The Dynamics of Plug-in Electric Vehicles in the Secondary Market and Their Implications for Vehicle Demand, Durability, and Emissions

April 2018

A Research Report from the National Center for Sustainable Transportation

Thomas Turrentine, University of California, Davis

Gil Tal, University of California, Davis

David Rapson, University of California, Davis

National Center for Sustainable Transportation

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Thomas Turrentine, UC Davis Plug-in Hybrid & Electric Vehicle Research Center

Gil Tal, UC Davis Plug-in Hybrid & Electric Vehicle Research Center

David Rapson, UC Davis Economics Department & Davis Energy Economics Program

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The Dynamics of Plug-in Electric Vehicles in the Secondary Market and Their Implications for Vehicle Demand, Durability, and Emissions

ABSTRACT

California is one of the first markets in the world to have a significant secondary market for plug-in electric vehicles (PEVs), which includes both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). This study examines the status of the nascent secondary PEV market in California. We examine who purchases these vehicles and how used PEVs are utilized. We examine the role of PEV purchase incentives both via surveys of used PEV buyers and through econometric analysis of detailed micro data. Results suggests that California PEV buyers have significantly higher incomes than the average household. If California seeks to broaden the used PEV market, lower income buyers must be brought into the market. On this count, the used PEV market appears to be beneficial, attracting buyers with slightly lower incomes than in the new PEV market. Results also indicate that used PHEV owners (and, more precisely, short-range used PEV owners) are charging their vehicles less than they could. In addition, results show that early used PEV buyers have significant knowledge gaps, such as being unaware of new PEV purchase incentives, which reduce their ability to compare price options. Overall, the early used PEV buyers were satisfied with the PEV technology and would redo their purchase or buy another PEV. This bodes well for the future of the PEV market. High occupancy vehicle stickers were a powerful motivator for a subset of PHEV used buyers, perhaps due to the lack of new stickers being available at the time of and preceding the survey. Our econometric analysis shows that the presence of new BEV purchase subsidies correlates with a small net outflow of used PEVs to states that do not offer new BEV subsidies. If this modest exit of PEVs grows overtime, it could make it more difficult to achieve state level environmental goals, such as local pollution abatement or state-level GHG reduction targets. Our analysis finds that PEV sales to minority groups show no clear signs of market access discrimination in the new or used PEV markets. Finally, our findings show that PHEV and BEV markets and consumers operate differently from each other, suggesting the need to be careful about treating them identically in analysis and policy-formation.

EXECUTIVE SUMMARY

In order to meet California ‘s climate goals and clean air standards, the state is aiming to accelerate the adoption of zero emission vehicles (ZEVs), including battery electric vehicles (BEVs) and transitional-ZEVs or plug-in hybrid electric vehicles (PHEVs). The most recent state goal encapsulated in Executive Order B-48-18 seeks five million ZEVs in California by 2030. Several California Air Resources Board (CARB) programs support this goal. For example, CARB’s Advanced Clean Car ZEV regulation requires vehicle manufacturers to sell a growing percentage of ZEVs based on their total passenger car and light-duty truck sales in the state. Also, the

California Vehicle Rebate Project incentivizes consumer to buy or lease ZEVs through rebates, with higher rebate given to lower-income consumers.

Although the focus has been on the ZEV market acceleration and technology development of new ZEVs, emissions benefits depend on these vehicles being utilized for many years beyond their first owner, and powered by an ever-cleaner electric grid. Furthermore, the cost of buying or leasing a new ZEV is dependent on the residual values of those cars at the secondary market. In the market for conventional vehicles, used vehicle sales make up the clear majority of all transactions while new vehicle buyers are a smaller share of households. Therefore, used PEV sales have the potential to be significant in the market as a whole. As the number of used PEVs grows, the secondary market for PEVs will have an increasing impact as used PEV buyers join new buyers in adopting this new technology. A strong used vehicle market will allow higher adoption rates of both new and used first time buyers. However, little is known about the nascent secondary PEV market in California that is slowly emerging. Understanding the buyers of used PEVs, their sociodemographic characteristics, their knowledge about the technology, charging opportunities and incentives, is crucial in informing policies to help develop a strong ZEV market and better utilize ZEVs to maximize the environmental and social benefits.

The goals of this study were to explore California's early secondary PEV market between 2011 and 2015 to understand: 1) who purchases used PEVs and their motivations, 2) the factors that determine the price of used PEVs, 3) awareness of PEVs and new PEV purchase incentives prior to purchase, 4) vehicle usage characteristics like frequency of charging, location and type of charging infrastructure, and measure of vehicle miles traveled, 5) the effect of state level PEV purchase incentives on the flow of used PEVs across state lines, and 6) barriers that low-income and minority ethnicity buyers may experience when seeking to purchase PEVs. This research was accomplished through two methods. First, a survey of used PEV owners was administered in 2016 with results compared with surveys of new PEV owners previously deployed by co-PI. Second, econometric analyses were performed utilizing two detailed micro datasets of purchase behavior in the national wholesale market for used vehicles and in the state of California.

Survey results show that this early set of used PEV were satisfied with the PEV technology, as 95% would repeat their purchase or get a different PEV. A significant subset of early used PHEV buyers was motivated by carpool lane access stickers, which at the time of the survey were in limited supply. Their motivation for these carpool stickers is also observed with a higher price for PEVs with these stickers. Compared to new PEV owners, these early used PEV owners tended to have higher driving needs and yet plugged in their PHEVs less often resulting in higher gasoline usage thus decreasing the expected emission benefits. The survey results indicate that early adopters of used PEVs had knowledge gaps regarding the potential cost of a comparable new PEV, with about 40% being unaware of purchase incentives for new PEVs. The low awareness among a population of PEV buyers may reflect even lower awareness among the general population. The survey results suggest that current buyers of used PEVs have socio-demographic characteristics similar to new PEV buyers, though this may change as older and lower priced PEVs enter the used vehicle market. For example, early used PEV buyers still have relatively high incomes compared with average car-owning households, although slightly less than new PEV buyers. The survey results suggest very limited penetration rate to lower-income households and low-income communities. To achieve its ZEV adoption goals, California must continue to broaden the used PEV market.

The econometric portion of this research examines the relationship between new PEV incentives and the flow of used PEV trade across states, and seeks to identify barriers to PEV purchase opportunities that may exist among low-income and minority ethnic populations. Our trade results show that states with purchase incentives for new BEVs exhibit lower used-BEV prices and a higher rate of used BEVs exiting the state. This analysis uses the baseline level and prices differences in the HEV market as a control group for BEVs and PHEVs. In 2014-2015, the presence of new BEV subsidies led to a 4.5-4.6 percent increase in the rate of BEVs leaving those states and a $250-400 price discount. There does not appear to be a similar effect of new PHEV subsidies on the rate of exit of used PHEVs. While California is the largest exporter of BEVs, it still experienced only a small net flow of BEVs out of the state during this period. So, while the phenomenon that we document is consistent with the economic incentives created by the differential subsidy treatment of new and used PEVs, it is also not a large effect in absolute terms. However, as the size of the used market increases, failure to address these market forces could possibly lead to a continued and growing exit of PEVs. Some programs in the state already are moving towards a sensible remedy, such as the Enhanced Fleet Modernization Plus Up program that offers subsidies for used PEVs in addition to new.

Our analysis of PEV sales to minority and low-income groups does not reveal evidence of systematic barriers in the new or used PEV markets. In new PEV markets, low-income customers pay approximately the same price for PEVs than do higher-income buyers. While there are differences in prices paid across various demographic groups, they suggest that non-Hispanic whites and Asians, not Hispanics and African Americans, pay a price premium when purchasing new PHEVs and BEVs. This may be due to differences in unobserved car attributes (e.g. trim). Moreover, local availability, as measured by distance traveled, does not appear to explain the gap in adoption for new PEVs. In the used market, there is modest evidence of heterogeneous barriers across ethnic and income groups. Non-whites buying PHEVs, and Hispanics buying BEVs, on average pay lower prices in the used PEV market as their income increases. While these results do not indicate evidence of systematic differences in market treatment towards potentially-disadvantaged communities, they also reflect differences in unobserved (to the researchers) attributes. We therefore suggest that further research would be valuable insofar as it may overcome these selection concerns.

