incentive	0.478	-0.0819
	(0.329)	(0.331)
Electric vehicle supply equipment city-level incentive	-0.267	0.360
	(0.239)	(0.267)
Transport Preferences/Behavior		
Number of cars	0.117**	0.110
	(0.0584)	(0.0672)
Number of miles	0.00267	0.000219
	(0.00234)	(0.00201)
Climate and Environmental Factors		
Environmental lifestyle	-0.102	-0.101
	(0.129)	(0.131)
Climate Change is a problem	-0.0197	-0.103
	(0.105)	(0.111)
Demographics		
Age	-0.0209***	-0.0112**
	(0.00443)	(0.00476)
Male	0.390***	0.0372
	(0.144)	(0.154)
Education	0.0550	-0.0135
	(0.0621)	(0.0703)
Income	-0.0918*	-0.0237
	(0.0517)	(0.0507)
Political leaning	0.0819**	0.0674
	(0.0414)	(0.0414)
Suburban	-0.581***	-0.272
	(0.187)	(0.195)
Rural	-0.473**	-0.306
	(0.216)	(0.222)
Constant	1.876***	2.113***
	(0.575)	(0.613)
N	1,945	1,945

R^2	0.3379	0.2639

Standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01

Figure 4. R-Squared Decomposition Values (in Percentage of Explained Variation of the Dependent Variable) and 90 percent Confidence Intervals (in red).



Notes: Confidence intervals obtained from bootstrapping with 2,000 repetitions. Graphs are associate with the Table 2 regression results.

Table 5. R-Squared Decomposition Values, 2011, 2017, and Difference between 2011 and 2017

Table 2 Results	**BEV 2011**	**BEV 2017**	**Difference**	**PHEV 2011**	**PHEV 2017**	**Difference**
Relative Advantage	59.0%	53.2%	-5.8%	48.2%	49.4%	1.2%
PEV-Related Experiences	5.4%	9.3%	3.9%	6.8%	15.8%	9.0%
PEV Policies	2.5%	4.1%	1.5%	3.5%	4.7%	1.3%
Transport Preferences/Behavior	17.7%	11.4%	-6.3%	22.1%	15.8%	-6.3%
Climate and Environmental Factors	0.3%	0.5%	0.2%	0.8%	0.6%	-0.2%
Demographics	14.5%	20.9%	6.3%	18.2%	13.3%	-5.0%
Table 3 Results	**BEV 2011**	**BEV 2017**	**Difference**	**PHEV 2011**	**PHEV 2017**	**Difference**
Barriers	37.1%	36.1%	-1.0%	35.6%	33.1%	-2.5%
Benefits	28.6%	25.6%	-3.1%	26.5%	27.7%	1.2%
PEV-Related Experiences	4.5%	8.0%	3.4%	5.1%	12.9%	7.8%
PEV Policies	2.2%	3.4%	1.2%	2.7%	3.9%	1.2%
Transport Preferences/Behavior	0.4%	0.5%	0.2%	0.8%	0.5%	-0.3%
Climate and Environmental Factors	14.6%	9.1%	-5.4%	15.2%	11.9%	-3.3%
Demographics	12.1%	16.6%	4.5%	13.5%	9.4%	-4.1%
Table 4 Results		**BEV 2017**			**PHEV 2017**	
Relative Advantage		51.3%			45.1%	
PEV-Related Experiences		12.1%			22.5%	
PEV Policies		3.8%			4.3%	
Transport Preferences/Behavior		0.5%			0.5%	
Climate and Environmental Factors		11.2%			15.0%	
Demographics		20.5%			12.3%	

Supporting Information

Here, we include three robustness checks. In the first model, presented in Table A1, we replace the climate and environmental beliefs with a set of variables that measure the importance of specific vehicle attributes: price, size, appearance and fuel economy. We do this because empirical evidence suggests that consumers care a great deal about vehicle attributes that they enjoy or need, and may be unwilling to compromise on these attributes (Higgins et al., 2017; Tran et al., 2012). All four of these variables are defined in Table 1. Results do not change for the primary variables of interest in any substantive way.

