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Hybrid, plug-in hybrid, or electric—What do car buyers want?

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HIGHLIGHTS

- We assess consumer interest in various electric-drive vehicle designs.
- Web-based design games completed by 508 households from San Diego, California.
- Plug-in hybrids are most popular, followed by hybrids and conventional vehicles.
- Only a few percent opted for a pure electric vehicle.
- Electric-drive associated with intelligence, responsibility, and environment.

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ABSTRACT

We use a survey to compare consumers' stated interest in conventional gasoline (CV), hybrid (HEV), plug-in hybrid (PHEV) and pure electric vehicles (EV) of varying designs and prices. Data are from 508 households representing new vehicle buyers in San Diego County, California in 2011. The mixed-mode survey collected information about access to residential recharge infrastructure, three days of driving patterns, and desired vehicle designs and motivations via design games. Across the higher and lower price scenarios, a majority of consumers designed and selected some form of PHEV for their next new vehicle, smaller numbers designed an HEV or a conventional vehicle, and only a few percent designed an EV. Of those who did not design an EV, the most frequent concerns with EVs were limited range, charger availability, and higher vehicle purchase prices. Positive interest in HEVs, PHEVs and EVs was associated with vehicle images of intelligence, responsibility, and support of the environment and nation (United States). The distribution of vehicle designs suggests that cheaper, smaller battery PHEVs may achieve more short-term market success than larger battery PHEVs or EV. New car buyers' present interests align with less expensive first steps in a transition to electric-drive vehicles.

1. Introduction

Electric-mobility is often framed as an important component in a successful societal transitions toward deep greenhouse-house reductions (Williams et al., 2012). The uptake and use of hybrid (HEVs), plug-in hybrid (PHEVs) and electric vehicles (EVs) in the passenger vehicle market will involve meaningful shifts in social and technical systems (Sovacool and Hirsh, 2009). To investigate how consumer interest in electric-drive vehicles may guide such shifts, we engage a sample of new car buyers in a mixed-mode survey process in which they design their next potential vehicle for purchase.

The survey collected a rich, disaggregated dataset on consumers' precursor conditions, e.g., access to a place to charge a plug-in vehicle, as well as their beliefs, attitudes, and interests in electric-drive vehicles. We ascertain their interest through design games in which respondents construct a desired vehicle, rather than choosing from a choice set as is typical of stated or revealed preference choice models (Bunch et al., 1993; Ewing and Sarigollu, 2000; Hidrue et al., 2011; Train, 1980).

Our present approach extends the in-depth survey methods utilized for electric-vehicles in the 1990s (Kurani et al., 1994, 1996), and more recently applied to plug-in hybrid-electric vehicle (PHEV) demand in a 2007 survey of U.S. new-vehicle buyers (Axsen and Kurani, 2009) and the linking of PEV demand with green electricity (Axsen and Kurani, 2013). These studies utilized what we call "design games" to improve researchers' understanding of consumers' goals for advanced automotive batteries (Axsen et al., 2010) and the resulting energy and GHG implications of PHEV use in California (Axsen and Kurani, 2010; Axsen et al., 2011). We advance the 2007 nationwide survey method by expanding the vehicle design space to include conventional

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vehicles (CVs), HEVs, PHEVs, and EVs. Prices within the electric-drive design games are based on a battery cost model. The feasibility and potential cost of home vehicle recharging installation is assessed as part of the questionnaire and reflected back to the respondent during the vehicle design game.

2. Types of electric-drive vehicles and chargers

We first describe electric-drive vehicle concepts relevant to this study. HEVs rely solely on gasoline energy and are never plugged in; an electric motor and a small but relatively high-power battery offer improved energy efficiency and recapture of kinetic energy. The term plug-in electric vehicle (PEV) includes vehicles designed to plug into the electrical grid: PHEVs and EVs. PHEVs can be powered by gasoline, grid electricity, or both. PHEVs typically have larger, more powerful electric motors and larger batteries than HEVs; thus ceteris paribus their prices are higher. The charge-depleting (CD) range is the distance a fully charged PHEV can be driven before depleting its electric battery. A PHEV can be designed for either all-electric operation (AE) during this CD range, using only electricity from the battery, or for blended (B) operation using both electricity and gasoline. In this paper we identify PHEV design based on CD range and operation, i.e., AE-X or B-X, where X is the CD range in miles. Holding X constant, an AE-X design requires a battery that can deliver more power and store more energy than a B-X design. In all PHEVs, charge-sustaining (CS) mode relies solely on gasoline. Thus during CS mode a PHEV, as with a conventional HEV, would have improved fuel economy relative to a conventional gasoline vehicle. EVs are powered solely by electricity and only operate in CD mode, thus ceteris paribus they require still larger batteries that store more energy than PHEVs. We refer to such vehicles as EV-X.