Overall this study is focused on early market plug-in vehicles sold in the used market after a relatively short time. Nevertheless, the results suggest that improving the information on purchase incentives available for new and used PEVs and higher level of education and awareness may help create a more robust used market. The price of used PEVs suggests that, in this early phase of the market, PHEVs retain more of their value relative to BEVs. However, that may change once longer range BEVs enter the used car market. Future work will benefit from a more mature market. There will be value in replicating the work in this project to understand the composition of buyers' changes, and to overcome statistical power issues inherent in small sample settings. We suggest expanding this work to examine three main topics: 1) The impact of the secondary market on the spatial distribution of PEVs and the derived demand for home and work charging infrastructure. This topic will also have an impact on the expected impact of the used market on GHG and criteria pollutant emissions and inform the level of infrastructure investment required to sustain the growing PEV power needs. 2) How the secondary market responds to the presence of incentives in the market in general, and how the patterns of trade may differentially benefit certain income and ethnic communities. 3) The extent to which activity in the secondary market affects new PEV sales. Of particular interest may be the impact of the residual value on the private and lease markets, and the rate of PEV trade between California and other states.

1 Introduction

In most vehicle markets in the world there are very few used plug-in electric vehicles (PEVs). California is one of the first markets to have a significant secondary PEV market - about 5-8% of about 300,000 PEVs in California were being used by a second owner in 2016. In the market for conventional vehicles, used vehicle sales make up the clear majority of all transactions while new vehicle buyers are a smaller share of households. Therefore, used PEV sales have the potential to be very significant in the market as a whole. As the number of used PEVs grows, the secondary market for PEVs will expand as used PEV buyers join new buyers in adopting this new technology.

Researchers at the Plug-in Hybrid & Electric Vehicle Research Center (PH&EV Center) completed Tasks 1-3 as laid out in the original scope of work (survey of used PEV owners and analysis of the data). A working paper titled "First Look at the Plug-in Vehicle Secondary Market" has been published with the findings and is available on the website for the Institute of Transportation Studies at UC Davis. Task 4, econometric analysis of auction and dealer transaction data, was completed separately by Dr. David Rapson. The results from both parts of the research are detailed in this report.

The sample of used PEV buyers under study in the survey portion of this research was dominated by buyers who had learned about and planned to buy the specific vehicle they purchased. The vehicles tended to be relatively new with low mileage, relatively low prices, and still under warranty. This may not be the case in the future, when the PEV market will contain more and older vehicles with high mileage that are over the battery and powertrain warranty limit. Used PEV buyers are more utilitarian than new PEV buyers as reflected by their high driving need, but they may be less committed to electric driving; they do not always plug in their plug-in hybrid vehicles. As shown in our price analysis, HOV stickers have a high impact on the price paid and they may be negatively correlated with charging behavior. If given the chance, the majority of used PEV buyers would choose to repeat their purchase.

The econometric portion of this research compared flows of BEVs, PHEVs, and HEVs in and out of California and price differences between used PEVs and HEVs when new-PEV incentives were available or absent. In areas with new PEV incentives, used BEVs in general (no model differentiation) had reduced transaction prices while used PHEVs had mixed results. Comparing sales of specific vehicle models in incentive and non-incentive states showed that in general, the presence of new-PEV incentives is associated with higher used-PHEV prices and lower used-BEV prices. Price and market access discrimination for minority groups is not evident in the new PEV market. There are mixed results for the used PEV market. In general, non-white, low-income populations face higher prices in the used PEV market, relative to a baseline, than they do in the new PEV market. Some people travel farther to buy used PEVs than they do to buy used (internal combustion engine) ICE vehicles, there is not a pattern that would indicate systematic discrimination (e.g. Hispanics travel farther to buy used PHEVs but less far to buy used BEVs). While we admit that our empirical approach cannot control for all potential vehicle composition effects, we view our results as being most consistent with a market that provides access to all ethnicities and income groups.

The state of California plans to have 1.5 million zero-emission vehicles, most of them plug-in electric vehicles, on California roadways by 2025 and 5 million by 2030. This translates to 1.5 million sales of new vehicles and almost the same number of households purchasing and using a PEV between 2010 and 2025. This encompasses households that purchase a new PEV and drive it for many years as well as households who purchase or lease more than one PEV over the years. Some households will purchase or lease their second or third new PEV over this period while others will buy the used vehicles coming into the market – enjoying the lower price, but lacking some of the incentives available to the new vehicle buyers. In the general car market, two-thirds of all U.S. vehicle purchases are for used vehicles (Edmunds, 2013). Households that purchase their first PEV (whether it is new or used) are incorporating new technology into their life and are part of the social diffusion of the plug-in vehicles in the state. PEV owners with older vehicles, whether purchased new or used, are expected to have reduced performance and effective electric range.

A relatively defined set of households who purchase new vehicles in California will be the engine of the PEV deployment, leasing or buying not only the first PEVs, but a second or third PEV in the coming decade, and accelerating the used PEV market. Not every household buys or leases a new vehicle. According to the 2012 Caltrans survey and the 2009 National Household Travel Survey (NHTS) survey, two thirds of the households surveyed did not purchase a new vehicle in the last 5 years. Some in this group did not purchase any new vehicle and others did it in longer intervals than 5 years. Based on the household fleet reported in the surveys we know that 7% of households purchased 2 or more new vehicles in the last 5 years, which make this group responsible for up to one-third of the new vehicles sold (Figure 1-1).

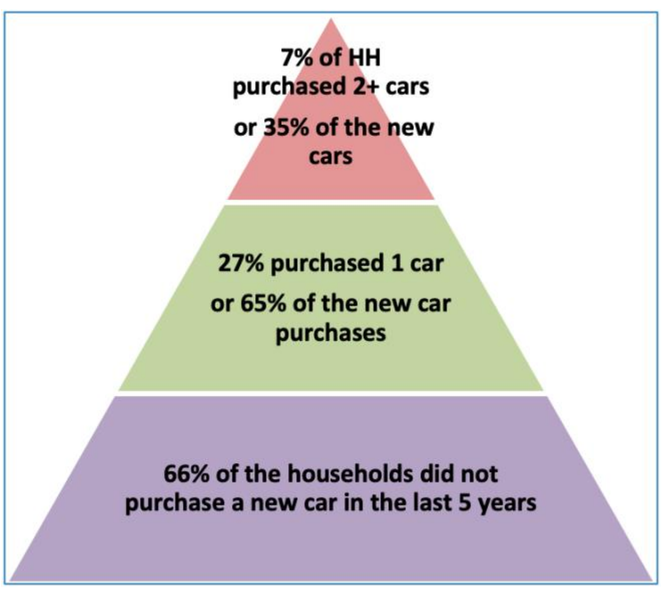

Figure 1-1. New-vehicle-buyers in California

In our 2015 survey, conducted by the UC Davis PH&EV research center, that samples the first 5 years of PEV adopters in California we found that about 23% of the households who purchased a 2015 model year PEV are doing it for the second time. Of those, 12% have two PEVs now (In Figure 1-2, "Have 2+ PEVs") and 13% moved to the secondary market (In Figure 1-2, "Had a PEV").

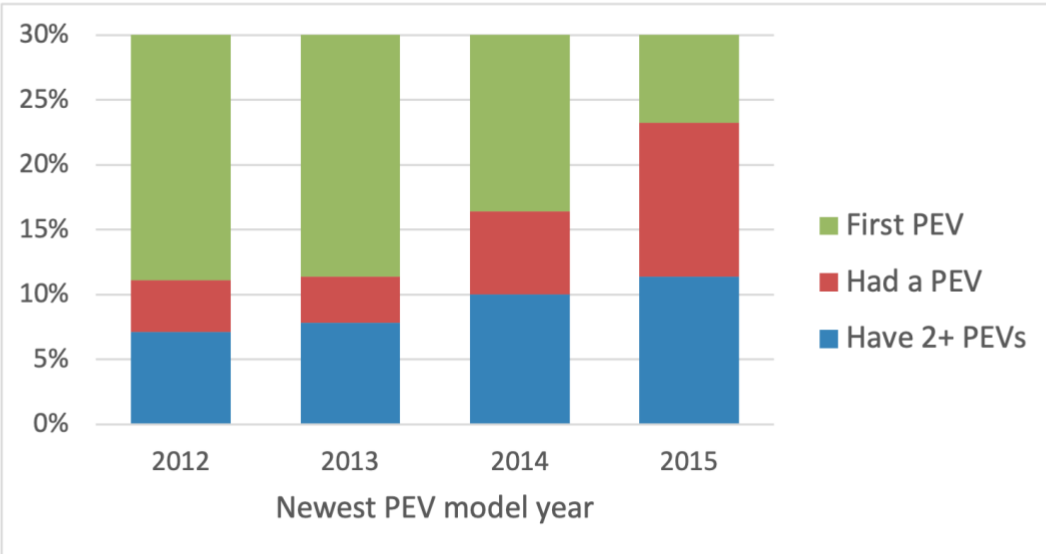

Figure 1-2. Current new PEV Buyers in California by model year

The multi-vehicle buyers, along with the two and three-year lease promotions, are expected to ramp up the market by purchasing a second and third plug-in vehicle and subsequently create a used market by selling their older vehicles. Using the same Californian sample of the 2009 national household travel survey, we expect that about a third of the PEVs will be sold within 5 years of purchase and more than 17% of the PEVs will be sold within 2 years of purchase to second owners.