In Table A2, we repeat the models presented in Table 2 but with the inclusion of a familiarity variable. Including this variable allows us to control for those that already know about PEVs and have already formed opinions about them. Results again do not change substantively.

In Table A3, we remove those respondents that took the survey in both 2011 and 2017, to rule out the possibility of testing effects. Results do not change substantively.

Table A1. Robustness Check Model Results with Vehicle Attribute Preferences, where Dependent Variable is Intent to Purchase or Lease a BEV or PHEV, 2011 and 2017

	Model 1 BEV 2011	Model 2 BEV 2017	Model 3 PHEV 2011	Model 4 PHEV 2017
Barriers and Benefits				
Relative Advantage (Benefit / Barrier)	2.265***	2.322***	1.992***	1.908***
	(0.200)	(0.182)	(0.208)	(0.169)
PEV-Related Experiences				
Own PEV	0.807	-0.234	-0.537	1.248**
	(1.056)	(0.593)	(0.892)	(0.527)
Ads	0.301**	0.112	0.289*	0.437***
	(0.134)	(0.146)	(0.167)	(0.154)
See charger	0.293	0.306***	0.208	0.274***
	(0.235)	(0.0853)	(0.176)	(0.0875)
PEV Policies				
PEV purchase rebate at state-level	0.000101	0.000216***	0.0000451	-0.00000291
	(0.0000774)	(0.0000668)	(0.0000781)	(0.0000695)
HOV lane access	0.174	-0.0502	0.132	0.0495
	(0.183)	(0.156)	(0.194)	(0.170)
ZEV state	-0.00538	-0.479**	0.0653	-0.0493
	(0.165)	(0.187)	(0.194)	(0.205)
Public charger state policies	0.0305	-0.347	-0.0903	0.400
	(0.290)	(0.274)	(0.318)	(0.280)
PEV city-level incentive	-0.032	0.354	0.454	-0.455
	(0.328)	(0.345)	(0.391)	(0.347)
Electric vehicle supply equipment city-level incentive	-0.397**	-0.343	-0.387**	0.199
	(0.159)	(0.266)	(0.171)	(0.278)
Transport Preferences/Behavior				
Number of cars	0.206***	0.0934	0.200***	0.113
	(0.0738)	(0.0606)	(0.0716)	(0.0710)
Number of miles	-0.00401*	0.00223	-0.00331	-0.000445
	(0.00209)	(0.00236)	(0.00257)	(0.00209)
Demographics				
Age	-0.00946**	-0.0203***	-0.00349	-0.0071
	(0.00413)	(0.00464)	(0.00456)	(0.00518)
Male	0.213	0.392***	0.151	0.0418
	(0.136)	(0.147)	(0.155)	(0.159)
Education	0.0556	0.0717	0.101	0.00406
	(0.0607)	(0.0654)	(0.0729)	(0.0750)
Income	0.107	-0.0916*	0.208**	-0.0262
	(0.0753)	(0.0534)	(0.0840)	(0.0518)
Political leaning	0.0885**	0.0960***	0.122***	0.0888**
	(0.0345)	(0.0355)	(0.0394)	(0.0370)
Suburban	-0.0785	-0.459**	0.0659	-0.161
	(0.186)	(0.198)	(0.200)	(0.206)
Rural	-0.476**	-0.322	-0.453**	-0.217
	(0.203)	(0.230)	(0.218)	(0.239)
Importance of Vehicle Attributes				
Size	-0.148	-0.420***	-0.305*	-0.0174
	(0.161)	(0.156)	(0.170)	(0.171)
Cost	0.117	-0.0652	0.0751	0.0723
	(0.155)	(0.152)	(0.175)	(0.160)
Appearance	-0.232	0.113	-0.246	0.0089
	(0.165)	(0.189)	(0.171)	(0.192)
Fuel Economy	0.158	0.184	0.434***	0.502***
	(0.139)	(0.144)	(0.156)	(0.155)
Constant	-0.312	1.391***	-0.417	0.980*
	(0.490)	(0.482)	(0.556)	(0.516)
N	1,856	1,710	1,846	1,710
R^2	0.2978	0.3493	0.2333	0.2634

Standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01

Table A2. Robustness Check Model Results with Familiarity Variable, where Dependent Variable is Intent to Purchase or Lease a BEV or PHEV, 2011 and 2017

	Model 1 BEV 2011	Model 2 BEV 2017	Model 3 PHEV 2011	Model 4 PHEV 2017
Barriers and Benefits				
Relative Advantage (Benefit / Barrier)	2.153***	2.250***	1.720***	1.842***
	(0.190)	(0.192)	(0.208)	(0.184)
PEV-Related Experiences				
Familiar with PEVs	-0.386	-0.185	0.0885	0.164
	(0.249)	(0.211)	(0.265)	(0.251)
Own PEV	0.739	-0.170	-0.528	1.219**
	(0.736)	(0.539)	(0.681)	(0.519)
Ads	0.356***	0.0692	0.342**	0.392**
	(0.129)	(0.144)	(0.167)	(0.153)
See charger	0.145	0.309***	0.282	0.295***
	(0.140)	(0.0806)	(0.179)	(0.0845)
PEV Policies				
PEV purchase rebate at state-level	0.000118*	0.000221***	0.0000598	0.0000094
	(0.0000706)	(0.0000628)	(0.000071)	(0.0000670)
HOV lane access	0.243	-0.068	0.105	0.102
	(0.154)	(0.145)	(0.182)	(0.165)
ZEV state	-0.0715	-0.483***	0.0373	-0.0791
	(0.146)	(0.179)	(0.178)	(0.190)
Public charger state policies	0.148	-0.398	-0.0667	0.109
	(0.255)	(0.259)	(0.282)	(0.279)
PEV city-level incentive	-0.147	0.432	0.340	-0.110
	(0.296)	(0.330)	(0.375)	(0.342)
Electric vehicle supply equipment city-level incentive	-0.303**	-0.276	-0.353**	0.366
	(0.140)	(0.245)	(0.164)	(0.276)
Transport Preferences/Behavior				
Number of cars	0.174***	0.138**	0.206***	0.142**
	(0.0662)	(0.0575)	(0.0697)	(0.0666)
Number of miles	-0.00363*	0.0025	-0.00234	0.000141
	(0.00195)	(0.00225)	(0.00243)	(0.00203)
Climate and Environmental Factors				
Environmental lifestyle	-0.192	-0.122	-0.125	-0.126
	(0.119)	(0.131)	(0.131)	(0.135)
Climate Change is a problem	-0.074	0.0211	-0.236*	-0.0509
	(0.106)	(0.107)	(0.123)	(0.113)
Demographics				
Age	-0.0102***	-0.0207***	-0.00325	-0.0102**
	(0.00371)	(0.00440)	(0.00413)	(0.00479)
Male	0.268**	0.403***	0.166	0.0382
	(0.126)	(0.145)	(0.144)	(0.156)
Education	0.105*	0.0802	0.107	-0.00126
	(0.0557)	(0.0624)	(0.0680)	(0.0704)
Income	0.0859	-0.0884*	0.171**	-0.0273
	(0.0678)	(0.0520)	(0.0765)	(0.0511)
Political leaning	0.0678**	0.0878**	0.0844**	0.0765*
	(0.0345)	(0.0414)	(0.0415)	(0.0415)
Suburban	-0.119	-0.543***	0.0416	-0.239
	(0.166)	(0.188)	(0.185)	(0.198)
Rural	-0.408**	-0.463**	-0.472**	-0.300
	(0.184)	(0.218)	(0.209)	(0.223)

