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Understanding the Impact of Charging Infrastructure on the Consideration to Purchase an Electric Vehicle in California

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Understanding the Impact of Charging Infrastructure on the Consideration to Purchase an Electric Vehicle in California

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16. Abstract
This research makes explicit and tests an implicit assumption in policies promoting public investment in plug-in electric vehicle (PEV) charging infrastructure: even people who are not already interested in PEVs see public PEV charging. Data from a survey representing all car-owning households in California are combined with per capita counts of public PEV charging locations and PEV registrations to estimate a structural equation model for two central variables: the extent to which participants have already considered acquiring a battery electric vehicle (BEV) or plug-in hybrid electric vehicle (PHEV), and whether and how many places people see PEV charging. The model controls for socio-economic and demographic measures as well as participants' awareness, knowledge, and assessments of PEVs. The model also controls for the known spatial correlation between PEV registrations and public PEV charging locations. The conclusion is there is no evidence of a relationship between public charging location density and participants reporting they see PEV charging locations. Nor is there a relationship between public charging location density and PEV purchase consideration. The evidence indicates there is little reason to assume building more public PEV charging means more people will see that charging or that more people will consider purchasing a PEV. Rather, awareness, knowledge, and positive assessments of PEVs allow people to see PEV charging in their local environment. In short, interest in PEVs is a prerequisite to people seeing PEV charging. Concomitant investments to increase awareness of PEVs and engagement in a transition to them as well as in PEV charging infrastructure may be a more effective way to grow the PEV market.

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Glossary

Acronym	Definition
AVE	average variance explained
BEV	battery electric vehicle
CFA	confirmatory factor analysis
CFI	comparative fit index
CR	construct reliability
HOV	high occupancy vehicle
L2	level 2
PEV	plug-in electric vehicle
PHEV	plug-in hybrid electric vehicle
RMSEA	root mean squared error of approximation
SEM	structural equations modeling
SRMR	squared root mean residual
TLI	Tucker-Lewis Index

Executive Summary

Executive Summary

A lack of pervasive public charging is claimed to be one of the primary barriers to faster and more widespread growth of plug-in electric vehicle (PEV) markets. Flowing from such claims is a belief that investing in more public PEV charging will spur PEV demand. Here a PEV is a vehicle that can be plugged into an electricity source, either a battery electric vehicle (BEV) or a plug-in hybrid electric vehicle (PHEV).

Without contesting whether more PEV charging is required, this research posits there is a necessary—and heretofore missing—link between increasing public PEV charging infrastructure and increasing PEV sales: people who don't already drive PEVs must see PEV charging for it to affect their willingness to buy and drive PEVs. For the claim that increased public charging directly leads to higher PEV sales to be true, it must first be demonstrated that the density of charging infrastructure is related to whether consumers literally see PEV charging locations and that seeing more charging locations leads more people to consider purchasing or leasing PEVs.

We investigate two central hypotheses. First, is the density of public PEV charging locations associated with whether people report seeing public PEV charging, i.e., do more PEV chargers mean more people see PEV charging? Second, are reported sightings of public PEV charging infrastructure associated with PEV purchase consideration? To test these hypotheses, we specify a structural equation model to control for differences in PEV sales and PEV charging infrastructure that are exogenous to the study participants and their households. Participants are described in the model by socio-economic, demographic, and contextual measures of them, their residences, vehicles, and daily travel. Given all these, participants' PEV awareness, knowledge, and assessments are used to estimate the extent to which they have already considered acquiring a BEV and a PHEV.

The results indicate there is no link between the density of public PEV charging locations in participants' residential zip codes and whether they report they see PEV charging. Further, differences in PEV charging location density in participants' residential zip codes are not associated with how many participants have considered acquiring a PEV. Finally, given the other explanatory variables in the model, there is no association between whether people see PEV charging locations "in the parking lots and facilities [they] use" and their consideration of acquiring PEVs.

We find participants' prior interest in and engagement with PEVs are associated with whether they've: (i) seen PEV charging locations; and (ii) considered acquiring a PEV. Participants with low levels of prior interest and engagement are likely to report they've not seen PEV charging—regardless of how many actual charging locations are in their local area—and are likely to have given little to no consideration to acquiring a PEV. Measures of prior engagement include recalling they've seen advertising for PEVs across multiple media, ability to name currently available PEV make-models, correct knowledge of how PEVs are refueled, seeking information on PEVs, and positive conversations with a PEV owner they know. In addition to prior engagement, favorable assessments of PEVs are also associated with people seeing public PEV charging locations and considering a PEV for their household. These assessments include PEV charging availability, PEV charging duration and driving range, safety and reliability in comparison to conventional gasoline vehicles, marketability, and price.

Given these results, we posit that building more public PEV charging locations—in the absence of other activities to prompt interest in PEVs—is at best an inefficient means to support and promote PEV sales. Rather, the causality is the other way around; PEV charging does not cause interest in PEVs; interest in PEVs allows people to see PEV charging. People who are interested in PEVs and who have a favorable assessment of PEVs are more likely to see more PEV charging locations independent of the objective density of public PEV charger locations around their residences. That is, people with a high interest in PEVs who live in places with less public PEV charging infrastructure are more likely to report they see PEV charging than are people uninterested in PEVs living in places with more public PEV charging. Therefore, concomitant investments to increase awareness of PEVs and engagement in a transition to them as well as continued deployment of PEV charging infrastructure may be a more effective way to grow the PEV market.

These results support the argument that increasing awareness and interest in a transition—both societal and personal—to electric vehicles are vital, but unfulfilled, precursors to success. While this research helps to identify the factors associated with seeing charging locations and PEV purchase consideration, there needs to be a more comprehensive understanding of initial motivations and causes of interest and engagement with PEVs.

Data on households are from a survey of approximately 3,000 California car-owning residents administered in the first quarter of 2021. Measures of public PEV charging are the number of locations where Level 2 chargers and DC fast chargers are available in respondents' home postal (ZIP) codes converted to a per capita basis. Charger locations are from the US Dept. of Energy's Alternative Fuels Data Center charger location dataset. Total PEV registrations were identified in a comprehensive vehicle registration dataset for California and, as with charging locations, converted to a per capita measure at the ZIP code level.

Contents

Introduction

Plug-in electric vehicles (PEVs) are an important technology for reducing energy consumption and emissions from transportation. PEVs are key to meeting greenhouse gas and criteria pollutant emission, human health, eco-system and economic resilience, and renewable energy goals(1). PEVs, which, by definition, can be plugged into the electric grid, include battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). BEVs must be plugged-in, because they are powered exclusively by electricity from the grid; PHEVs may or may not be plugged-in, as they can be powered either directly by a liquid fuel, usually gasoline, or by electricity from the grid or generated onboard by the gasoline-powered internal combustion engine. In general, we use the collective term PEV but will use BEV and PHEV when the distinction is germane.

Public PEV charging is charging that is open to any PEV driver to use, though not all charging stations are compatible with all PEVs due to the variety of charging connectors and (in)compatibility with different charging powers. Public PEV charging may be located either at “destination” locations—i.e., locations to which people travel to accomplish some activity such as shopping or dining—or along routes to facilitate trips longer than a PEVs range between destinations. Typically, public PEV charging is taken to be charging that is purpose-built for public use and usually provides Level 2 or DC fast charging rather than merely coincidental access to a pre-existing 110V outlet (that might support Level 1 charging).

Billions of public dollars are being invested in PEV charging infrastructure across the US. California has previously spent or committed nearly 1 billion dollars (2,3). Late in 2021, the state committed another $314 million dollars (4) to light-duty PEV charging. The California Public Utilities Commission (CPUC) has authorized electric utilities to spend another $738 million over a 5-year period. Much of the $800 million dollars that Electrify America will spend in California is for PEV charging infrastructure. Large sums are also being spent by other states, e.g., New York State is spending $250 million over 7 years. Electrify America is spending $2 billion nationwide. It is in the public interest that this infrastructure has its intended effect on PEV sales and use. If infrastructure is not having its intended effect, public spending may not be as effective in fostering PEV markets and in creating electric-vehicle miles travelled.

Public PEV charging infrastructure’s role is argued to be twofold. First, it may encourage consumers to purchase PEVs (perhaps especially those who haven’t already). Second, it may increase the use of PEVs by those who drive them (5). PEV charging infrastructure is frequently cited as a key facilitating condition for PEV market growth—though it is often stated in the opposite sense, i.e., an absence of PEV charging is a primary barrier to market growth (6). Simply, the argument for more PEV charging infrastructure is often stated as, “If you build it, they will charge” (5).

Without necessarily contesting this assertion, this research explores whether building public PEV charging infrastructure is enough or whether other activities such as marketing and promotion of the necessity of a transition to PEVs and of PEVs themselves may be required for people who are not PEV owners to be aware of—literally, to see—PEV charging infrastructure around them (7). Whether PEV charging succeeds in encouraging consumer PEV purchase and use depends on consumers, especially those who don't already own PEVs, perceiving (again, *seeing*) charging infrastructure in their environment. It is not enough that charging exists; people must (at least) perceive its existence and form either or both an expectation that PEV chargers are discoverable and a "mental map" (8) of charging opportunities. In this study we test these hypotheses:

1. whether there is a relationship between how much public PEV infrastructure is present and whether people see it, and
2. whether differences in the amount of public PEV infrastructure or whether people see it are associated with those same people's consideration of acquiring a PEV.

We use data from car-owning households (all cars, not just PEVs) from a survey completed in 2021 by nearly 3,000 respondents across California. These data are supplemented by data on the contemporaneous (with the household survey) counts of charging locations and PEV registrations in survey participants' home zip codes. The analysis also controls for density of PEVs in the participants' home zip codes as there is geographic correlation between where there are PEVs and where there is PEV charging infrastructure. Further, the analysis describes who does and does not see PEV charging.

Literature Review

Three areas of literature are reviewed:

1. Studies that explore the role of charging infrastructure on PEV sales.
2. Studies that characterize consumer PEV purchase intention based on perception, awareness, and density of charging infrastructure.
3. Studies that characterize consumer awareness, knowledge, and attitudes toward PEVs.

We start by comparing studies that reach different conclusions about the role of public charging infrastructure in PEV sales and use. Cass and Grundoff (5) conclude the diffusion of a visible network of charging infrastructure is necessary for non-adopters to overcome range anxiety. Greene et al. (6) similarly report public charging infrastructure provides benefits to both current and prospective PEV adopters. Ou et al. (9) simulate the impact of public charging infrastructure on PEV sales in China and conclude the impact of public charging on PEV sales varies depending on the battery technology. Narassimhan et al. (10) performed regression analysis on U.S. PEV purchase data from 2008 to 2016, reporting PEV charging infrastructure significantly influenced per capita PEV purchases. Additionally, Sierzchula et al. (11) performed regression analysis of PEV sales data from 30 different countries; the availability of chargers was the best predictor of PEV sales. Mersky et al. (12) also conclude charger availability to be the best predictor of PEV sales in Norway.

In contrast, other studies have found a weak or non-existent relationship between public charging and PEV sales. Nazari et al. (13) report the number of public PEV charging stations was only statistically significant for households choosing PHEVs, but not BEVs. Miele et al (14) used survey data from Canadian new car buyers to simulate the sales impact of increasing charging infrastructure, incorporating both consumer awareness and supply constraints. They report new PEV market share from 2020 to 2030 may not substantially benefit from increased infrastructure. Gnann et al. (15) utilized an agent-based market diffusion model for PEVs and their charging infrastructure in Germany. They concluded that public PEV charging infrastructure is not necessary for PEV market penetration, since many households have accessibility to at-home charging. Lin et al. (16) suggest that widespread access to at-home charging has a greater impact on PEV sales than does access to public and workplace charging. Plotz et al. (17) et al. found that compared with public DC fast charging, public Level 1 and 2 charging stations would need to be subsidized for a long time and do not facilitate PEV sales. They do however suggest public charging may be important for people without access to charging at home. In a literature review of consumer preferences for charging infrastructure, Hardman et al (18) found the most important charging location to convince people to purchase a PEV was at home, followed by workplace, and finally public locations.

While there are differing results in the literature regarding the impact of public charging infrastructure on PEV sales, most of these studies base their conclusions on correlation between PEV charging and PEV sales rather than causation. Chakraborty et al. (19) cautioned against the assumption of causality between PEV charging infrastructure and sales. In a study of factors influencing PEV adoption in California, they found that while there was a positive association between Level 2 public charging and BEV sales, no causal claims could be drawn from the results. It is possible external factors drive the growth of both BEV sales and Level 2 public charging. It may also be the case that causality occurs in the opposite direction, that is, BEV sales lead to more investments in public charging infrastructure.