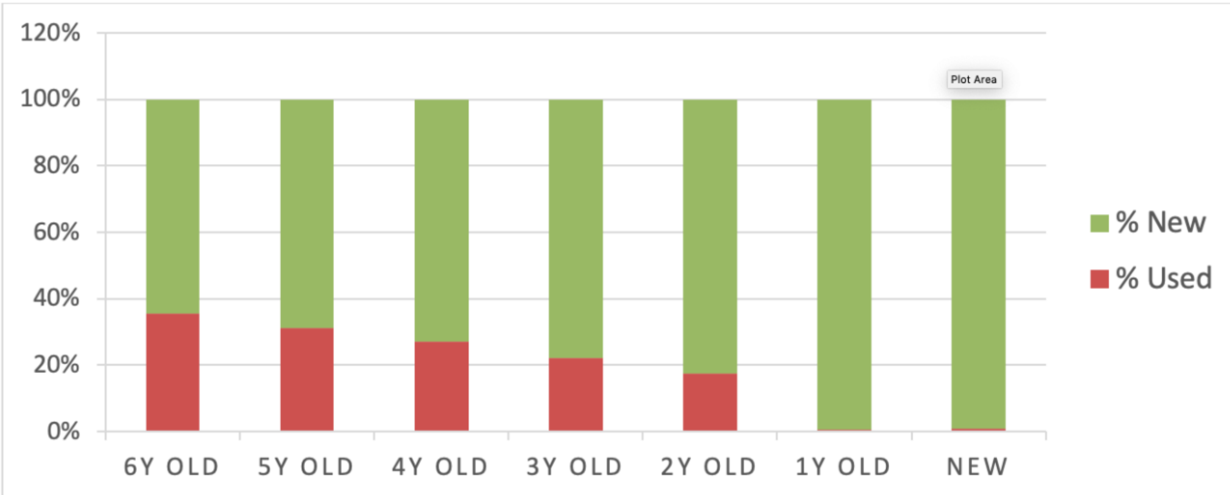

Figure 1-3. Ownership Status by Model Year

In the case of PEVs buyers, we expect higher sales rates than sales rates of ICE vehicle buyers as a result the higher income of the households purchasing PEVs. The buyers of used conventional vehicles face different costs, incentives, and in many cases, exhibit different socioeconomic characteristics. Nevertheless, there are many households that do not purchase new vehicles yet have incomes similar to new vehicle buyers as described by the blue line (66% of all households) in Figure 1-4.

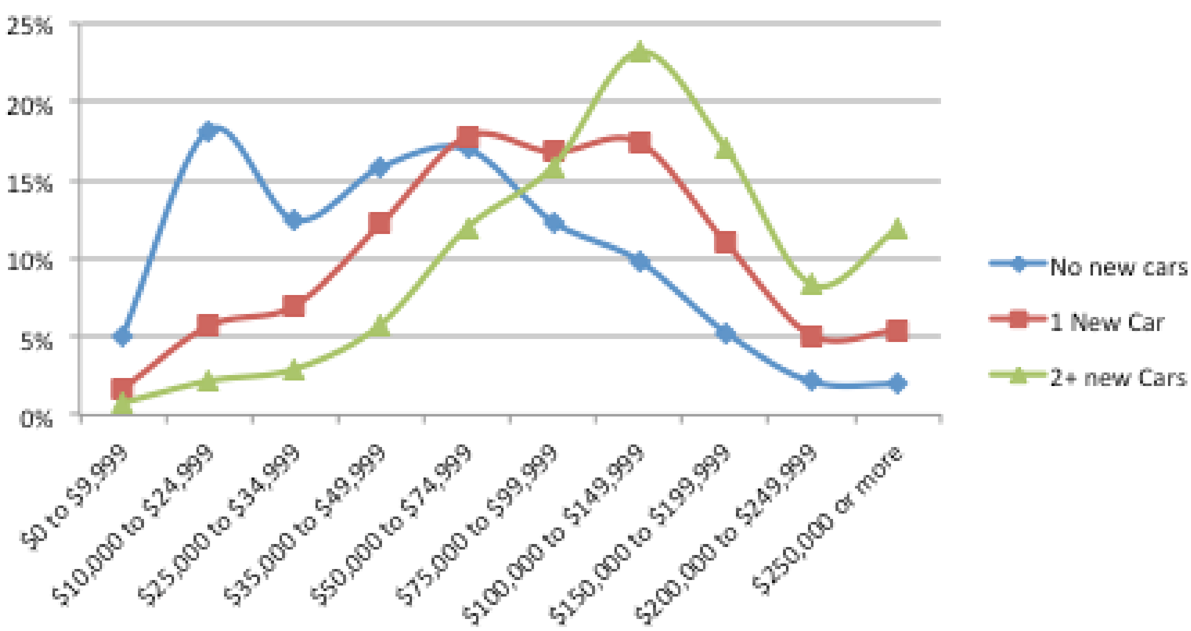

Figure 1-4. Income level of used PEV households by number of new vehicles purchased in the last 5 years

Based on the DMV records from the first half of 2016, we estimate that about 14,000 PEVs were already purchased by a second owner in California, not including second owners who had the vehicle for fewer than 6 months and leasers of new PEVs who later purchased their vehicles.

1.1 Literature Review

California had one of the first substantial plug-in electric vehicle markets in the world starting in 2011, and therefore the first substantial secondary market by roughly 2015. There is limited literature on the plug-in vehicle secondary market, so we also identified several papers that focus on the alternative fuel vehicle secondary market, mainly hybrid electric vehicles (HEVs), that look at resale value, consumer preference, and the impact on the new market. We expect the used HEV market to behave similarly to the used PEV market reflecting the tendency of buyers to adopt new technologies but differ from it with regard to the adoption of limited range BEVs and the adoption levels for households with limited ability to charge their PEVs at home.

The residual value of plug-in cars is a function of consumer perception on reliability and durability as discussed by the national academy report (Brenna et al., 2016) and demonstrated using stated preference survey by Bühler et al. (2011). The secondary market is also heavily impacted by the subsidies and incentives for new vehicles and the impact of similar policies, which we document for the first time in this report. Studies on the depreciation cost of hybrid vehicles show lower depreciation than regular cars in Japan (Iwata et al., 2016), as well as lower depreciation for vehicles branded as green compared to unbranded hybrid vehicles (i.e. a hybrid version of a conventional vehicle) (Majid et al., 2015). Another study found that traditional hybrid vehicles have a greater resale value as a proportion of the original purchase price than conventional vehicles. Results from Propfe et al., 2012 imply that cars with an electric powertrain component will maintain their value as they age due to the reduced maintenance costs associated with electric vehicles. Gas prices also have an impact on the secondary vehicle market as an increase in gas prices will (all else equal) increase the demand for fuel-efficient and alternative fuel vehicles (Busse et al., 2013).

The residual value of the vehicles likely has a strong impact on the ability of the original owner to buy a second plug-in vehicle, as first suggested by Fudenberg and Tirole (1998) as a general feature of durable goods markets. The extent to which the secondary market influences the original equipment manufacturer (OEMs) depends on the durability of the product, as shown by Chen et al. (2013). If the product is durable and reliable in the secondary market, it may lead to buyers choosing a used vehicle over a new vehicle, if it is not perceived as being durable, they may be more likely to invest in a new vehicle.

Purchase incentives and reduced taxes for the original owner may have an impact on the vehicle's residual value. They may lead to a future increase in the supply of used cars on the market and may bring down the price of used cars as demonstrated by Noparumpa et al. (2016). This reduction in price can affect the economy in several ways. Additionally, car manufacturers may be impacted as the presence of used cars affects the pricing ability and sale of future models.

1.2 Research Objectives

This project consists of two parts. The first part of this is study investigates the initial wave of used PEV buyers through a survey in order to characterize their knowledge and beliefs about the technology, experience with PEV technology and their charging systems, reasons for choosing to purchase a used PEV at this moment in a technology rollout, their actual travel behavior, the perceived condition of their vehicle at time of purchase, experience with the retail system and incentive system, as well as the prices they paid. The study characterizes the emerging market for used PEVs enabling the possibility for comparison with other survey results from new PEV buyers to understand whether these first used PEV buyers are coming from similar sociodemographic groups that have been buying new PEVs or if the used market is expanding the market to new segments of buyers.