Constant	0.748	1.754***	0.764	1.700***
	(0.511)	(0.593)	(0.617)	(0.659)
N	2,102	1,945	2,095	1,945
R^2	0.3105	0.3316	0.2201	0.2492

Standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01

Table A3. Robustness Check Model Results with Overlapping Sample Removed, where Dependent Variable is Intent to Purchase or Lease a BEV or PHEV, 2011 and 2017

	Model 1 BEV 2011	Model 2 BEV 2017	Model 3 PHEV 2011	Model 4 PHEV 2017
Barriers and Benefits				
Relative Advantage (Benefit / Barrier)	2.381***	2.177***	1.886***	1.817***
	(0.192)	(0.210)	(0.218)	(0.202)
PEV-Related Experiences				
Own PEV	0.574	-0.300	-0.424	1.431***
	(0.789)	(0.601)	(0.708)	(0.502)
Ads	0.287**	0.0982	0.350**	0.411**
	(0.134)	(0.151)	(0.170)	(0.161)
See charger	0.0585	0.291***	0.240	0.320***
	(0.154)	(0.0886)	(0.192)	(0.0931)
PEV Policies				
PEV purchase rebate at state-level	0.000153**	0.000251***	0.0000629	-0.00000127
	(0.0000778)	(0.0000688)	(0.0000777)	(0.0000743)
HOV lane access	0.199	-0.0693	0.0153	0.234
	(0.171)	(0.165)	(0.200)	(0.186)
ZEV state	0.0921	-0.592***	0.175	-0.0744
	(0.157)	(0.188)	(0.190)	(0.204)
Public charger state policies	0.0779	-0.363	-0.110	0.163
	(0.289)	(0.278)	(0.305)	(0.306)
PEV city-level incentive	-0.266	0.372	0.388	-0.344
	(0.323)	(0.354)	(0.408)	(0.366)
Electric vehicle supply equipment city-level incentive	-0.242	-0.354	-0.260	0.347
	(0.157)	(0.272)	(0.184)	(0.315)
Transport Preferences/Behavior				
Number of cars	0.192***	0.182***	0.224***	0.207***
	(0.0717)	(0.0635)	(0.0764)	(0.0771)
Number of miles	-0.00538***	0.00263	-0.00354	-0.000358
	(0.00196)	(0.00240)	(0.00246)	(0.00204)
Climate and Environmental Factors				
Environmental lifestyle	-0.106	-0.199	-0.0644	-0.147
	(0.121)	(0.142)	(0.140)	(0.147)
Climate Change is a problem	-0.0695	0.0228	-0.211	-0.0545
	(0.103)	(0.111)	(0.130)	(0.122)
Demographics				
Age	-0.0102***	-0.0216***	-0.00379	-0.0101*
	(0.00393)	(0.00483)	(0.00436)	(0.00533)
Male	0.264*	0.419***	0.146	0.103
	(0.137)	(0.159)	(0.154)	(0.171)
Education	0.112*	0.103	0.118	0.0108
	(0.0602)	(0.0658)	(0.0749)	(0.0774)
Income	0.0630	-0.0519	0.120	-0.0118
	(0.0733)	(0.0541)	(0.0804)	(0.0565)
Political leaning	0.0619*	0.0929**	0.0782*	0.0838*
	(0.0373)	(0.0449)	(0.0461)	(0.0462)
Suburban	-0.139	-0.632***	-0.0529	-0.309
	(0.184)	(0.200)	(0.202)	(0.215)
Rural	-0.420**	-0.590**	-0.470**	-0.428*

	(0.199)	(0.231)	(0.229)	(0.243)
Constant	0.117	1.579**	0.657	1.581**
	(0.522)	(0.629)	(0.641)	(0.676)
N	1,702	1,549	1,696	1,549
R^2	0.3408	0.3535	0.2355	0.2689

Standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01