There are also studies that have examined the impact of charging infrastructure awareness, perception, and density on PEV consideration. These, too, reach contradictory results. Li et al. (20) conclude that situational factors such as insufficient charging infrastructure are major barriers to increasing consumer PEV purchase intention. Similarly, Tiwari et al. (21) report that negative perception of charging infrastructure reliability negatively influences PEV purchase intent. Huang et al (22) conclude higher satisfaction with the amount of charging infrastructure and charging time to be positively associated with purchase intention. In contrast, Hardman et al. (23) found in Sacramento, California in 2018 that awareness of charging infrastructure had a negative impact on consideration, while the density of PEV chargers was not associated with consideration. Bailey et al. (24) used a sample of Canadian new car buyers to explore whether charger awareness was associated with PEV purchase interest. Their results indicated that when controlling for the availability of Level 1 charging at home, the relationship between public charging awareness and PEV purchase interest was weak or non-existent.

Prior literature has also characterized consumer exposure to and attitudes toward PEV technology and their role in fostering consideration. Kurani et al. (25) found that in California, the state with the highest number and proportion of PEV sales in the U.S., awareness, knowledge, and experience is low, and consequently, new car buyers' valuations of PEVs remains largely unformed. Additionally, studies such as Kurani et al. (26) and Long et al. (27) have found that these metrics have not been increasing over time from 2013 to 2017. Regarding PEV consideration, Bunce et al. (28), Krause et al. (29), and Franke and Krems (30) find increased PEV familiarity and experience are associated with greater acceptance of PEV technology. In a report detailing American sentiments toward issues surrounding PEVs, Singer (31) concluded through descriptive statistics of survey data that consumers will only purchase PEVs after they are aware of the technology and willing to consider purchasing a PEV. Both Burgess et al. (32) and Kurani et al. (4) found that positive interaction between PEV owners and non-PEV owners led to non-owners having higher valuations of PEVs; PEV owners may therefore be able to act as agents of social influence.

Method

This section describes the data, approach, and analytical tools used to address the hypotheses about the relationship between whether participants living in places with more PEV charging locations report seeing more of these locations than those living in places with fewer charging locations and whether this has a relationship with BEV and PHEV purchase consideration. Structural equations modeling (SEM) is used to test the central hypotheses and several ancillary hypotheses controlling for differences in PEV sales and charging infrastructure that are exogenous to the participants and their households, participants' PEV awareness, knowledge, and assessments, as well as characteristics of participants and their households.

Data

To build the SEM, data are combined from three sources:

1. A survey of car owning households in California conducted in the first quarter of 2021,
2. Contemporaneous counts of PEV charging locations by zip code, and
3. Contemporaneous counts of PEV sales by zip code.

Household Survey Data

This report draws on data from a large sample survey conducted in California during the first quarter of 2021. It measures consumer awareness, knowledge, assessments, and consideration of PEVs (as well as fuel cell electric vehicles [FCEVs], though they are not included here. The study population was all car-owning households in California. A copy of the survey is available as "Supplemental Material" to the report on eScholarship.

The sample was recruited by a professional survey firm. Participants were recruited from panels of people maintained by a variety of commercial firms for the express purpose of participating in research. Participants are typically screened based on criteria relevant to each study to which they are invited. Firms providing this service typically reward participation based on how many studies a person completes and the time and effort required to do so. Because all recruiting is done by the vendor and because these firms typically maintain cooperative relationships with each other allowing them to recruit from each other's panels, the number of initial invitations to the pre-screening questionnaire for this study is unknown. Thus, a traditional response rate cannot be calculated. What is known is the number of people who screened into this study's questionnaire and how many completed it. The completion rate was in the low-70 precents.

Participants were screened into this study via a pre-questionnaire establishing eligibility, determined primarily by respondent age (for reasons of informed consent and for quota sampling), respondent sex (for quota sampling), household vehicle ownership (for basic eligibility), household income (for quota sampling), and residential zip code (for quota sampling). Quotas for age, sex, and income were set to match regional distributions within California for car-owning households. The analysis here is for the state, i.e., it does not use the regional stratification. Because the data set was originally designed to represent regions with equal sized regional samples, it is re-weighted to represent the state (as the individual regions are of different population sizes).

PEV Charger Location and Vehicle Registration Data

Counts of PEV charging locations by zip code were produced by combining publicly available charger location information from the US Department of Energy Alternative Fuels Data Center with data from Recaro Plugshare. Charger location data from the two sources were merged using a method described by Xu et al (2021) (33). Counts of PEVs in each zip code were created from a record of privately owned light duty vehicles in California from the California Department of Motor Vehicles. Vehicle Identification Numbers (VIN) in this dataset were processed through a decoder to identify each vehicle's fuel type and power sources. Both variables are converted to ZIP code-level population densities, i.e., PEV charging locations or registrations per 10,000 people in each ZIP code.

Model Specification: Variables in the Analysis

The variables central to the main hypothesis of this study are *do people see PEV charging infrastructure* and *to what extent they have already considered acquiring a PEV*. Additional variables provide means to understand who sees PEV charging and who has considered a BEV or PHEV. These include measures of awareness, knowledge, and assessment of PEVs (latent variables) as well as contextual and descriptive variables. Contextual variables account for participants' existing automobile ownership, daily travel, and capability to charge a PEV at home. Descriptive variables include participant and household level socio-economic and demographic measures. Finally, two PEV infrastructure and market related factors, per capita counts of public Level 2 and DC fast charging locations as well as BEV and PHEV registrations within participants' home zip codes are treated as exogenous variables. These variables are informed by prior literature which find these factors to be associated with PEV adoption. All variables used in the analysis are listed and briefly described in Table 1 and Table 2.

Seeing PEV Charging Infrastructure

The variable *See charging locations* is based on participants' answer to this question, "Have you seen any electric vehicle charging spots in the parking garages and lots you use?" The closing phrase, "you use," is intended to both prompt recall of specific places participants visit and heighten the personal relevance of any recollection. The possible responses are paraphrased as, "No," "I don't know," "Yes, at one location," "Yes, at a few locations," and "Yes, at several locations."

PEV Purchase Consideration

Purchase consideration combines affect (negative, neutral, positive) and action (nothing, information search [short of shopping], active shopping, acquisition, and possibly disposal). The question is asked separately for BEVs and PHEVs. The question for BEVs is shown next; changes for PHEVs are made to the introductory sentence and the vehicle type in the responses.

"Battery electric vehicles (BEVs) run only on electricity; they plug-in to charge their batteries. Have you considered buying a BEV for your household? Select one.

- ❑ I (we) have not—and would not—consider buying a BEV.
- ❑ I (we) have not considered buying a BEV, but maybe someday we will.
- ❑ The idea has occurred, but no real steps have been taken to shop for a BEV.
- ❑ Started to gather information about BEVs but haven't really gotten serious yet.
- ❑ Shopped for BEVs, including a visit to at least one dealership to test drive.
- ❑ I (we) already have, or have had, a BEV."

Explanatory Variable: PEV Awareness

Awareness is assessed by whether people are aware of PEV purchase and use incentives as well as whether they recall seeing PEV advertising across a variety of media. These are classified as "awareness" rather than "knowledge" since neither relies on correct recall of specific information.

Awareness of Incentives

The question about awareness of incentives is asked generically. Measuring awareness of incentives is complicated by differences in what entities have offered incentives, differences in when different incentives have been offered, as well as in differences in practical access to incentives that on their face are offered to broad populations but may only be relevant or available to specific people or groups. For example, California offered HOV lane access to anyone in the state buying (or leasing) a qualifying vehicle. Whether HOV lane access confers any actual incentive depends not only on a person's travel routes but on whether HOV lanes exist where they drive. Further, the large sample survey was not designed to be a program evaluation tool for any given incentive. Finally, specifically naming or describing incentives will bias answers in favor of recall whether or not a person has previously heard of the incentive.

Given all this, awareness of incentives is ascertained via this question, "As far as you are aware, is each of the following offering incentives to consumers to buy and drive vehicles powered by alternatives to gasoline and diesel?" "Each of the following" includes federal, state, and local governments, electric utilities, automobile manufacturers and dealers, oil companies, and "other businesses." The possible responses are, "No," "I'm not sure," and "Yes." The variable *Number of incentives* is the count of "Yes" responses, excluding oil companies. (No such incentives have been offered. The response was included as a check on the accuracy of reported responses.) The variable ranges in value from zero to eight.

Advertising Awareness

The variable for advertising awareness is based on the question, "Have you recently seen or heard about battery electric vehicles, plug-in hybrid electric vehicles or fuel cell electric vehicles through any of these in your area?" Participants respond "yes" or "no" to these seven items:

- Ride and drive events where people may see and test drive vehicles

- Television advertising
- Radio advertising
- Billboards or other roadside signs
- Social media advertising on platforms such as Facebook, Twitter, Instagram, Snapchat, LinkedIn, Pinterest, YouTube, or others
- Print media advertising such as magazines and newspapers
- Taxis or cars used by Uber or Lyft drivers

The variable takes the value of the number of "yes" responses, ranging from zero to seven.

PEV Knowledge

The six measures of PEV knowledge all require some level of summary assessment (familiarity and experience), engaged effort (information search), or recall of correct details (fueling and naming PEVs).

BEV (PHEV) Familiarity and Experience

Vehicle types are defined by their "fuel" (gasoline (and diesel), electricity, and hydrogen) and the means of converting that fuel into motion (an internal combustion engine, an electric motor, or the combination of the two in a hybrid drivetrain). For participants, these types are named: Gasoline, Hybrid, Plug-in Hybrid Electric, Battery Electric, and Hydrogen Fuel Cell Electric. Participants are asked, "Are you familiar enough with these types of vehicles to make a decision about whether one would be right for your household?" Answers are on a scale from -3 (No) to +3 (Yes). Here, only the scores for BEVs and PHEVs are used in their respective models.

Using the same vehicle types and answer scale, participants are also asked, "How much driving experience do you have in these types of vehicles?" Again, only the scores for BEVs and PHEVs are used in their respective models.

PEV Information Search

Participants are asked yes or no, "Have you previously searched for information about purchasing or leasing electric vehicles?" If yes, they are then asked to indicate which of a variety of sources they have searched:

- Family member
- Friends
- Co-workers
- A stranger driving an electric vehicle
- Electric vehicle driver clubs or other groups
- Car manufacturers
- Car dealerships/salespeople
- Electric utility
- Electric car charger manufacturers
- Air Quality District
- City Government

- State Government
- Federal Government
- Car reviews
- Non-profit organizations
- Other, please describe

A binary distinction between whether participants have searched for information on PEVs is used by assigning a value of 1 to this variable if participants have searched from at least one of above sources, and 0 if they have not searched from any of the above sources.

Fueling BEV (PHEV)

Participants are asked, "From what you understand, which of these vehicles are fueled with gasoline and which are plugged in to charge with electricity?" The vehicle types are "gasoline," "battery electric," "hybrid," and "plug-in hybrid electric." The answer categories from which participants select one are:

- Only fueled with gasoline
- Only plugged in to charge with electricity
- Both fueled with gasoline and plugged in to charge with electricity
- I don't know

A score of 0 or 1 is assigned to the variable for each vehicle type depending on whether the participant's response is incorrect (0) or correct (1). Only the scores for BEV and PHEV fueling are used in their respective models.

Name BEV (PHEV)

The variables assessing whether people can name a BEV or PHEV are simplifications of responses to a sequence of questions. The simplifications are simple binary yes/no distinctions. The full range of possible answers are described first, then mapped into the binary categories.

Participants are asked yes or no if they can name a BEV and a PHEV, "that is being sold in the US." If yes, they are asked to type in a make name in one text box and a model name in another. Sets of rules of varying stringency are applied to assess whether the provided make/model names are correct. Here, we use the "moderate" rules to establish the values of the Name BEV and Name PHEV variables. In the proffered make and model name, the make and model may be mismatched, but the response counts as correct if the model is correct and it is the correct vehicle type, i.e., if offered in response to the BEV question, the proffered model must be a BEV and the same for PHEVs. For example, the response "Ford Leaf" counts as a correct answer to the question about BEVs: Nissan makes the Leaf, not Ford, but the Leaf is a BEV. (This contrasts with the lax rules which allow BEV names to count as correct for PHEVs and vice versa.) The final variable values are binary distinctions based on simplifying the range of negative, incorrect, and correct responses. The following range of values results from applying the moderate rules.