The survey assessed the buyer's understanding of the costs and benefits of PEVs and background variables including location, socioeconomics, and demographics. This portion of the project was led by PH&EV Center researchers, Dr. Gil Tal and Dr. Thomas Turrentine.

The second part of this project employs econometric analysis of dealer and auction data to examine the overall market for used PEVs. There are two main objectives for this part of the project. First, we seek to understand how the flow of used PEVs between US states responds to the presence of new PEV subsidies. We use a rich dataset of wholesale auction market transactions from Manheim to investigate this question. The second econometric objective is to attempt to identify barriers to used PEV market access that may be presented to low income or minority ethnic populations in California. The main dataset supporting this part of the analysis was provided by Experian. These data include transaction prices, demographic characteristics and information about the geographic location of buyers and dealers. This portion of the project was managed by Dr. David Rapson.

Ultimately, the goal of this study was to help identify barriers in the policy and retail system that might limit a liquid and well-functioning used PEV market, as well as to understand how the used PEV market will impact the overall market penetration prospects for PEVs. We hope that results from this project will provide context for future efforts to estimate longer-term emissions benefits of PEVs.

2 Used PEV Owner Survey

2.1 Used PEV Owner Survey Methodology

The online survey used for this study was designed and conducted at the UC Davis PH&EV Center. Potential used PEV owners were identified via DMV records and recruited through a letter with a link to the survey. The survey was administered in April 2016.

2.1.1 Survey Tool

The survey includes questions on household socio-demographic factors, household fleet (Figure 2-1), and vehicle purchase questions including questions that will allow owners of PEVs to indicate their vehicle preferences (for example: EV range, charging speed, BEV/PHEV, size) and the willingness to pay for those characteristics.

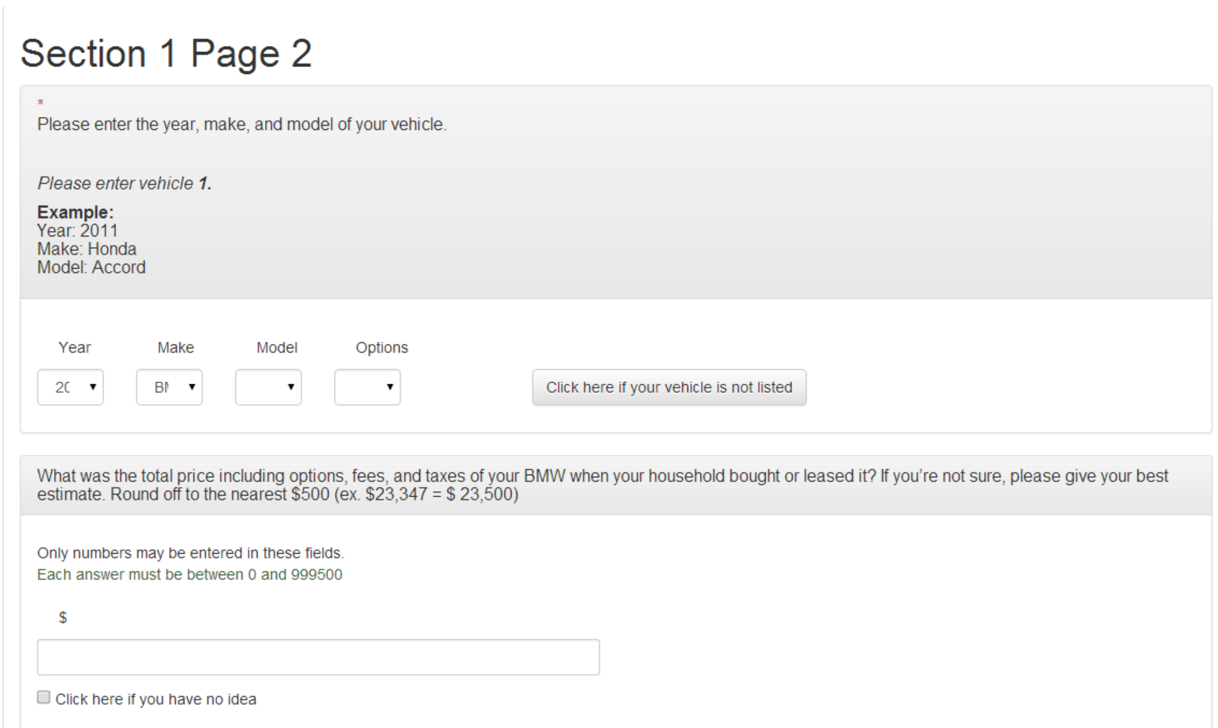

Figure 2-1. Vehicle Selection Survey Tool

We used a web-map survey tool (Figure 2-2) to collect data on travel behavior and charging activity, both actual and preferred, including the use of HOV lanes. The web-map survey allows users to indicate their origins, destinations, and preferred routes and to indicate preferred charging locations.

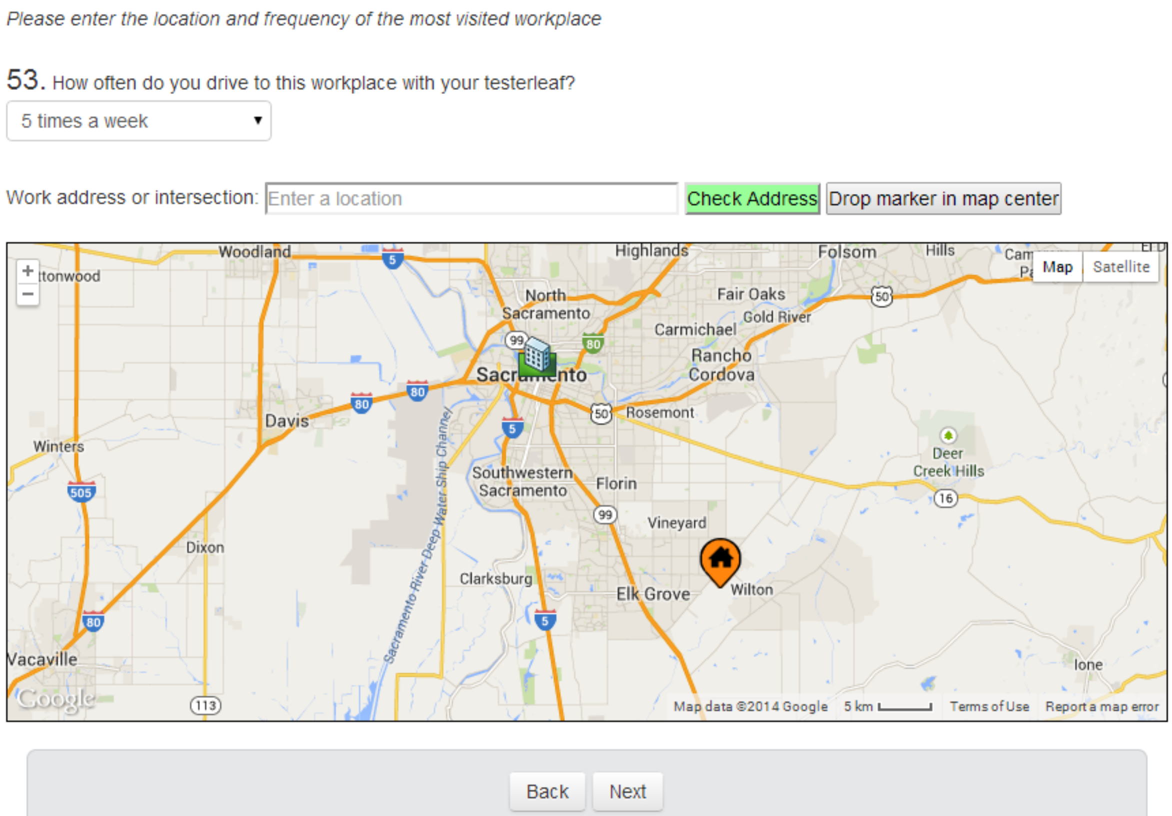

Figure 2-2. Web Map Survey Tool

The survey includes skip-logic to maximize the collected data with minimum survey burden. The questions are based on vehicle type, charging type and vehicle use. Questions on the vehicle purchase process are split based on private party purchase or dealer purchase and based on first time PEV buyers vs. second-time owners.