At present in the U.S., PEVs can potentially be recharged using different levels of electrical service; two are pertinent to home PEV charging. Level 1 uses 110/120 V outlets, which is the most prevalent in residences in North America. Level 1 is likely sufficient for many smaller-battery PHEV designs, e.g., those that have B-X operation and/or shorter CD ranges. Level 2 charging uses 220/240 V circuits are not ubiquitously available in residences in North America, and where they are, there may only be a few for the highest-power appliances. Home access to Level 2 charging requires installation of a specialized residential vehicle charger. At the time of this study, these home chargers can cost several thousand dollars to purchase and install. A Level 2 charger can recharge a battery three to six times faster than a Level 1 charger. Faster charging may be useful for the larger batteries in some PHEVs and may be essential for EVs. Even faster rates of charging are possible, but as they require higher power electrical service than routinely found in residential buildings, we do not present such high power recharging as a residential option to respondents in our survey.

3. Approaches to PEV market research

We focus on consumer demand and motivations relating to vehicle purchase, not on use except as anticipated use might relate to the consumers' purchase decisions. There are studies that assess (Turrentine et al., 2011) or anticipate (Kurani et al., 2009; Skippon and Garwood, 2011) consumer PEV driving and recharging patterns. These two approaches show that even if households form an interest in PEVs based on their existing lifestyles, many households who drive PEVs explore and adapt their entire households' travel to a suite of household mobility tools that now includes the new plug-in vehicle (Woodjack et al., 2012). We expect that the three-day diary used in the present study may also reflect the respondents' present travel back to themselves. We do not attempt in the survey to have respondents reformulate that travel around a plug-in vehicle, though they may do so themselves in the design games.

To motivate our present research design, we organize this discussion of previous PEV market studies into three different approaches. First, constraints analyses produce forecasts of PEV market penetration based on car buyers' physical, resource, and functional constraints such as home recharge access and driving patterns, i.e., there is no effort to directly assess consumer interest in electric-drive. Consumer access to residential recharge infrastructure has been estimated using housing data as proxies, e.g., building type and year of construction. For examples, Nesbitt et al. (1992) estimated the proportion of residences with recharge access to be 28 percent in the U.S. More recently, Williams and Kurani (2006) estimated the proportion to be 15 to 30 percent in California. Other constraints analyses assess the proportion of consumers with present driving patterns that match stipulated PEV range capabilities (Bradley and Quinn, 2010; Gonder et al., 2007; Karplus et al., 2010). Pearre et al. (2011) used driving diary data to conclude that a 160 km range EV (with home charging only) could meet the travel needs of 17 to 32 percent of U.S. drivers, depending on drivers' willingness to change their travel behavior such as redistributing trips among household drivers and vehicles.

Second, discrete choice models have been used to forecast PEV market share based on different attribute combinations and consumer segments. Discrete choice models typically assess demand by representing consumers as self-interested individuals who consciously tradeoff different vehicle attributes to produce the highest utility (following the rational actor model). Attribute values are estimated based on choice sets derived either from hypothetical (stated) consumer data (e.g. Brownstone et al., 2000; Bunch et al., 1993; Hidrue et al., 2011; Potoglou and Kanaroglou, 2007) or actual (revealed) market data (e.g. Wall, 1996). Choice models tend to focus on functional aspects of PEVs, such as vehicle size, purchase price, operating cost, and performance, in addition to car buyer demographic characteristics (e.g. Train, 1980). Some studies include additional explanatory factors, such as environmental and technology attitudes (Ewing and Sarigollu, 2000), information sharing (van Rijnsoever et al., 2009) and changes in market penetration and acceptance of the new vehicle technology (Axsen et al., 2009). However, because these models tend to focus on the functional aspects of PEV technology, their conclusions focus on functional drawbacks of PEVs compared to conventional vehicles, such as increased purchase price, reduced storage space due to batteries, limited driving range and increased refueling time.

However, consumers are not just motivated by functional considerations—they may also consider symbolic and societal dimensions (Axsen and Kurani, 2012a). A predominantly functional approach neglects many intangible factors that motivate consumer purchase decisions (Steg, 2005). These factors may include the desire to represent and communicate aspects of the driver's self-identity, e.g., intelligence or pro-environmental values (Heffner et al., 2007). Many of these motivations are learned by the consumer as they and their social networks gain exposure to the new technology (Axsen and Kurani, 2012a).

A third approach to PEV market research seeks to incorporate this added complexity. Researchers examine the effects of consumer learning on the prospects for transitions to electric-drive and to address limitations of the constraints studies and choice models. For example, focus groups and interviews conducted at the advent of the period of policy, technology, and market activity regarding EVs in the 1990s reported that most consumers had so little familiarity with EVs that their preferences for novel