For BEVs:

- **No**: Participant indicates they are unable to name a BEV.
- **Yes: Wrong**: Participant indicates they can name a BEV but the model name they offer is not a BEV.
- **Yes: Right (Tesla actual)**: Participant indicates they can name a BEV and the name they give is Tesla with a model name that is an actual Tesla model.
- **Yes: Right (Tesla other)**: Participant indicates they can name a BEV and the name they give is Tesla with a model name that is not an actual Tesla model.
- **Yes: Right (Leaf)**: Participant indicates they can name a BEV and the name they give includes “Leaf”: mismatched make names are counted as correct, e.g., “Honda Leaf” is counted as correct even though Nissan makes the Leaf EV.
- **Yes: Right (Bolt)**: Participant indicates they can name a BEV and the name they give includes “Bolt.” Again, mismatched make names are counted as correct.
- **Yes: Right (Other BEV)**: Participant indicates they can name a BEV and the name they give is any other BEV model, allowing for mismatched make names.

For PHEVs:

- **No**: Participant indicates they are unable to name a PHEV.
- **Yes: Wrong**: Participant indicates they can name a PHEV but the model’s name they offer is not a PHEV.
- **Yes: Right (Prius)**: Participant indicates they can name a PHEV and the name they give includes a variation on “Plug-in Prius” or “Prius Prime”; mismatched make names count as correct.
- **Yes: Right (Maybe)**: Participant indicates they can name a PHEV and the name they give includes “Prius” but without a variation on the “Plug-in” or “Prime” qualifiers; mismatched make names count as correct.
- **Yes: Right (Volt)**: Participant indicates they can name a PHEV and the name they give includes “Volt”; mismatched make names count as correct.
- **Yes: Right (Other)**: Participant indicates they can name a PHEV and the name they give is any other PHEV model; mismatched make names count as correct.

For both BEVs and PHEVs, the final binary distinction between whether people can name a BEV or PHEV is achieved by applying these rules:

- **No (0)**: “No” and “Yes: Wrong”
- **Yes (1)**: All variants of “Yes: Right”

BEV (PHEV) Positive Conversation

Conversations with BEV and PHEV owners are assessed separately from "Information Seeking" as here the effect of any such conversations on survey participant's "thoughts or feelings" about BEVs or PHEVs is assessed, too. The variable value is assigned based on a sequence of three questions:

1. Do you know a BEV (PHEV) owner by name?
2. Have you spoken to this person about their BEV (PHEV)?
3. How have these conversations affected how you think or feel about BEVs (PHEVs)?

Using these three questions, the values of the "BEV (PHEV) Positive Conversations" variables are:

- **No (0)**: Respondent doesn't know a BEV (PHEV) owner by name, does know a BEV (PHEV) owner but has not spoken about the vehicle, or does know one and has spoken about the vehicle with them, but those conversations produced no change or a negative change.
- **Yes (1)**: Respondent knows a BEV (PHEV) owner, has spoken with them about their vehicle, and the conversation produced more favorable thoughts or feelings about BEVs (PHEVs).

PEV Assessments

Beyond awareness and knowledge, assessment involves an evaluation. Participants are asked to assess BEVs and PHEVs (separately) on nine items using a scale from -3 (strongly disagree) to +3 (strongly agree). The assessments may be relative to a participant's own context, such as their ability to plug in a PEV at home, or to an unspecified abstract idea about how much they think is enough, such as the range of EVs before needing to be charged. Assessments may be relative to how participants compare EVs to conventional gasoline vehicles, such as the price of EVs compared to gasoline vehicles, or the safety and reliability of EVs compared to gasoline vehicles. Finally, assessments may be relative to participants' assumed motivation for purchasing an EV, such as the environmental benefits or to summary judgements, such as the mass marketability of EVs.

A safety and reliability assessment were included by the researchers in the survey instrument in response to statements by non-PEV owners and PEV critics about possible safety hazards associated with running out of charge. The reliability assessment may relate to this same issue or to perceptions of "new" technology being inherently more prone to breaking down. None of these connotations are stated specifically in the items; participants are allowed to apply whatever meanings of "safety" and "reliability" are conjured in their minds by the comparison of BEVs and PHEVs to conventional gasoline vehicles. That the two items load together in factor analyses of each of the two sets (BEV and PHEV) nine assessment items suggest these concepts are more related to each other than to any of the others.

Note, for some items, positive scores on the disagree-agree scale favor BEVs and PHEVs (Charging Access and Marketability), while on other items, positive scores favor conventional gasoline vehicles (Safety and Reliability, Charging Duration and Range, and Price). Prior to analysis, those latter items are reverse coded so that for all items positive scores favor BEVs and PHEVs.

Factor analysis reveals that eight of these nine evaluation/assessment questions form four factors of related items. Factor scores are used to represent these eight items rather than their raw scores. The ninth item, BEV (PHEV) Price does not load with any others on a factor; in fact, a suitable factor solution is only obtained by omitting this item entirely. However, the (reverse-coded) raw score is maintained as a control variable.

Participant and Household Context and Description

Sex and age are collected for every member of the participants' households but only data for the participant are used here. A dummy variable is used for simple female-male distinction (female = 0; male = 1). Though the original survey item allows participants to select and specify non-binary options, so few did so they can't be analyzed here.

Participant age is measured in these categories:

- 19 to 29
- 30 to 39
- 40 to 49
- 50 to 59
- 60 to 69
- 70 to 79
- 80 or older

Based on requirements for consent to participate in the survey, participants must be 19 or older. Other household members may be younger, the two additional categories are "Under 7" and "7 to 18." The mid-point of each participants' age category is taken to create a continuous age variable.

Access to High Occupancy Vehicle lanes is asked as part of establishing participants' travel routines as California allows single-occupant EVs—with the required stickers for visual identification—to drive in these lanes. The response categories allow participants to indicate "there are no HOV lanes on the routes they routinely drive," "there are HOV lanes but they are not able to use them," or "there are HOV lanes and they do use them." The absence of HOV lanes and the inability to use existing HOV lanes are treated as functionally similar so that the variable coding is reduced to a binary distinction between whether the participant uses HOV lanes or not (No= 0, Yes =1).

The other contextual variables are measured at the household level: number of vehicles, income, and reliable access to charging opportunity while the vehicle is parked at home, referred to as electricity access at residential parking spot.

Number of vehicles is the count of all motor vehicles (excluding motor homes, recreational vehicles, and motorcycles) the household owns or leases. It is treated as a continuous variable with values ranging from one to four. The original survey truncated the vehicle count with the category "4 or more vehicles."

Income is measured at the household level on a continuous scale, ranging from $0 to $200,000.

Electricity access at a residential parking spot is the electrical service to which the participants' households have reliable access at the location they park their vehicles while at home. The possible responses are:

- "A regular electrical outlet (110-volt). These are used for most home electrical appliances.
- "A high-power electrical outlet (220 to 240-volt). These are typically used for electric clothes dryers, electric stoves, electric furnaces, and air conditioners.
- "A piece of Electric Vehicle Supply Equipment (EVSE) designed specifically for charging an electric vehicle.
- "None of the above
- "I don't know."

This is ascertained for up to two vehicles in each household. The dummy variable is assigned a value of 1 if the participant has access to at least a 110-volt outlet (this amounts to the participant selecting any one or more of the first three responses above), and 0 if they do not (where "None of the above" and "I don't know" are treated as functionally similar).

Exogenous variables: PEV Sales and Charging Infrastructure Data

The model includes two exogeneous variables that account for the per capita number of Level 2 and DC fast charger locations and PEVs in respondents home postal (ZIP) codes. The total number of Level 2 and DC fast charger locations was computed by identifying all charging locations in each ZIP code from the US Dept. of Energy's Alternative Fuels Data Center charger location dataset and summing the total number of Level 2 and DC fast charger locations. The Level 2 and DC fast charging locations per capita variable was produced by dividing the total number of Level 2 and DC fast charging locations in each ZIP code by the population of that ZIP code. Total PEV registrations were identified in a comprehensive vehicle registration dataset for California. The Total PEVs per capita variable was produced by dividing the total PEVs in each ZIP code by the population of that ZIP code.

Model

A SEM is estimated to understand the effects of PEV charging infrastructure and PEV registrations per capita at the zip code level on whether people see PEV charging infrastructure as well as on BEV and PHEV consideration. SEM includes a measurement model and a structural model. The measurement model generates factor scores for the latent constructs. The structural model quantifies the relationships between latent constructs, the other explanatory variables (contextual, descriptive, awareness, knowledge, and assessment.), and the two variables central to the main hypothesis of this study: *do people see PEV charging infrastructure* and *to what extent have they already considered acquiring a PEV*.

Table 1. Variables included in the structural equation model

Variable Group	Measurement Level	Variable Name	Variable Type	Variable Description
Primary Hypothesis Testing	Participant	Seeing charging locations	Ordinal Categorical	Of the parking facilities the participant uses, in how many have they seen PEV charging
		BEV (PHEV) Purchase Consideration	Ordinal Categorical	Extent to which participant has already considered acquiring a BEV (PHEV)
PEV Awareness (explanatory variables)	Participant	Number of Incentives	Continuous	Count of sources of PEV Purchase and Use Incentives of which participant is aware
		Advertising Awareness	Continuous	Number of types of media in which participant has seen PEV advertising
PEV knowledge (explanatory variables)	Participant	Fueling a BEV (PHEV)	Dummy	Whether participant knows how a BEV (PHEV) is refueled
		Name a BEV (PHEV)	Dummy	Whether participant can correctly name (make/model) a BEV (PHEV) for sale in the US
		BEV (PHEV) Familiarity	Continuous	Self-rating of familiarity with BEVs (PHEVs)
		BEV (PHEV) Experience	Continuous	Self-rating of driving experience in BEVs (PHEVs)
		PEV Information Search	Dummy	Whether participant has searched for information on BEVs or PHEVs
		BEV (PHEV) Positive Conversation	Dummy	Whether participant has had a positive conversation with a PEV owner about their BEV (PHEV
Contextual and Descriptive (explanatory variables)	Participant	Sex	Dummy	Male = 1; Female = 0
		Age	Continuous	Mid-point of participant's age category
		HOV lane use	Dummy	Whether participant uses HOV lanes
	Household	Number of vehicles	Continuous	Number of household vehicles
		Income	Continuous	Household income
		Electricity access at residential parking spot	Dummy	Whether participant has access to electrical power service at home parking location
PEV infrastructure and market variables (exogenous variables)	Residential Zip Code	Charging locations per capita	Continuous	Number of Level 2 and DC fast charger locations in participant's home zip code per 10,000 people
		PEV registrations per capita	Continuous	Number of PEV registrations in participant's home zip code per 10,000 people

Table 2. PEV Assessment Factors in the Analysis (Latent variable)

Factor Name	Description	Survey Question	Survey Question Variable Name
BEV (PHEV) Charging Access	Extent to which participants believe they could charge a BEV (PHEV) at home and whether there is enough charging for BEVs (PHEVs)	"My household would be able to plug in a battery electric vehicle to charge at home." "There are enough places to charge battery electric vehicles. "	BEV (PHEV) Plug in at home BEV (PHEV) Enough charging
BEV (PHEV) Safety and Reliability	Safety and reliability of BEVs (PHEVs) compared to conventional gasoline vehicles	"Gasoline powered cars are safer than battery electric vehicles. "Gasoline powered cars are more reliable than battery electric vehicles.	(inverse) BEV (PHEV) gasoline safer (inverse) BEV (PHEV) gasoline more reliable
BEV (PHEV) Marketability	Environmental effects of BEVs (PHEVs) compared to conventional gasoline vehicles and whether BEVs (PHEVs) are ready to be mass marketed.	"Battery electric vehicles are less damaging to the environment than gasoline powered vehicles. "Battery electric vehicle technology is ready for mass automotive markets."	BEV (PHEV) Less damage to environment BEV (PHEV) Mass market
BEV (PHEV) Charging Duration and Range	Perception of charge time and electric range	"It takes too long to charge battery electric vehicles." "Battery electric vehicles do not travel far enough before needing to be charged."	(inverse) BEV (PHEV) range too short (inverse) BEV (PHEV) charging too long
BEV (PHEV) Price	BEV (PHEV) purchase price compared to conventional gasoline vehicles	"Battery electric vehicles cost more to buy than gasoline vehicles."	(inverse) BEV (PHEV) Price

Measurement Model

Confirmatory factor analysis (CFA) is employed for the BEV and PHEV assessment factors described in the section “PEV Assessments.” The CFA is validated using the following measures: construct reliability, convergent validity, and discriminant validity. Construct reliability (CR) should be higher than 0.70 ($CR \geq 0.70$), and average variance explained (AVE) for each latent construct should be greater than or equal to 0.50 ($AVE \geq 0.50$) to achieve convergent validity; lastly, the squared inter-correlation between constructs should be lower than average variance explained to satisfy the discriminant validity. A single combined factor analysis of all the BEV and PHEV assessment indicators was conducted, however the factor solution which provided the best fit indices was not interpretable. Therefore, two distinct factor analyses were conducted to produce assessment scores for BEVs and PHEVs, generating separate sets of factor scores for the corresponding latent assessment constructs.