2.1.2 Survey Sample

Using DMV data from October 2015, the California Air Resources Board constructed a potential population of all used PEV owners in California who had registered a "used" PEV to their household. Potential used PEVs were identified if the vehicle had been transferred more than once and it had an odometer reading greater than 5,000 miles. Over 14,000 potential used PEVs were identified. We sent invitation letters to a randomly selected subsample of 4,700 households. Of those, we had 183 letters that were returned because of address problems and 913 who started the survey. 27.6% of the people who started the survey indicated that they did not have a used PEV – in most cases because they purchased or leased the vehicle new and the DMV title transfer did not reflect ownership change. Based on the survey response, those who indicated that they are not owners of used PEVs, we estimated that the starting population of used PEVs is about 10,130 households. Out of the valid starts, 82% completed the survey generating 602 usable surveys as described in Figure 2-3 and Figure 2-4. We believe that the high response rate can be attribute to the early adoption population and the 10 $100 gift cars raffled among the survey takers.

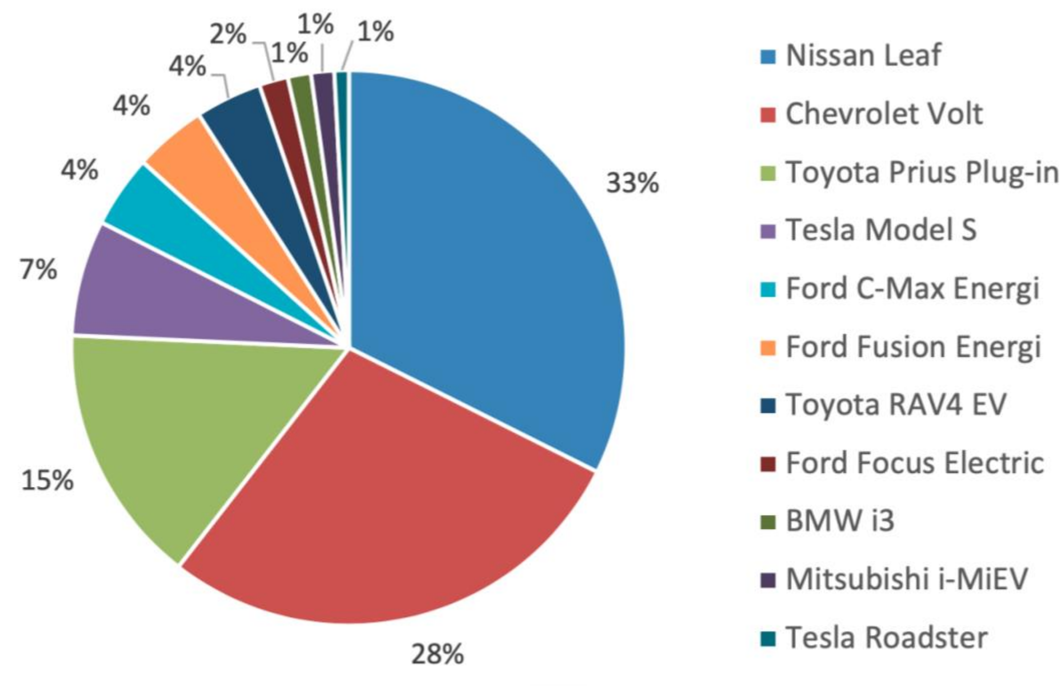

Figure 2-3. Used PEV surveys by vehicle model

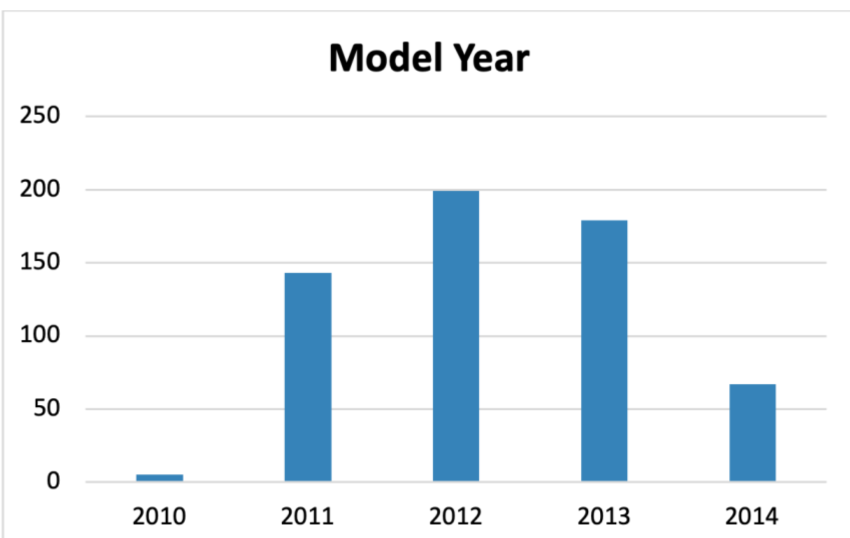

Figure 2-4. Used PEV surveys by model year

Most of the households in the survey owned the vehicle more than 6 months with an average of 15 months and therefore represent mostly buyers in 2015.

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2.1.3 New PEV Comparison Sample

To estimate the price paid for the PEVs purchased new, we use 2014 and 2015 new PEV buyer surveys conducted by our PH&EV center. The surveys allow us to estimate the actual price paid for those vehicles before and after incentives including the incentives that may be paid up to a year after the vehicle purchase such as the state CVRP and the federal tax credit. For this estimation we used the incentives values reported by the original buyers and not the default values. We used a total of 5,227 purchased vehicles (see

Table 2-1. New PEV sample used for comparison from previous surveys.

Model and Year	New PEV sample
BMW i3_2014	175
BMW i3_2015	26
Chevrolet Volt_2011	55
Chevrolet Volt_2012	109
Chevrolet Volt_2013	451
Chevrolet Volt_2014	370
Chevrolet Volt_2015	39
Ford C-Max Energi_2013	235
Ford C-Max Energi_2014	149
Ford C-Max Energi_2015	15
Ford Focus Electric_2012	17
Ford Focus Electric_2013	41
Ford Focus Electric_2014	86
Ford Fusion Energi_2013	115
Ford Fusion Energi_2014	239
Ford Fusion Energi_2015	27
Mitsubishi i-MiEV_2012	16
Nissan Leaf_2011	94
Nissan Leaf_2012	150
Nissan Leaf_2013	546
Nissan Leaf_2014	233
Nissan Leaf_2015	107

Model and Year	New PEV sample
Tesla Model S_2012	81
Tesla Model S_2013	388
Tesla Model S_2014	232
Tesla Model S_2015	34
Toyota Prius Plug-in_2012	262
Toyota Prius Plug-in_2013	244
Toyota Prius Plug-in_2014	455
Toyota RAV4 EV_2012	51
Toyota RAV4 EV_2013	76
Toyota RAV4 EV_2014	109

) to estimate both the price of the used vehicle purchased when it was new and the alternatives the used vehicle buyer had when purchasing the vehicle (i.e. what was the price of the same model but not the same year at time of purchase).

Table 2-1. New PEV sample used for comparison from previous surveys.

Model and Year	New PEV sample
BMW i3_2014	175
BMW i3_2015	26
Chevrolet Volt_2011	55
Chevrolet Volt_2012	109
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Ford Focus Electric_2013	41
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Ford Fusion Energi_2013	115

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Toyota RAV4 EV_2012	51
Toyota RAV4 EV_2013	76
Toyota RAV4 EV_2014	109

2.2 Survey Data Analysis Results

2.2.1 Used PEV Residual Value

The resale value of used PEVs is a very important factor for the success of the PEV market. OEMs, lease companies, and private owners who plan to buy the next new vehicle strive for high resale value while potential buyers of the used PEVs compare the price to new subsidized PEVs or lower priced ICEs and constantly look for lower prices. Figure 2-5 describes the up to 6 different price points for the same model and year; in this case, a Chevrolet Volt. The figure includes a purchase year represented by the different columns and model year for each group. In an extreme case, a model year 2014 can be purchased and used in calendar year 2013 if the first ownership was early and for a short time. The first bar is the full price paid for the vehicle based on the average price reported on the new buyers' survey. The second bar represents the MSRP as reported by the OEM and the third is the final price based on the average original price paid minus the reported incentives. The blue bars are based on the used buyer survey based on the purchasing year and reflect the vehicle's age at purchase and other factors such as the limited supply of vehicles purchased used in early years.

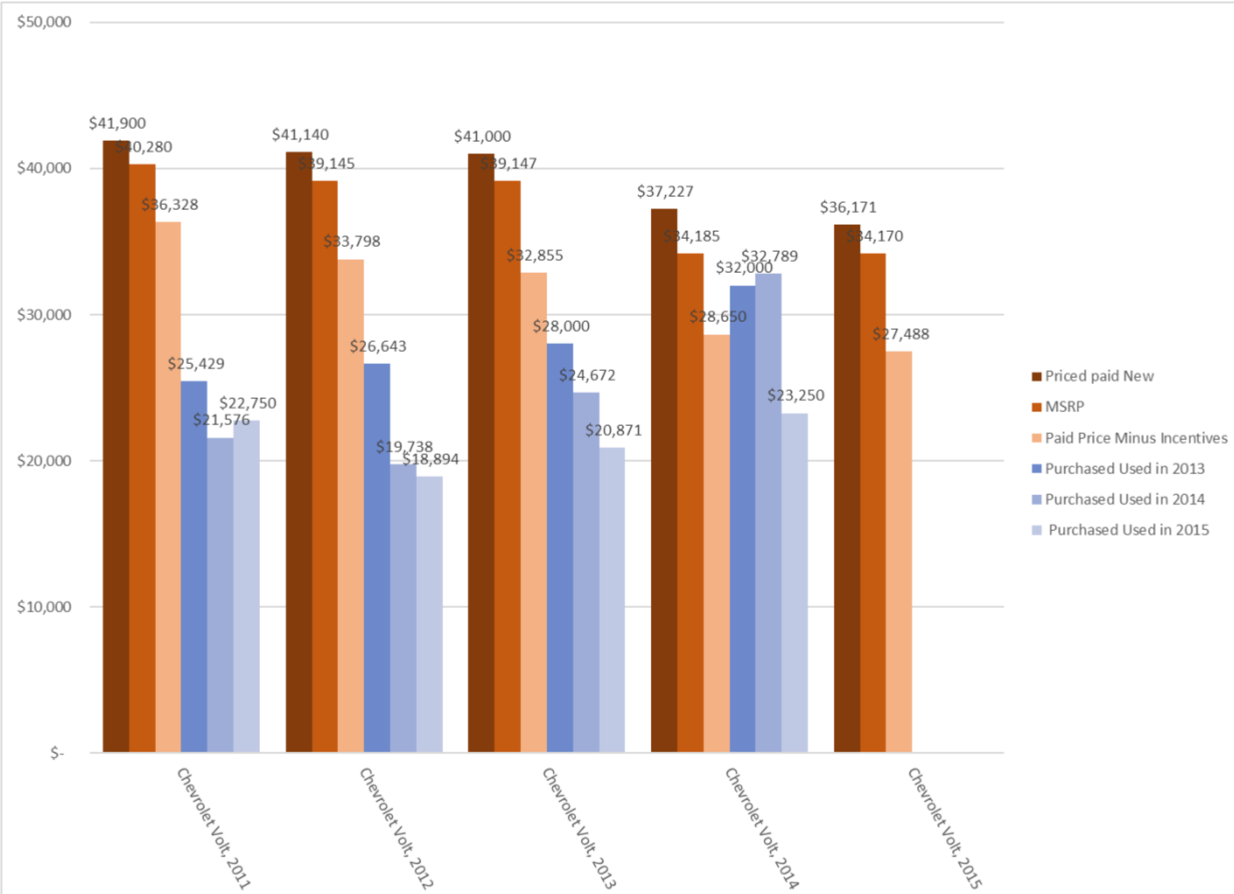


Figure 2-5. Chevrolet Volt price as new and used

Having up to six price points for each vehicle allows us to calculate the average residual value for the sale year based on the original values and the price of a similar vehicle at the time of purchasing the used vehicle. The residual value of a 2012 Volt sold in 2015 from the original seller's perspective (leasing companies, OEM or similar) is based on the resale price in 2015 ($18,894) divided by the original MSRP (as a proxy for the transaction price among diverse types of original owners), ($39,145) or 48.2%. A second reason to compare the price paid by the second owner to the MSRP is the availability of this price as a comparison point for buyers at the used market. This comparison may not reflect the actual residual value but may reflect the perceived change in price. The second buyer has a different perspective when buying the vehicle in 2015. Based on the second buyer's knowledge of incentives, the alternative price for a new 2015 Volt is $27,448 (or up to $34,170 if the buyer assumes zero incentives). In case of full knowledge on the incentives, the price paid for the used vehicle ($18,894) compared to buying a new one for $27,448 reflects a price of 31.2% savings compared to a new car.

Table 2-2**Error! Reference source not found.** represents the residual price of 2011 to 2014 model year PEVs sold in 2015 and how these prices compare to the price paid by the original owners of similar vehicles. We only show the prices of vehicles with sample size higher than 24. Overall the lowest value calculated is 34% (in red) for a 2011 LEAF compared to MSRP or 50% of the price of new LEAF in 2015. A one-year-old Plug-in Prius was sold for 80% of the MSRP or 98% (in green) of average prices paid by a private original owner after incentives, which may reflect the low availability of 2015 Plug-in Prius, which was discontinued that year, in the market and the low availability of HOV lane access stickers at the time.

Table 2-2. Used price divided by new prices

	MSRP	Full Price	Price Minus Incentives	Used Price in 2014	Used Price in 2015	price minus incentives of a 2015 model	Price paid in 2015 over MSRP	Price paid in 2015 over price paid by privte new owner	Price paid in 2015 over new car price
Nissan Leaf, 2011	$ 33,572	$ 34,990	$ 26,815	$ 15,497	$11,463	$ 22,779	**34%**	**43%**	**50%**
Nissan Leaf, 2012	$ 36,882	$ 35,852	$ 26,564		$12,508	$ 22,779	**34%**	**47%**	**55%**
Nissan Leaf, 2013	$ 31,517	$ 33,488	$ 24,380		$13,912	$ 22,779	**44%**	**57%**	**61%**
Tesla Model S, 2013	$ 87,217	$ 96,732	$ 87,974		$67,338	$ 105,998	**77%**	**77%**	**64%**
Ford Fusion Energy, 2013	$ 39,235	$ 41,243	$ 35,936		$25,288	$ 36,214	**64%**	**70%**	**70%**
Chevrolet Volt, 2012	$ 39,145	$ 41,140	$ 33,798	$ 19,738	$20,871	$ 27,488	**53%**	**62%**	**76%**
Chevrolet Volt, 2013	$ 39,174	$ 41,000	$ 32,855	$ 24,672	$20,871	$ 27,488	**53%**	**64%**	**76%**
Ford C-Max Energy, 2013	$ 31,665	$ 35,014	$ 29,664		$22,875	$ 29,900	**72%**	**77%**	**77%**
Toyota Prius Plug-in, 2012	$ 38,195	$ 36,211	$ 32,273	$ 24,823	$22,973	$ 27,951	**60%**	**71%**	**82%**
Toyota Prius Plug-in, 2013	$ 38,704	$ 34,259	$ 30,394		$24,412	$ 27,951	**63%**	**80%**	**87%**
Toyota Prius Plug-in, 2014	$ 34,307	$ 31,726	$ 27,759		$27,525	$ 27,951	**80%**	**99%**	**98%**

A linear regression model was estimated to explore the impact of different factors on the residual price using a subset of 520 vehicles not including Tesla model S and Tesla Roadster (

Table 2-3). We excluded those vehicles because of the different price ranges that create a biased impact on the larger market. As expected, the used PEV price is correlated positively with the original price paid (price paid when new) and negatively with time on the road (PEV age when purchased (years) and mileage (miles when purchased). We also noticed that the price of used PHEVs remains, on average, 10.3% higher value compared to the MSRP than BEVs, and that PEVs with HOV access stickers receive $715 more than PEVs without an HOV sticker. The regression model estimates a linear price deportation and cannot predict the price of used PEVs older than 4 years old. It is also cannot differentiate between the HOV sticker value of BEVs and PHEVs but it may reflect the low availability of green stickers for PHEVs at the time of data collection.