Structural Model

BEV and PHEV consideration are considered into two structural models. A single model of BEV and PHEV consideration and their respective control variables was tested but resulted in levels of multicollinearity that were too high. The separate BEV and PHEV models are structured identically to facilitate comparison of coefficient values and significance levels. The following model fit indices were used to test goodness of fit: root mean squared error of approximation ($RMSEA < 0.08$), squared root mean residual ($SRMR < 0.07$), and Tucker-Lewis index ($TLI > 0.90$). The TLI is usually bounded by 0 and 1, however it is non-normed, meaning it can sometimes exceed that threshold. When this is the case, it is interpreted as 1.00. The P-value was not used as a diagnostic due to its high sensitivity to sample size.

Figure 1 shows the conceptual framework of the SEMs. The two central variables, PEV consideration and seeing charging locations, both control for the following: charging locations per capita (paths 1 & 2), and PEV registrations per capita (paths 3 & 4), demographic factors (paths 8 & 11), PEV knowledge and awareness measures (paths 6 and 9), and assessment factors (paths 7 & 10). Including a relationship between advertising awareness and BEV (PHEV) consideration resulted in multicollinearity and therefore was removed. The covariance estimated in the model, between BEV (PHEV) consideration and seeing charging locations (path 5)[1], is denoted as a curved double-headed arrow, indicating that while the two things are allowed to be correlated, no causal relationship is stipulated. There is also a model-implied covariance between PEV registrations per capita and charging locations per capita (path 12). Please refer to the Appendix for the model implied covariance matrix of all the exogenous variables.

[1] The covariance between two variables is equal to their correlation times the product of the variables’ standard deviations, while the covariance of a variable with itself is the variable’s variance.

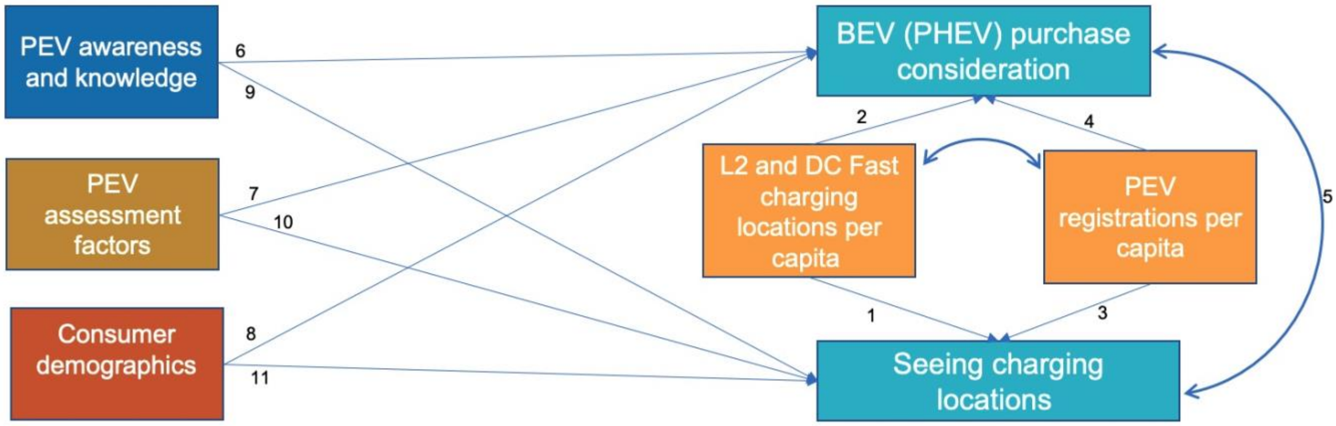

Figure 1. Conceptual Model Framework (path numbers are explained in the preceding paragraph). The colors on the left indicate categories of variables: blue for PEV awareness and knowledge; gold for assessment factors; and brown for contextual/descriptive.

Results

First, descriptive statistics provide an overview of the study participants' socio-demographic profiles, as well as distributions for the models' explanatory variables. Then we present results of the measurement models, followed by results of the structural models.

Descriptive Statistics

Table 3 provides the socio-demographic profile of survey participants compared with households in California from the American Community Survey 2019 5-year estimates. Several demographics differ across the two samples; our survey sample exhibits higher income and education, more household vehicles, and higher proportions of detached housing and home ownership than the American Community Survey data. There are no comparative measures for some of the variables available in our data. For examples, 20% of our survey participants use HOV lanes and 72% have electricity access at their residential parking spot.

Table 3. Socio-demographic Profile of Survey Participants Compared with Respondents to the California Subset of the 2019 American Community Survey (ACS)

Demographic	Category	Survey participants, percent	2019 ACS, percent
Sex	Male	47.7	49.7
Age (closest ASC age category in parentheses)	19 to 29 (20 to 34)	16.2	22.1
	30 to 39 (35 to 44)	22.7	13.4
	40 to 49 (45 to 54)	17.4	12.6
	50 to 59 (55 to 64)	15.5	12.1
	60 to 69 (65 to 74)	16.2	8.6
	70 or older (75 or older)	12.1	6.2
Household income	Less than $50,000	24.9	34.4
	$50,000 to $99,999	34.2	27.9
	$100,000 to $149,999	19.8	16.6
	$150,000 or more	21.0	21.1
Education level	Did not graduate high school	2.0	16.7
	High school graduate	12.3	20.5
	Some college	26.4	21.1
	College graduate	32.1	21.2
	Masters, Doctoral or Professional degree	21.2	12.8

Demographic	Category	Survey participants, percent	2019 ACS, percent
Number of household vehicles	1	48.4	32.8
	2	39.1	40.0
	3+	12.5	27.2
Home type	Detached house	62.2	57.7
	Apartment	13.4	23.5
	Attached house	12.7	7.0
	du-,tri-,or four-plex	5.7	7.9
	Other	6.0	3.9
Home ownership	Own	62.4	54.8
	Other	37.6	45.2

Figure 2 shows the distribution of responses to whether people have seen PEV charging locations. While most participants report they have seen PEV charging in one or more of the parking facilities they use, roughly one quarter either affirm they have not seen any or are unsure. Figure 3 shows the distribution of the extent to which people have considered acquiring a BEV (PHEV) for their household. Only a small portion of participants owns, has owned, or has actively shopped for a PEV. Most participants have given no consideration to acquiring either a BEV or a PHEV, and about one fourth profess outright opposition to doing so.

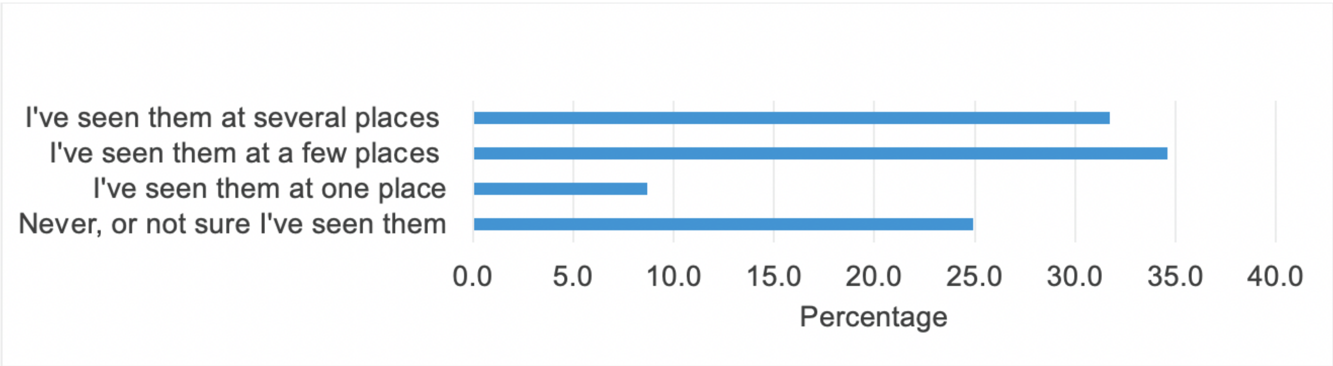

Figure 2. Distribution of Seeing Public PEV Charging: "Of the parking facilities you use, in how many have you seen PEV charging?"

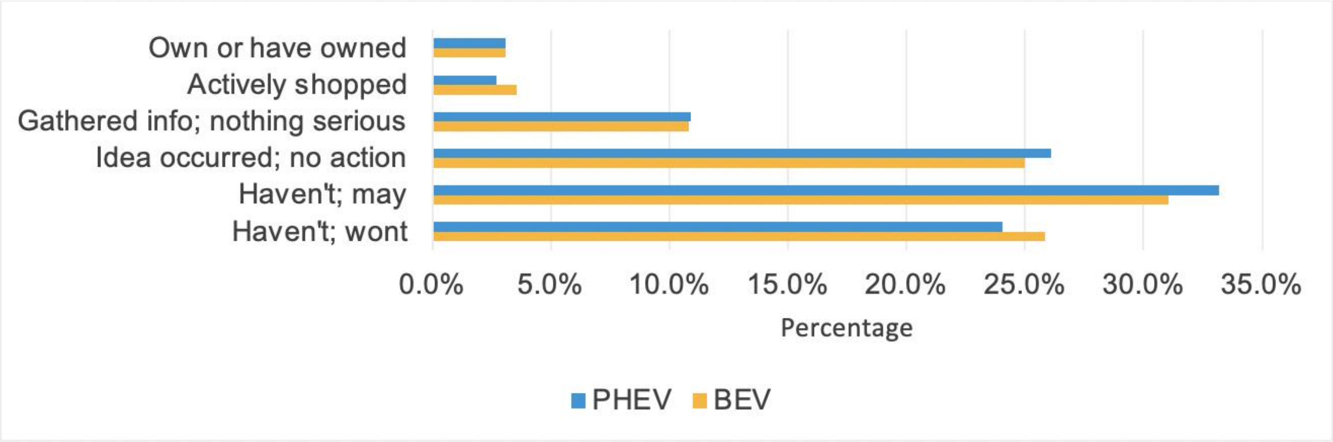

Figure 3. Distribution of BEV and PHEV Consideration: "Have you considered buying an PEV for your household?"

Figure 4 shows the percentage of participants who claim to have heard of incentives from different sources. Over 40% of participants are aware of federal and state government incentives, and over a third are aware of incentives offered from the California state government and vehicle manufacturers.

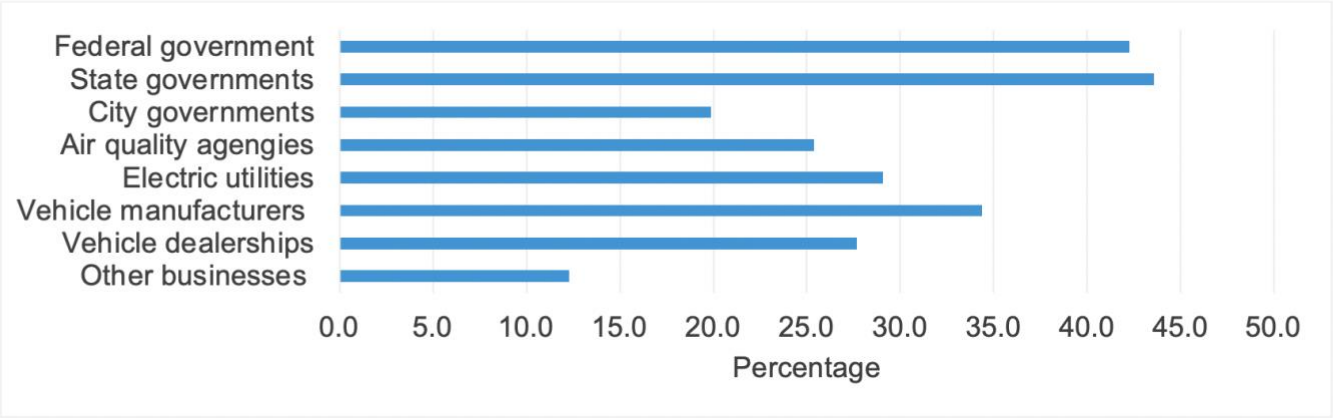

Figure 4. Participants reporting they have heard of different entities offering incentives for "alternatives to gasoline and diesel."

Figure 5 shows the distribution of number of sources of incentives participants report knowing. Though most participants claim to have heard of one or more incentives, a plurality of about one-third claim to know of no incentives to consumers to buy vehicles fueled by "alternatives to gasoline and diesel."