Table 2-3. Parameter Estimates for price paid when purchasing used PEV

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	6091	2070	2.94	0.0034*
PEV Type [BEV]	-1958	241	-8.12	<.0001*
PEV age when purchased (years)	-2950	249	-11.81	<.0001*
HOV Sticker [No]	-715	252	-2.83	0.0048*
Miles when purchased	-0.101	0.017	-6.05	<.0001*
Price paid when new	0.688	0.05	13.82	<.0001*

Summary of Fit

RSquare	0.602079
RSquare Adj	0.598208
Root Mean Square Error	4642.141
Mean of Response	20814.7
Observations (or Sum Wgts)	520

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	1.6759e+10	3.3519e+9	155.5426
Error	514	1.1076e+10	21549476	Prob > F
C. Total	519	2.7836e+10		<.0001*

Lack of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack of Fit	472	1.0422e+10	22080574	1.4172
Pure Error	42	654400057	15580954	Prob > F
Total Error	514	1.1076e+10		0.0819
				Max RSq
				0.9765

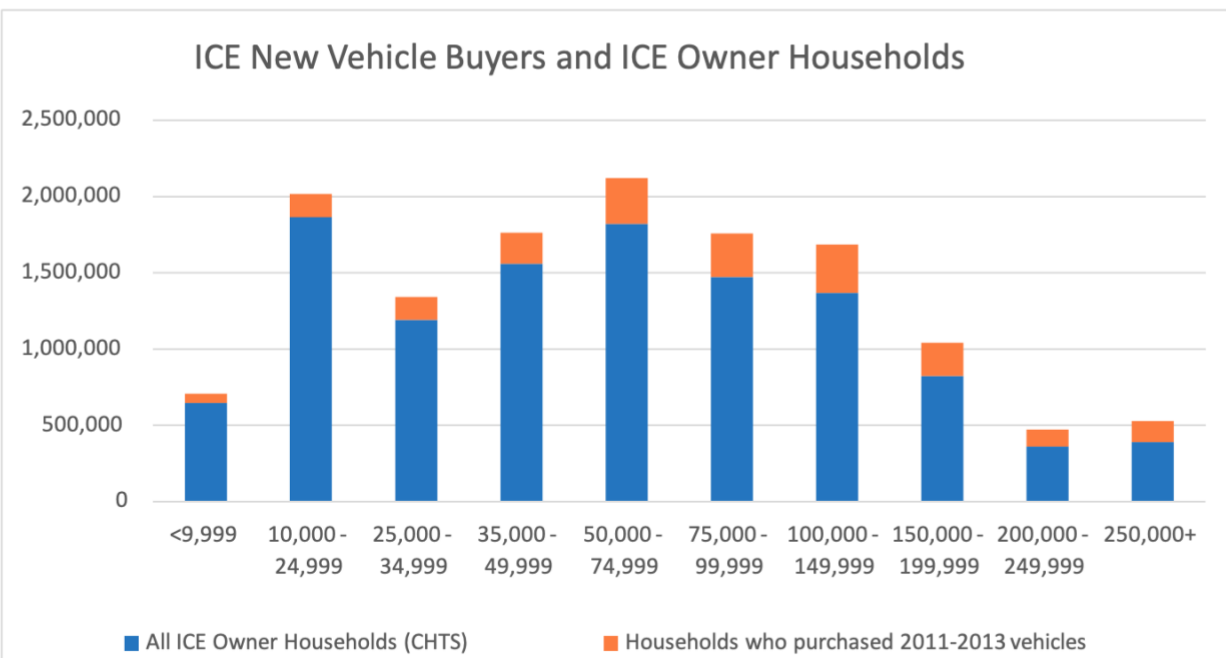
The model presented in

Table 2-3 does not reflect the variation in buyer's knowledge perspective and preference. The next section focuses on the households that purchased the vehicle and compares the used PEV buyers and the new PEV buyers. We do not currently have a valid comparison to new and used ICE buyers but we can compare general sociodemographic characteristics of this survey to the

2012 California travel household survey, taking into account the 4 years gap between the two data collections.

2.2.2 PEV Buyers Sociodemographic Characteristics

The survey data focuses only on buyers of used PEVs. We have no data on used ICE buyers. However, according to the 2012 California household travel survey (CHTS), new vehicle buyers have on average higher income than used ICE buyers[1]. Figure 2-6 explores the income distribution of households who purchased a model year 2011 and 2012 vehicle prior to our surveys (new or used). It suggests that even though households with higher income are more likely to buy a new vehicle, the number of households who did not purchase a vehicle at all or purchased a used vehicle is much higher. The average income of the ICE household owner population in 2012 is $89,800 for used buyers and $119,400 for new vehicle buyers. Buyers of new PEVs between 2012 and 2014 had an average household income of $227,000 (median response was $200,000 N=4198 not including Tesla owners.) Buyers of used PEVs have an average household income of $173,400 with median response of $150,000 (N=481 not including Tesla owners.) Figure 2-7 explores the average income differences between original owners and second owners. As expected, the income of the used PEV buyers is lower, other than the Prius and the Rav4 used buyers who have income almost as high as the original buyers reflecting the low availability of those models and the high demand for the used PEVs and HOV access stickers.



[1] The CHTS public data is available at: http://www.dot.ca.gov/hq/tpp/offices/omsp/statewide_travel_analysis/chts.html. This study utilized raw data cleaned by the PH&EV center, including new vehicles designations.

Figure 2-6. CHTS Household distribution by newest vehicle in the household

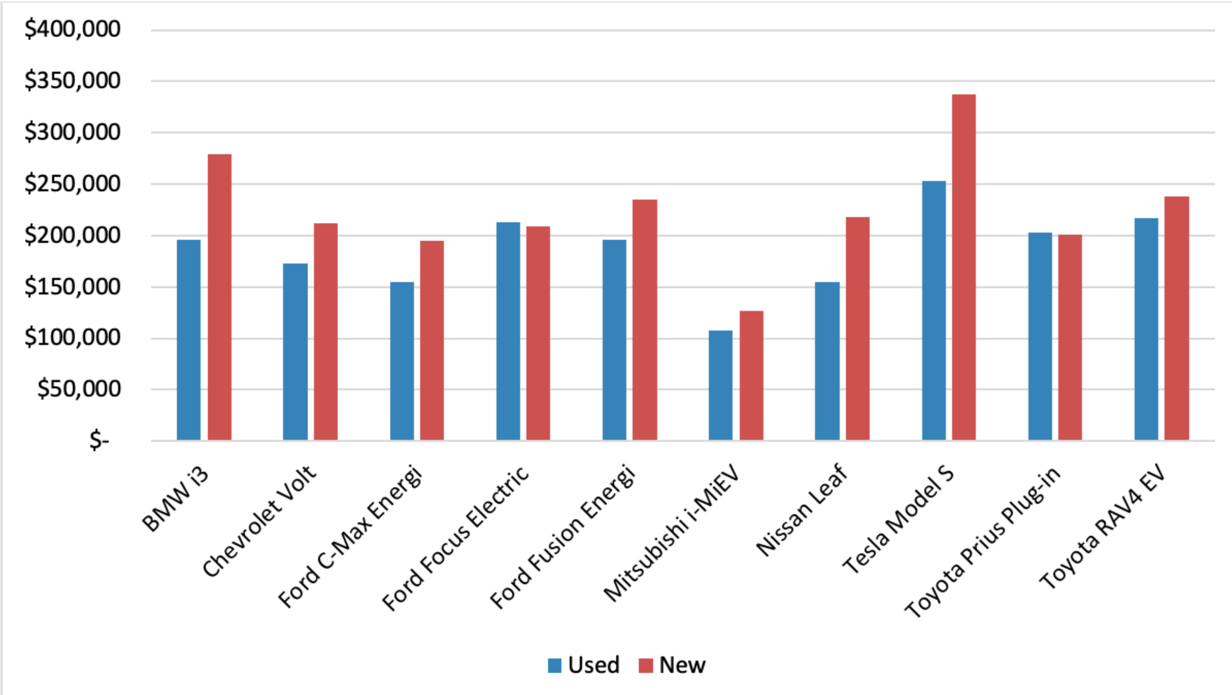


Figure 2-7. Average household income of buyers of new and used PEVs

The differences in income may reflect the preference of lower income buyers to purchase a lower priced PEV but may also reflect changes in preference between 2010 and 2015. We control for the change in price and preference over time by comparing the buyers of different vehicles in the same year. Figure 2-8 reflects the change over time, as buyers of new or used Volts in 2013 had similar income but the average income of used Volt buyers, for example in 2014 and 2015, drops faster than that of the new buyers. Comparing all the new and used PEV buyers per year in the years 2013-2015 using t-test shows a statistically significant income difference (α=0.05) even when not including Tesla owners in the new car buyer group.