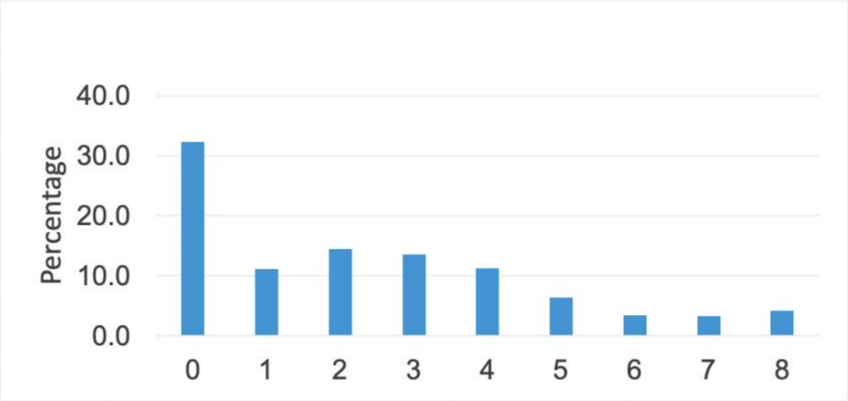

Figure 5. Number of incentives of which participants report being aware

While on average, participants report similar, low levels of familiarity and experience with BEVs and PHEVs, more participants knew how to correctly refuel a BEV than a PHEV. In addition, more participants were able to name a BEV than a PHEV. Figure 6 shows the distribution of participants who report seeing PEV advertising from different media. Television advertisements are the most frequently reported source, and social media was reported more frequently than print media, radio, and roadside signs. Figure 7 shows the names of BEVs and PHEVs participants were able to name, as well as the proportion of participants who were unable to name one or attempted to name one but were incorrect. In general, participants have little knowledge of names of PEVs available in the market; over half of the participants were unable to name a BEV and more were unable to name a PHEV. Just over a quarter of participants were able to correctly name Tesla (BEV), and just over 10% of participants could correctly name Prius (PHEV).

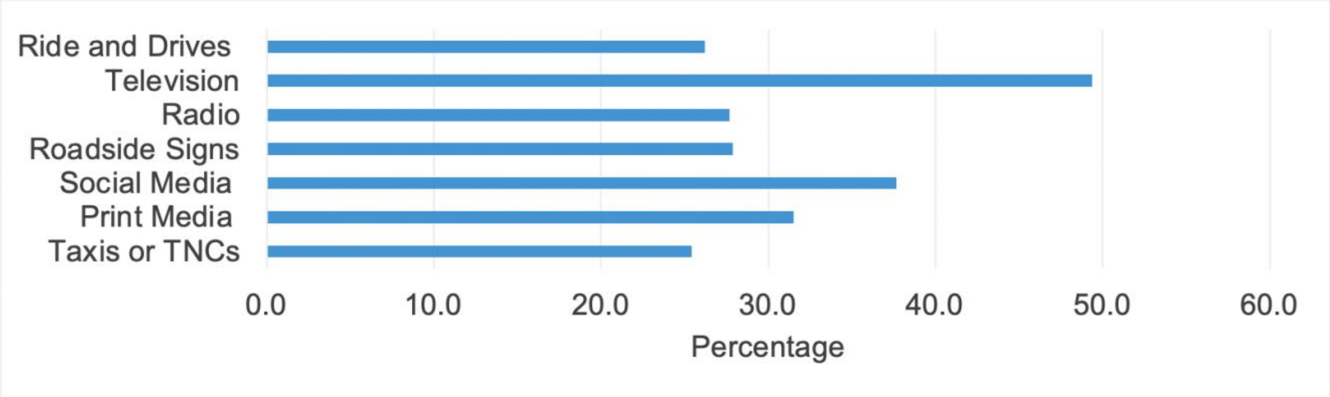

Figure 6. Participants who report seeing PEV advertising from different media.

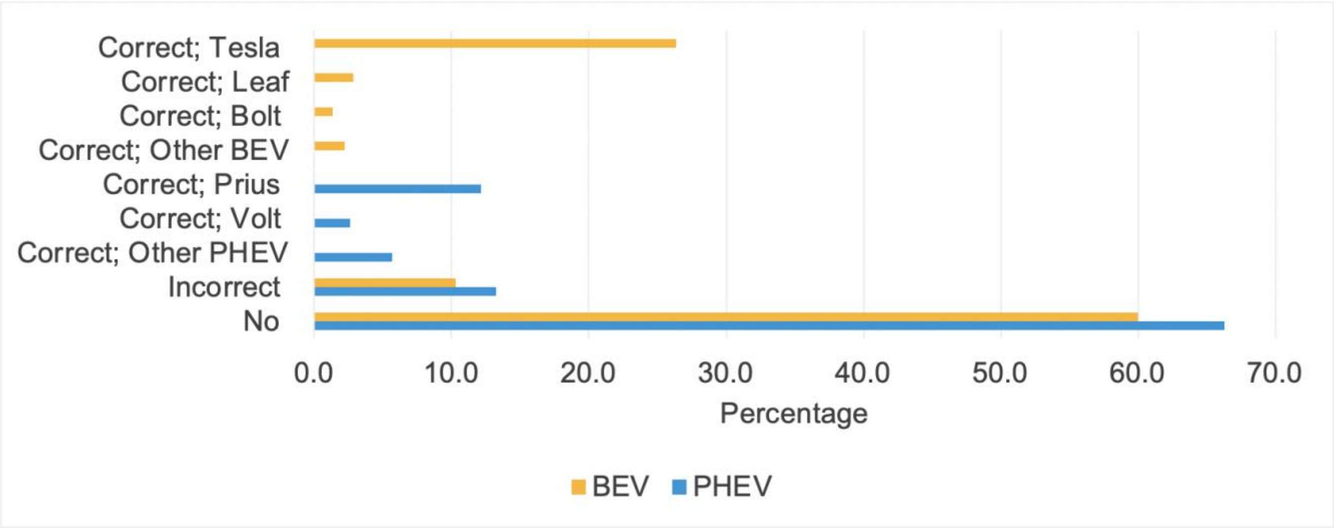

Figure 7. Whether participants were able to name a BEV or PHEV for sale in the U.S.

Figure 8 shows the sources from which participants have gathered information about PEVs. Participants predominantly gather information from vehicle manufacturers, followed by car reviews, friends, and family.

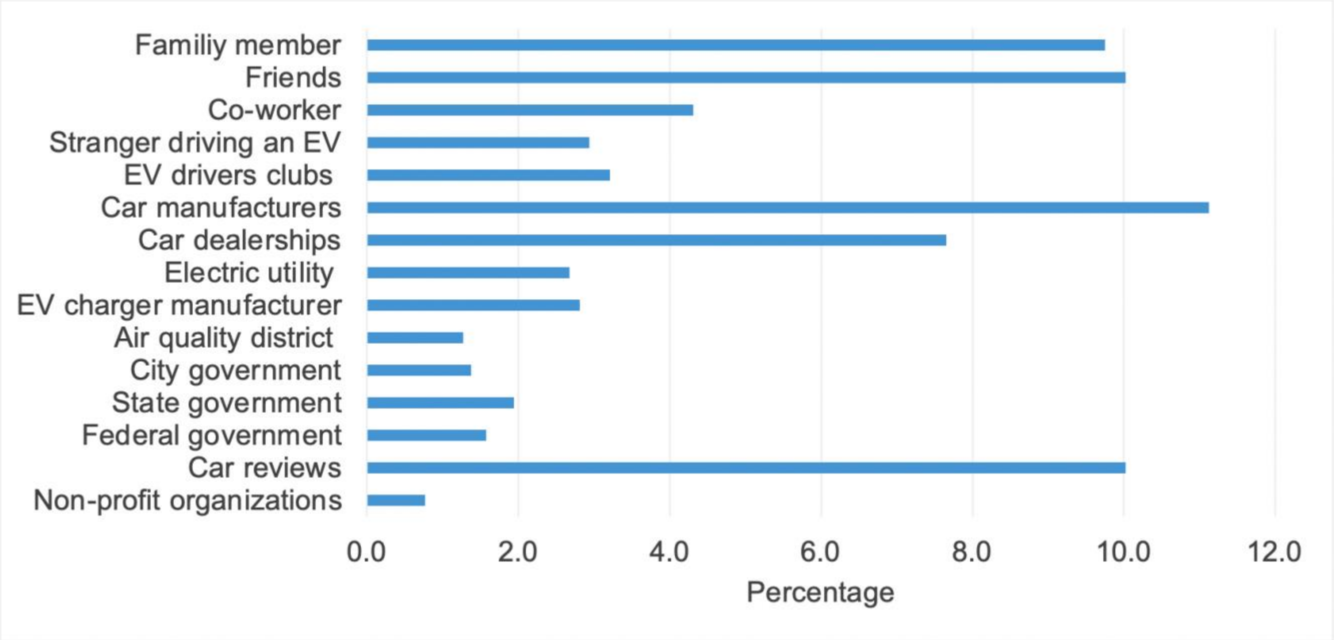

Figure 8. Participants who report seeking information on PEVs from the sources listed

Figure 9 shows the distribution of Level 2 and DC fast charging locations and PEV registrations per capita at the zip code level. The mean number across all zip codes in California of Level 2 plus DC fast charging locations per capita is 0.24. However, this value is biased upward by a few zip codes which have very high densities. The median number of chargers per capita is only 0.07. The mean number of PEV registrations per capita is 1.44 which is also subject to some upward bias by comparatively few zip codes; the median is 1.03.

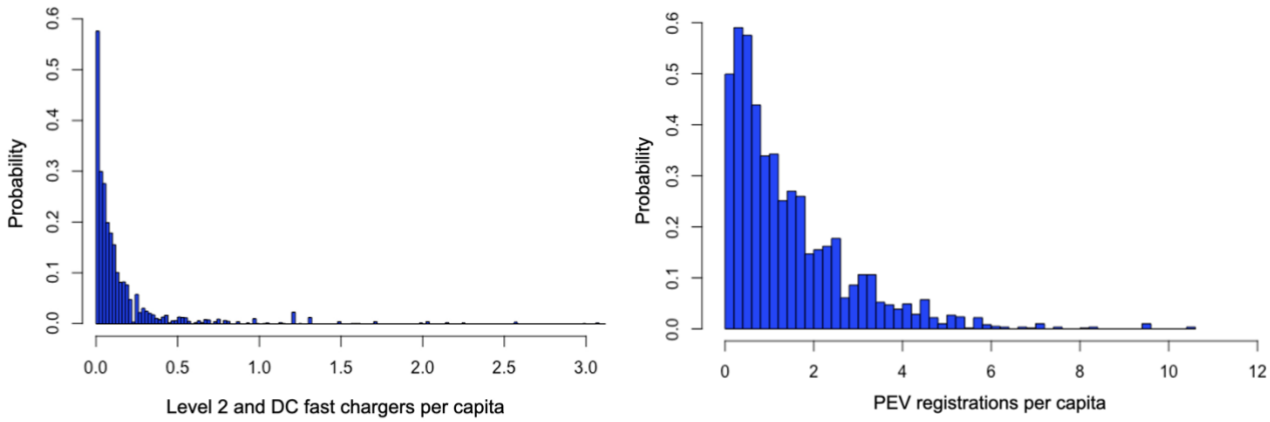

Figure 9. Distribution of Number of PEV charger locations and PEV registrations per 10,000 persons at the zip code level

Measurement Model

Table 4 and Table 5 present the factor loadings from confirmatory factor analysis (CFA) on the BEV and PHEV assessment factors. The results support the idea that eight of nine BEV and PHEV assessments represent four latent constructs. All observed indicators are significant in each latent factor and have a factor loading above 0.50. The ninth assessment related to the relative purchase price of BEVs and PHEVs compared to conventional gasoline vehicles is retained as a separate control variable in the structural model. Attempting to include it in the CFA produced factor loadings below 0.5. Additionally, the CFA results in Table 6 and Table 7 demonstrate that discriminant validity, construct reliability, and convergent validity all exceed the recommended thresholds. We use the assessment factor scores to predict each participants' individual factor score for use in the structural model.

Table 4. BEV Assessment Confirmatory Factor Analysis Results

Latent Construct	Indicator	Factor Loading	Standard Error	P-value
BEV charging duration and range	(inverse) BEV range too short (inverse) BEV charging too long	0.750 0.775	0.000 0.041	 0.000
BEV safety and reliability	(inverse) BEV gasoline safer (inverse)BEV gasoline more reliable	0.786 0.834	0.000 0.034	 0.000
BEV charging access	BEV plug in at home BEV enough charging	0.630 0.821	0.000 0.053	 0.000
BEV marketability	BEV less damage to environment BEV mass market	0.530 0.893	0.000 0.095	 0.000

Table 5. PHEV Assessment Confirmatory Factor Analysis Result

Latent Construct	Indicator	Factor Loading	Standard Error	P-value
PHEV charging duration and range	(inverse) BEV range too short (inverse) BEV charging too long	0.782 9.756	 0.030	 0.000
PHEV safety and reliability	(inverse) BEV gasoline safer (inverse)BEV gasoline more reliable	0.821 0.871	 0.029	 0.000
PHEV charging access	BEV plug in at home BEV enough charging	0.671 0.747	 0.045	 0.000
PHEV marketability	BEV less damage to environment BEV mass market	0.548 0.862	 0.090	 0.000

Table 6. BEV Assessment Factor Reliability and Validity

BEV Assessment Factors	BEV Charging Duration and Range	BEV Marketability	BEV Charging Access	BEV Safety and Reliability	Composite Reliability
BEV charging duration and range	**0.58**				0.73
BEV marketability	0	**0.54**			0.69
BEV charging access	0	0.39	**0.52**		0.68
BEV safety and reliability	0.38	0.01	-0.02	**0.65**	0.79

Table 7. PHEV Assessment Factor Reliability and Validity

PHEV assessment Factors	PHEV Charging Duration and Range	PHEV Marketability	PHEV Charging Access	PHEV Safety and Reliability	Composite Reliability
PHEV charging duration and range	**0.59**				0.74
PHEV marketability	0	**0.53**			0.68
PHEV charging access	-0.02	0.44	**0.5**		0.67
PHEV safety and reliability	0.47	0	-0.01	**0.716**	0.83

Structural Model

The structural model (Figure 10) tests hypotheses about the relationship among participants': (i) socio-economic descriptions; (ii) contextual backgrounds; (iii) PEV awareness, knowledge, and assessment factors; (iv) consideration of BEVs (PHEVs); and (v) whether they see public PEV charging locations—while controlling for densities of PEV registrations and PEV charging locations in their residential zip codes. Covariance between PEV registrations per capita and charging locations per capita controls for the known aggregate relationship between PEV sales and PEV charging deployments without specifying a causal relationship between the two. Similarly, covariance between BEV (PHEV) consideration and seeing charging locations allows those to covary without stipulating that one causes the other. The model is illustrated in Figure 10 which elaborates the conceptual model in Figure 1 to show all the modeled relationships between variables. The statistically significant relationships in the estimated structural models, in addition to the model-implied covariance between PEV registrations and charging locations per capita, are shows in Figure 11 (BEVs) and Figure 12 (PHEVs); non-significant relationships are omitted. For example, in Figure 10 we see the model includes the effect of the number of incentive sources of which a participant is aware on their consideration of both BEVs and PHEVs. However, this effect is non-significant in both the BEV and PHEV model, thus the link from *Number of incentives* to *BEV (PHEV) purchase consideration* is omitted in both Figure 11 and Figure 12. For the significant effects in Figure 11 and Figure 12, the link is labeled with the odds ratio.

The odds ratios, their standard errors, and their p-values for all estimated relationships illustrated in Figure 10 are shown for BEV (PHEV) consideration (Table 8), seeing charging locations (Table 9), and the covariances (Table 10). These are interpreted as the increase in the odds of being in a higher rather than lower category of consideration or seeing charging locations rather than not seeing them for a unit increase in one variable while holding all other variables constant. That is, the odds ratios are indicators of the size of the effects. The tests of significance indicate whether we are confident the odds ratios are different from 1.0 (which indicates no effect). Table 10 shows the covariance results, which are interpreted as the increase in the odds of one variable increasing for a unit increase in the other variable while holding all other variables constant. Table 11 provides the goodness-of fit model indices for the two models; all indices exceed their recommended threshold.

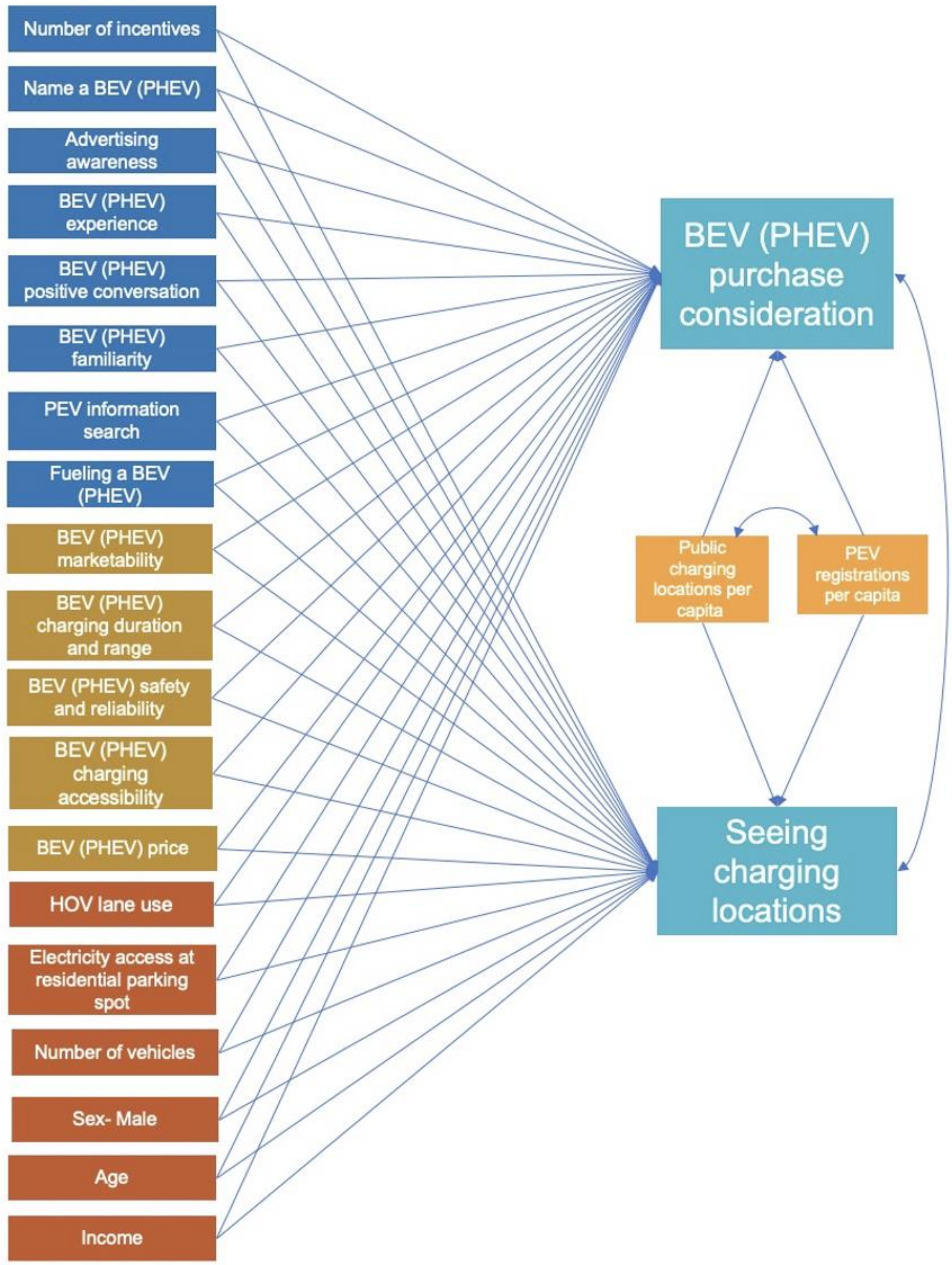

Figure 10. All modeled effects in structural models for BEVs and PHEVs. The colors on the left indicate categories of variables: blue for PEV awareness and knowledge; gold for assessment factors; and brown for contextual/descriptive.

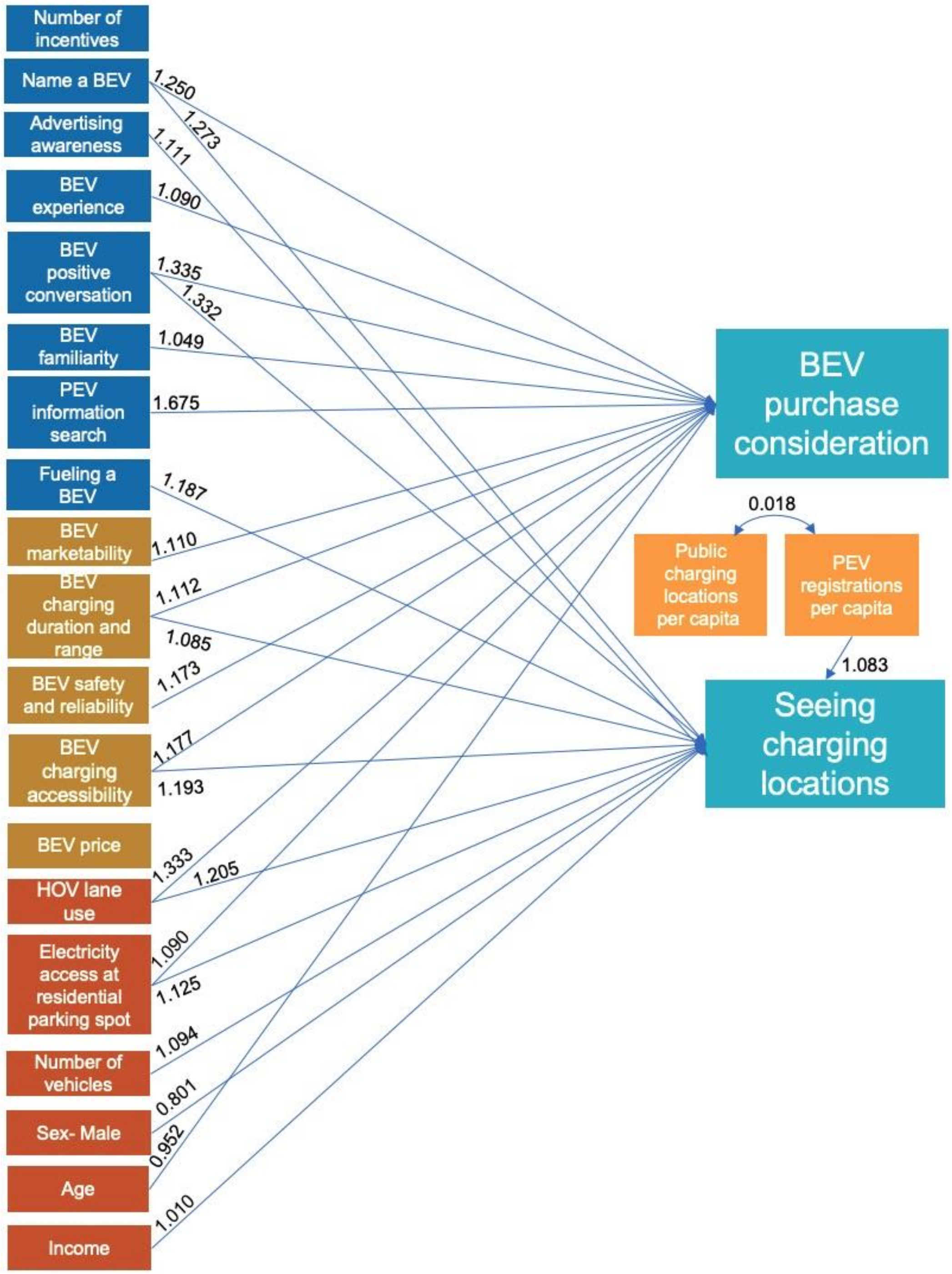

Figure 11. Statistically significant effects in the structural model for BEVs. The numbers indicate odds ratio. The colors on the left indicate categories of variables: blue for PEV awareness and knowledge; gold for assessment factors; and brown for contextual/descriptive.

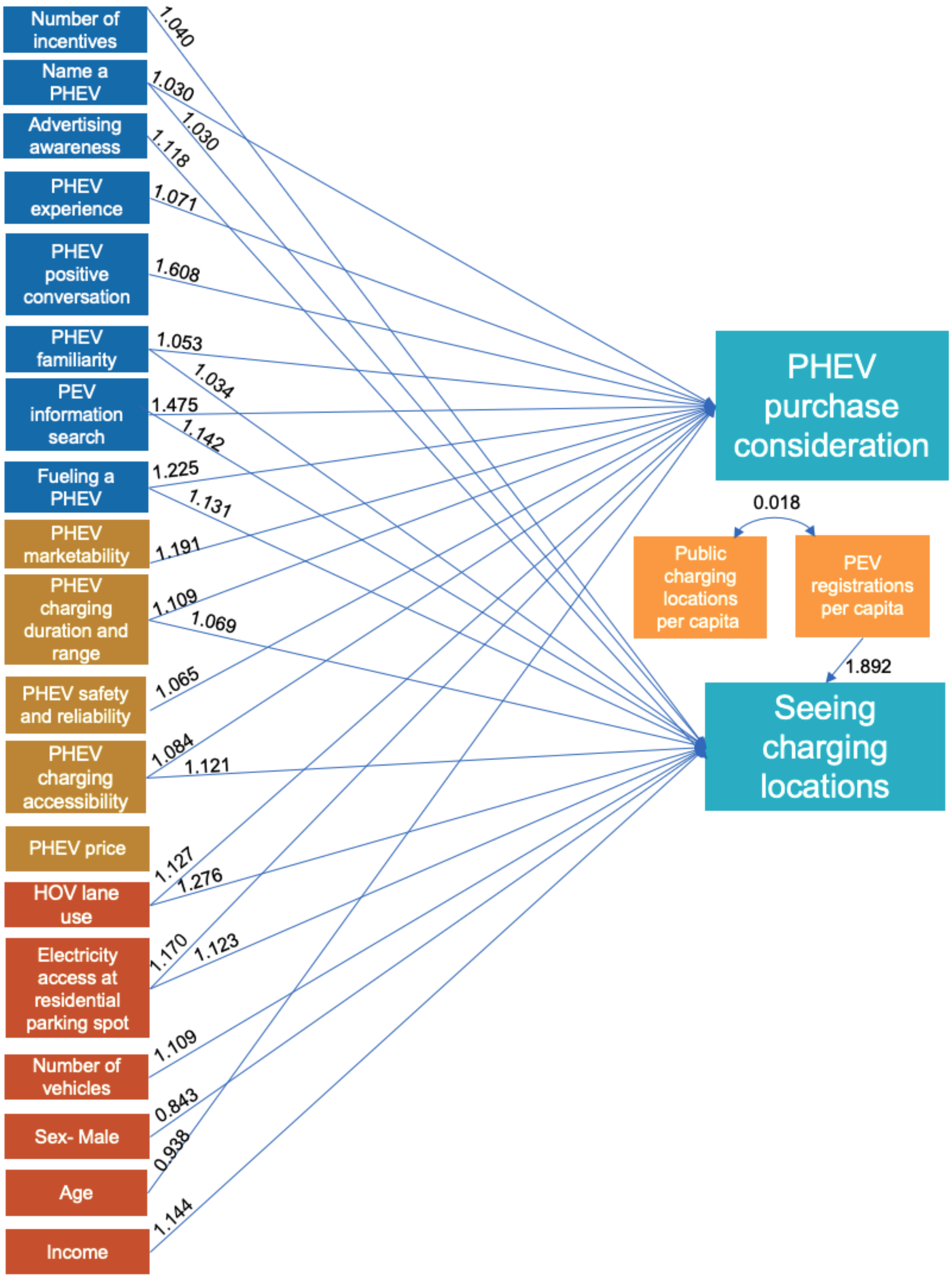

Figure 12. Statistically significant effects in the structural model for PHEVs. The colors on the left indicate categories of variables: blue for PEV awareness and knowledge; gold for assessment factors; and brown for contextual/descriptive.

Table 8. Structural Equation Model Results for BEV and PHEV consideration

	BEV purchase consideration				PHEV purchase consideration			
	Odds Ratio		Std. error	P-value	Odds Ratio		Std. error	P-value
Fueling a BEV (PHEV)	1.050		0.050	.327	1.225	***	0.037	0.000
Name a BEV (PHEV)	1.250	**	0.055	0.001	1.165	***	0.038	0.000
Number of incentives	1.017		0.010	0.921	1.006		0.010	0.567
BEV (PHEV) familiarity	1.049	***	0.012	0.000	1.053	***	0.008	0.000
BEV (PHEV) experience	1.090	***	0.009	0.000	1.071	***	0.010	0.000
PEV information search	1.675	***	0.040	0.000	1.475	***	0.042	0.000
BEV (PHEV) positive convo	1.335	**	0.061	0.001	1.608	***	0.067	0.000
BEV (PHEV) charging access	1.177	***	0.021	0.000	1.084	**	0.025	0.006
BEV (PHEV) safety/reliability	1.173	***	0.018	0.000	1.065	**	0.021	0.004
BEV (PHEV) marketability	1.110	***	0.027	0.000	1.191	***	0.037	0.000
BEV (PHEV) charging duration and range	1.112	**	0.019	0.002	1.109	***	0.022	0.000
BEV (PHEV) price	0.993		0.011	0.376	0.976		0.012	0.047
Sex- Male	1.020		0.036	0.952	0.990		0.036	0.789
Age	0.952	***	0.013	0.000	0.938	***	0.014	0.000
Income	1.002		0.024	0.581	1.008		0.025	0.753
HOV lane access	1.333	***	0.041	0.000	1.127	**	0.042	0.005
Number of household vehicles	1.094	**	0.049	0.006	1.001		0.029	0.963
Electricity access at residential parking spot	1.090	*	0.044	0.049	1.170	*	0.044	0.010
Charging locations per capita	1.029		0.016	0.064	1.013		0.011	0.267
PEV registrations per capita	0.974		0.162	0.872	1.023		0.015	0.131

Statistical significance of P-values: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’

Table 9. Structural Equation Model Results for Seeing Charging Locations

	Seeing charging locations- BEV			Seeing charging locations- PHEV		
	Odds Ratio	Std. error	P-value	Odds Ratio	Std. error	P-value
Advertising awareness	1.111 ***	0.013	0.000	1.118 ***	0.013	0.000
Fueling a BEV (PHEV)	1.187 ***	0.048	0.000	1.131 **	0.044	0.001
Name a BEV (PHEV)	1.273 ***	0.048	0.000	1.030 **	0.048	0.005
Number of incentives	1.026	0.014	0.065	1.040 **	0.013	0.004
BEV (PHEV) familiarity	1.015	0.011	0.166	1.034 **	0.010	0.009
BEV (PHEV) experience	0.997	0.015	0.858	0.975	0.015	0.110
PEV information search	1.075	0.058	0.218	1.142 *	0.058	0.023
BEV (PHEV) positive convo	1.332 *	0.083	0.021	1.067	0.086	0.449
BEV (PHEV) charging access	1.193 ***	0.028	0.000	1.211 ***	0.032	0.000
BEV (PHEV) safety/reliability	0.983	0.026	0.508	1.023	0.027	0.401
BEV (PHEV) marketability	1.020	0.038	0.603	0.975	0.046	0.586
BEV (PHEV) charging duration and range	1.085 *	0.027	0.043	1.069 *	0.030	0.039
BEV (PHEV) price	0.990	0.013	0.456	0.993	0.015	0.621
Sex- Male	0.801 ***	0.045	0.000	0.843 ***	0.044	0.000
Age	1.039 *	0.017	0.011	1.027	0.017	0.114
Income	1.010 ***	0.029	0.000	1.144 ***	0.029	0.000
HOV lane access	1.205 **	0.057	0.001	1.276 ***	0.058	0.000
Number of household vehicles	1.130 ***	0.031	0.000	1.109 **	0.031	0.001
Electricity access at residential parking spot	1.125 *	0.048	0.015	1.123 *	0.049	0.018
Charging locations per capita	1.004	0.033	0.892	1.004	0.033	0.892
PEV registrations per capita	1.083 ***	0.017	0.000	1.892 ***	0.017	0.000

Statistical significance: p-values of 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’

Table 10. Covariance Results

	Covariance: BEV model			Covariance: PHEV model		
	Odds Ratio	Standard Error	P-value	Odds Ratio	Standard Error	P-value
BEV (PHEV) Consideration ~~ Seeing charging locations	1.008	0.016	0.371	0.987	0.017	0.416

Statistical significance of P-values: 0 '***' 0.001 '**' 0.01 '*'

Table 11. Model Fit Indices

Model specification	Model summary	RMSEA	RMSR	TLI
BEV model	Test-statistic = 7.263 df = 1 N = 2,530	0.043	0.019	9.035
PHEV model	Test-statistic = 1.075 df = 1 N = 2,530	0.038	0.017	1.081

RMSEA, root mean squared error of approximation; RMSR, root mean square of residuals; TLI, Tucker-Lewis index; df, degrees of freedom of the model

Impact of charging location density

The estimated effect of residential zip code-level charging location density (Fig. 1, Path 1) on whether participants report seeing PEV charging is not statistically different from zero. Additionally, neither the BEV nor the PHEV model identified a significant relationship between residential zip code-level charging location density and BEV or PHEV purchase consideration (Path 2). However, the estimated effect for PEV registrations per capita produces higher odds of seeing more charging locations in both models (Path 3).

PEV purchase consideration

The model results also show that the effect charging location density has on BEV or PHEV purchase consideration is not statistically different from zero (Fig. 1, Path 5). Rather, participants' prior engagement with PEVs is associated with higher odds of both BEV and PHEV purchase consideration (Path 6). Engagement includes PEV knowledge (naming a BEV (PHEV)), and PEV awareness (prior PEV information search and having a positive conversation with a BEV (PHEV) owner). In the BEV model, prior PEV information search produces the highest odds ratio of all variables for purchase consideration. Conversely, in the PHEV model, having a positive conversation with a PHEVs owner produces the highest odds ratio for consideration. Increases in familiarity and experience produce a small increase in the odds of higher consideration in both models, while the effect of the number of incentive sources participants are aware of is not statistically different from zero for either BEV or PHEV consideration.

Engagement measures also include the latent PEV assessments: charging duration and range, marketability, safety and reliability, and charging access. All four produce significant effects; more positive assessments of

BEVs and PHEVs increase the odds of higher BEV and PHEV consideration (Path 7). However, there are differences in the magnitude of these effects between BEVs and PHEVs: the odds ratio for PHEV marketability is higher for PHEV purchase consideration than BEV marketability is for BEV purchase consideration. Conversely, the odds ratios for safety and reliability and charging access are higher for BEV purchase consideration than for PHEV purchase consideration. The price variable is not statistically different than zero for either BEV or PHEV purchase consideration.

In regard to demographics (Path 8), household income does not produce a result statistically different from zero for either BEV or PHEV purchase consideration. Having HOV lane access, electricity access at a residential parking spot, and being younger do increase the odds ratio of higher levels of BEV and PHEV purchase consideration. The effect size of commute HOV lane access is more than twice as large for BEV consideration as for PHEV consideration.

Seeing Charging locations

BEV (PHEV) knowledge and advertising awareness increase the odds of seeing more charging locations in both the BEV and PHEV model (Path 9). The assessment factors related to charging, charging access and charging duration/range, also produce a positive and significant odds ratio for seeing charging locations in both models (Path 10). In regard to demographics (Path 11), the estimated effect of income on seeing charging locations is positive and statistically significant in both models. Having HOV lane access, electricity access at residential parking spot at home, more household vehicles, and being female also increase the odds ratio of seeing more charging locations in both models.

Relationship between charging location and PEV registration density

The model-implied covariance matrix (please refer to the Appendix) indicates a positive covariance between charging locations per capita and PEV registrations per capita (Path 12); an increase in charging locations per capita is associated with an increase of PEV registrations per capita (and similarly, increasing PEV registration density is associated with increasing PEV charging location density). No causal inference is drawn from this result.

Discussion

Impact of charging infrastructure on PEV sales

Prior research has indicated there is a relationship between PEV sales and PEV charging infrastructure (2,3,10). Based on this, some stakeholders posit that the benefits of a growing PEV charging network, and public charging in particular, are two-fold: they overcome an impediment to PEV market growth by reducing consumers' fears about the lack of charging infrastructure, and they increase the proportion of electric miles that are driven for PEV owners (2, 33). Early investment in charging infrastructure has been recommended as a solution to "range anxiety" and to achieve a multiplier effect on PEV sales (10). Both these lines of argument assume people see PEV charging locations when and where they are installed, and that this leads to buyers considering and ultimately buying a PEV.

This research indicates this assumption is not true. We find there is no relationship between public charging location density and participants reporting they see PEV charging locations. Nor is there a relationship between public charging location density and PEV purchase consideration. Further, we find the relationship between seeing charging locations and PEV purchase consideration is also not statistically different from zero.

Taken together, these show there is little reason to assume that building more public PEV charging locations means more people will see that charging or that more people will consider purchasing a PEV. These results extend those of Bailey at al. and Krause et al. (24,29) which also found a weak relationship between public charger awareness and PEV interest. We do find that consumers living in regions with more PEV registrations per capita are more likely to see charging locations in the parking lots and facilities they use. This could be the result of a social network effects (e.g., coworkers, friends, acquaintances etc. owning PEVs), or perhaps reflect more PEV drivers living in these areas and having more utilization and awareness of their surrounding charging network.

PEV purchase consideration

Our findings indicate positive assessments of BEV and PHEV charging accessibility—both at and away from home, rather than the density of charging locations, leads to higher levels of PEV purchase consideration. This further suggests perceptions of PEV charging access may be formed independent of actual PEV charging density. We also find that higher awareness, better knowledge, and more positive assessments increase the odds of higher PEV purchase consideration. The exception is awareness of sources of incentives which has no effect on either BEV or PHEV consideration. Krause et al. (29) similarly found the availability of incentives did not impact interest in PEVs but argue that more accurate knowledge of PEV incentives would likely lead to an increase in consumer interest. The price variable, which captures positive perception of PEVs' price relative to gasoline vehicles, was significant only for PHEV consideration, and had a relatively small negative impact, suggesting PHEVs with lower MSRPs relative to conventional vehicles may be less appealing to consumers.

We find demographic and contextual factors such as being younger, having electricity access at the residential parking spot, and using HOV lanes to be positively associated with PEV purchase consideration. Prior studies have shown that access to charging from home is the most influential charging location in the decision to purchase a PEV, and home is the most frequently used charging location (18). Canepa et al. (35) found that for residents of multi-unit dwellings, a key barrier to PEV adoption is a lack of access to public or private charging. For the PEV market shares to increase from predominantly owners of single-family homes, to include more renters living in apartments, more efforts may be needed to increase charging access for consumers without electricity access at their residential parking spot. Our finding on age aligns with some stated preference studies (36, 37), but is in contrast with most studies on actual EV buyers (38). Lastly, our finding on HOV lane use aligns with studies that find access to HOV lanes has a strong positive association with PEV sales (39).

Seeing Charging Locations

The factors associated with more people seeing more public PEV charging locations include their prior engagement with PEVs. This "engagement" includes being able to correctly name a PEV make for sale, knowing how PEVs are refueled, seeing PEV advertising across multiple media, and having a positive assessment of charging accessibility. In other words, the people who report they see public PEV charging locations are the people who are interested in seeing them, and who already have a positive assessment of charging accessibility. People who see PEV charging locations report seeing them across the range of actual PEV charging densities observed in 2021 at the time that survey data was collected from households.

Our findings indicate that interest and engagement with PEVs leads to PEV purchase consideration and seeing signs of PEVs (such as charging), not the other way around: the mere presence of the signs does not appear to prompt purchase consideration. Increasing awareness, cultivating knowledge, enhancing experience, and improving assessments of PEVs may be at least useful if not necessary prerequisites for leveraging ongoing PEV charging infrastructure investments. In short, investing in both engagement and increasing awareness of PEV charging infrastructure alongside developing charging infrastructure may be a more effective way to grow the PEV market. In particular, engagement methods that focus on increasing interest to look for PEV charging locations may be an effective strategy to improving consumers' assessment of charging accessibility, and therefore achieving the desired multiplier effect on PEV sales.

Differences in BEV and PHEV Purchase Consideration

This study also finds differences between factors associated with BEV versus PHEV consideration. For example, a positive conversation with a PHEV owner increases the odds of having higher levels of PHEV purchase consideration more than a positive conversation with a BEV owner does for BEV purchase consideration. Still, for both vehicle types, amplifying the effects of these conversations would likely increase purchase consideration. Additionally, the estimated effects for knowledge, i.e., the ability to naming a PHEV and knowing how PHEVs are fueled, has a larger effect on PHEV purchase consideration than the corresponding knowledge has on BEV purchase consideration. This result may indicate knowledge of BEV names though more common than knowledge of PHEV names has less effect on consideration. This is consistent with the fact “Tesla” is by far the most named BEV (or PEV for that matter). In short, so many people can repeat the name “Tesla” it is likely that even people who won’t consider one, can name one. The same may be true for fueling; it may take more concerted effort to learn how PHEVs are refueled compared to BEVs especially given that consumers have been found to be confused about PHEV technology in general (27). For the BEV model, the knowledge measures have a larger effect on whether participants report seeing charging locations, but for the PHEV model knowledge has larger effect on consideration.

Conclusion

In this study, we estimate a structural equation model to investigate the relationship between PEV charging infrastructure awareness, actual measure of PEV infrastructure, and PEV consideration, controlling for public PEV charging location and PEV densities at the zip code level. We find households living in areas with more public PEV charging locations per capita are not more likely to report they see PEV charging locations than those living in regions with fewer such locations per capita. Further, whether people report seeing PEV charging is not associated with the consideration they have given to acquiring either a BEV or a PHEV. The implication of this result is that building PEV charging alone may not lead to more people seeing PEV charging, and even if people see charging this alone may not lead to increased purchase consideration of a PHEV or BEV.

Investments in PEV charging alone are unlikely to lead to increased PEV sales. The factors which are positively associated with whether people report seeing public PEV charging and higher levels of consideration are measures of peoples' prior engagement with PEVs: are they aware of incentives and advertising, do they have knowledge of available PEVs and how they are fueled, what are their assessments of PEV charging availability, PEV performance and price. In short, the people who see public PEV charging are those who are engaged enough with PEVs to see public charging—independent of how much charging there is in their local environment. Since prior research showed these measures of PEV awareness, knowledge, and assessment have not been improving over time (26,27) more efforts may be needed to engage car buyers in the transition to PEVs, and based on the results of this study, deploying EV charging is not a strategy to do this.

While public charging access does not appear to influence PEV consideration, the same is not true for home charging. We find access to charging at home is significantly correlated with considering purchasing a PHEV or BEV. People living in multi-unit dwellings may have a higher demand for public PEV charging, therefore, developing an interest to see public PEV charging may be even more important for them. This research emphasizes the need to prioritize targeting consumer engagement with PEVs to help meet PEV milestone goals.

The results gained from this analysis provide new insights into how consumers perceive PEV charging, and the factors which influence PEV consideration and PEV charging awareness and may caution against developing PEV charging infrastructure as an engagement approach. Further research should explore the effectiveness of broad engagement strategies on encouraging PEV adoption, such as marketing, social marketing, and social movements.

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Appendix

Table 12. BEV Model Implied Covariance Matrix

	Number of Incentives	Fueling a BEV	Naming a BEV	BEV famil-iarity	BEV exper-ience	PEV info search	BEV positive convo	BEV charging	BEV safety/ reliability	BEV market-ability
Number of Incentives	4.705									
Fueling a BEV	-0.005	0.203								
Naming a BEV	0.032	0.068	0.225							
BEV familiarity	1.463	0.099	0.249	4.658						
BEV experience	1.570	-0.193	-0.085	1.491	4.423					
EV information search	0.347	0.001	0.031	0.306	0.364	0.209				
BEV positive conversation	0.171	0.002	0.022	0.134	0.162	0.053	0.115			
BEV charging	0.936	-0.057	-0.004	0.906	1.278	0.195	0.093	1.527		
BEV safety and reliability	-0.245	0.102	0.112	0.204	-0.493	0.035	0.034	-0.241	1.645	
BEV marketability	0.558	-0.006	0.025	0.573	0.628	0.123	0.062	0.747	0.101	0.674
BEV charging duration/ range	-0.159	0.030	0.026	-0.032	-0.356	0.010	0.017	-0.152	1.052	0.042
BEV price	-0.197	-0.015	-0.042	-0.294	-0.109	-0.013	-0.015	-0.092	0.603	0.004
Sex- male	0.213	0.012	0.034	0.295	0.207	0.035	0.014	0.117	-0.033	0.057
Age	-0.597	0.096	0.105	-0.367	-1.052	-0.114	-0.013	-0.424	0.089	-0.233
Income	1.895	-0.157	0.154	2.233	3.724	0.550	0.344	2.150	-0.746	0.878
HOV lane access	0.160	-0.009	0.000	0.108	0.149	0.032	0.015	0.087	-0.016	0.046
Number of vehicles	0.025	0.020	0.035	0.037	-0.071	-0.006	0.010	-0.015	0.030	-0.021
Electricity access	0.158	0.001	0.017	0.233	0.216	0.034	0.019	0.184	-0.023	0.074
PEV registrations per capita	-0.001	0.003	0.009	0.026	0.019	0.004	0.002	0.008	0.007	0.008
Level 2 and DC Fast chargers per capita	-0.053	0.007	0.008	0.062	0.077	0.007	0.003	0.043	0.045	0.031
Advertising awareness	2.613	-0.094	-0.052	1.282	2.046	0.402	0.166	1.042	-0.431	0.588

Table continues on next page.

	BEV charging duration and range	BEV price	Sex- male	Age	Income	HOV lane access	Number of vehicles	Elec- tricity access	PEV regist- rations per capita	Level 2 and DC Fast chargers per capita	Advert aware- ness
BEV charging duration and range	1.247										
BEV price	0.712	2.594									
Sex- male	-0.048	-0.040	0.250								
Age	-0.130	-0.364	0.002	2.702							
Income	-0.881	-0.618	0.372	0.010	31.912						
HOV lane access	0.001	0.018	0.039	-0.142	0.165	0.164					
Number of vehicles	0.012	-0.022	-0.023	0.060	0.922	-0.016	0.602				
Electricity access	-0.039	-0.055	0.182	0.011	0.615	0.065	0.109	0.198			
PEV registrations per capita	0.006	-0.011	0.005	0.022	0.161	0.001	-0.005	0.002	0.018		
Level 2 and DC Fast chargers per capita	0.016	0.000	0.017	-0.023	0.087	0.010	-0.024	0.002	0.032	1.278	
Advertising awareness	-0.153	0.016	0.202	-1.289	2.275	0.217	-0.034	0.145	-0.014	0.034	5.159

Table 13. PHEV Model Implied Correlation Matrix

	Number of Incentives	Fueling a PHEV	Naming a PHEV	PHEV famili-arity	PHEV exper-ience	PEV info search	PHEV positive convo	PHEV charg-ing	PHEV safety/ reliability	PHEV marketa bility
Number of Incentives	4.705									
Fueling a PHEV	-0.004	0.249								
Naming a PHEV	0.049	0.051	0.166							
PHEV familiarity	1.323	0.140	0.173	4.719						
PHEV experience	1.597	-0.150	-0.014	1.308	4.235					
PEV information search	0.347	0.007	0.028	0.282	0.318	0.209				
PHEV positive conversation	0.139	0.005	0.010	0.118	0.163	0.041	0.092			
PHEV charging	0.878	-0.026	0.033	0.898	1.095	0.182	0.078	1.494		
PHEV safety and reliability	-0.278	0.131	0.100	0.125	-0.655	0.023	-0.001	-0.210	1.612	
PHEV marketability	0.480	0.019	0.042	0.524	0.477	0.100	0.048	0.732	0.038	0.561
PHEV charging duration/range	-0.265	0.099	0.080	-0.008	-0.618	0.001	-0.014	-0.231	1.178	-0.054
PHEV price	-0.292	-0.015	-0.001	-0.270	-0.255	-0.036	-0.039	-0.193	0.661	-0.144
Sex- male	0.213	0.012	0.013	0.196	0.233	-0.024	0.012	0.105	-0.034	0.051
Age	-0.597	0.087	0.091	-0.283	-1.020	0.035	-0.014	-0.329	0.127	-0.123
Income	1.895	-0.051	0.131	2.128	3.401	-0.114	0.212	2.059	-0.752	0.775
HOV lane access	0.160	-0.007	0.002	0.078	0.166	0.550	0.009	0.077	-0.023	0.039
Number of vehicles	0.025	0.040	0.031	0.019	-0.146	0.032	0.000	0.018	0.046	0.007
Electricity access	0.158	0.023	0.007	0.212	0.208	-0.006	0.015	0.196	-0.027	0.071
PEV registrations per capita	-0.001	0.002	0.003	0.017	0.008	0.034	0.001	0.008	0.005	0.006
Level 2 and DC Fast chargers per capita	-0.530	0.009	0.012	0.001	0.046	0.007	-0.003	-0.016	0.016	-0.001
Advertising awareness	2.613	2.613	-0.036	1.115	2.028	0.402	0.146	0.959	-0.174	0.252

Table continues on next page.

	PHEV charging duration and range	PHEV price	Sex- male	Age	Income	HOV lane access	Number of vehicles	Electricity access	PEV registrations per capita	Level 2 and DC Fast chargers per capita	Advert aware-ness
PHEV charging duration and range	1.355										
PHEV price	0.423	2.226									
Sex- male	-0.078	-0.032	0.250								
Age	0.019	-0.165	-0.021	2.702							
Income	-0.124	-0.344	0.129	0.010	31.912						
HOV lane access	-0.016	0.045	0.039	-0.142	0.165	0.164					
Number of vehicles	0.048	-0.021	-0.023	0.060	0.992	-0.016	0.602				
Electricity access	-0.080	-0.057	0.182	0.012	0.615	0.065	0.109	0.198			
PEV registrations per capita	-0.004	-0.005	0.005	0.022	0.161	0.001	-0.005	0.002	0.018		
Level 2 and DC Fast chargers per capita	0.012	0.048	0.017	-0.023	0.087	0.010	-0.024	0.002	0.032	1.278	
Advertising awareness	-0.137	0.017	0.203	-0.343	0.160	0.218	-0.033	0.145	-0.014	0.034	5.159