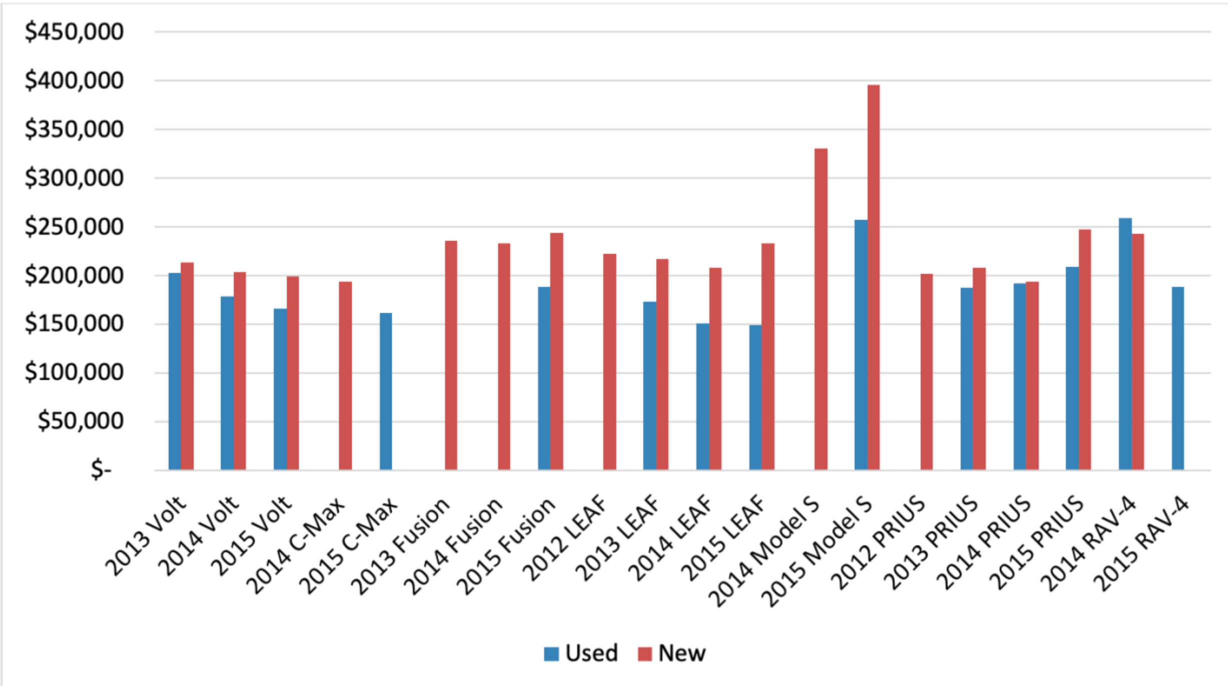


Figure 2-8. Average Household income of buyers of new and used PEV by vehicle model and purchase year

2.2.3 PEV Buyer Household Fleet and Vehicle Preference

In order to better understand the household decision to buy a used PEV, we start with exploring the other vehicles in the households of those who bought used PEVs. Our first set of questions aims to check if the used PEV buyers purchased mostly new or used cars in the past. Overall 49% had only used vehicles in their household fleet. Of these, 12% had only previously purchased one used vehicle, and 38% had more than one used vehicle. On the other hand, more than half the sample, 51%, purchased new ICE vehicles in the past but elected to buy a used PEV. 3.5% of the total sample had two PEVs all of them a mix of new and used vehicles, with the used PEV being the second PEV while the first PEV was purchased new. This may reflect a change in habit, buying a new vehicle and not used as no used PEVs were available a few years ago. The results find no household with two used PEVs at this point.

2.2.4 Purchase Preference: Initial Interest in PEVs

The 2015 sample of used PEV buyers are early adopters, who buy a new technology that in many cases, based on income levels, is common around their community similar to the buyers of new PEVs. We asked the buyers for their interest in acquiring a PEV when they started the search for a vehicle to purchase and 28% answered that they were only interested in the specific make and model they ended up purchasing, while 33% answered that they were only interested in PEVs and not in ICEs. Only 11% started the search for the new vehicle with only some interest in PEVs and 4% started shopping for an ICE, but converted to a PEV in the shopping process. Asking a similar question on a continuous scale (Figure 2-9) shows similar patterns (in these figures the average and median are represented by diamond and vertical line, with quartiles represented by the box).

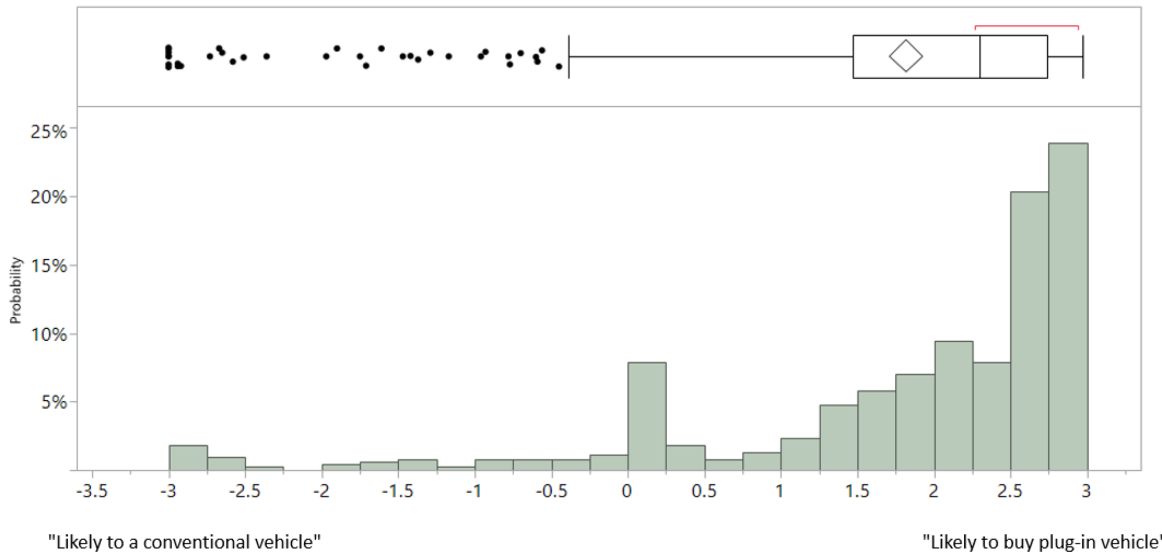


Figure 2-9. Likely to buy ICE or PEV

When asked about the probability of buying a used vehicle or a new vehicle (Figure 2-10), 67% of the respondents answered that they were more likely to buy a used vehicle while only 15% take into equal consideration buying a new or used vehicle, though 18% are more likely to buy new.

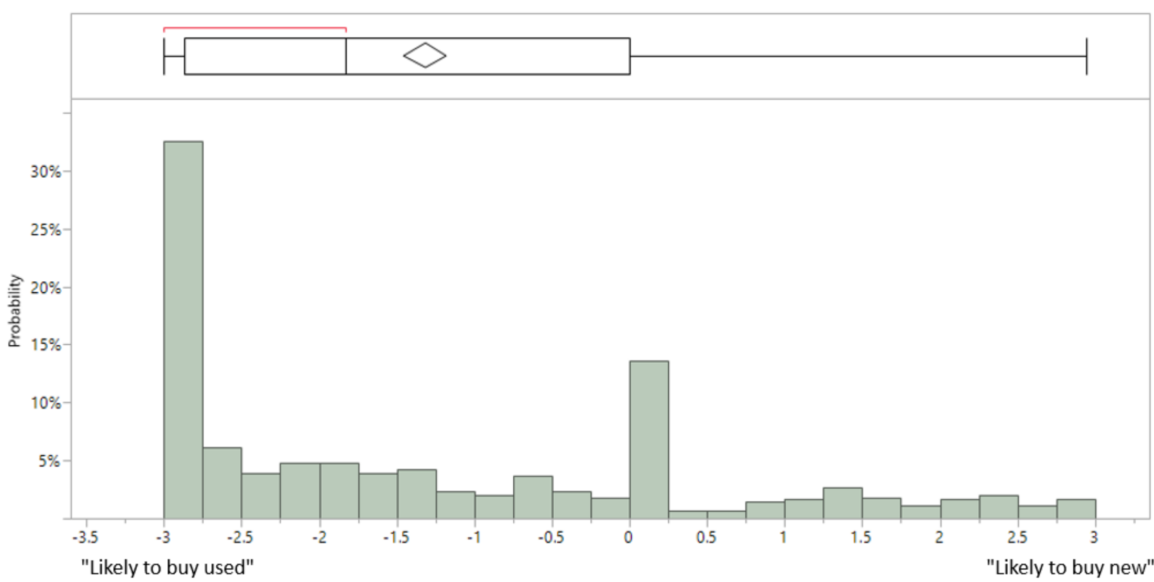


Figure 2-10. Likely to buy new or used

When combining the two questions together we find that most buyers are more likely to buy a used PEV (red color), and we do notice that our sample includes only one buyer (gray point on the upper left side) who starts as a potential buyer of new ICEs who ends up buying a used PEV (Figure 2-11).

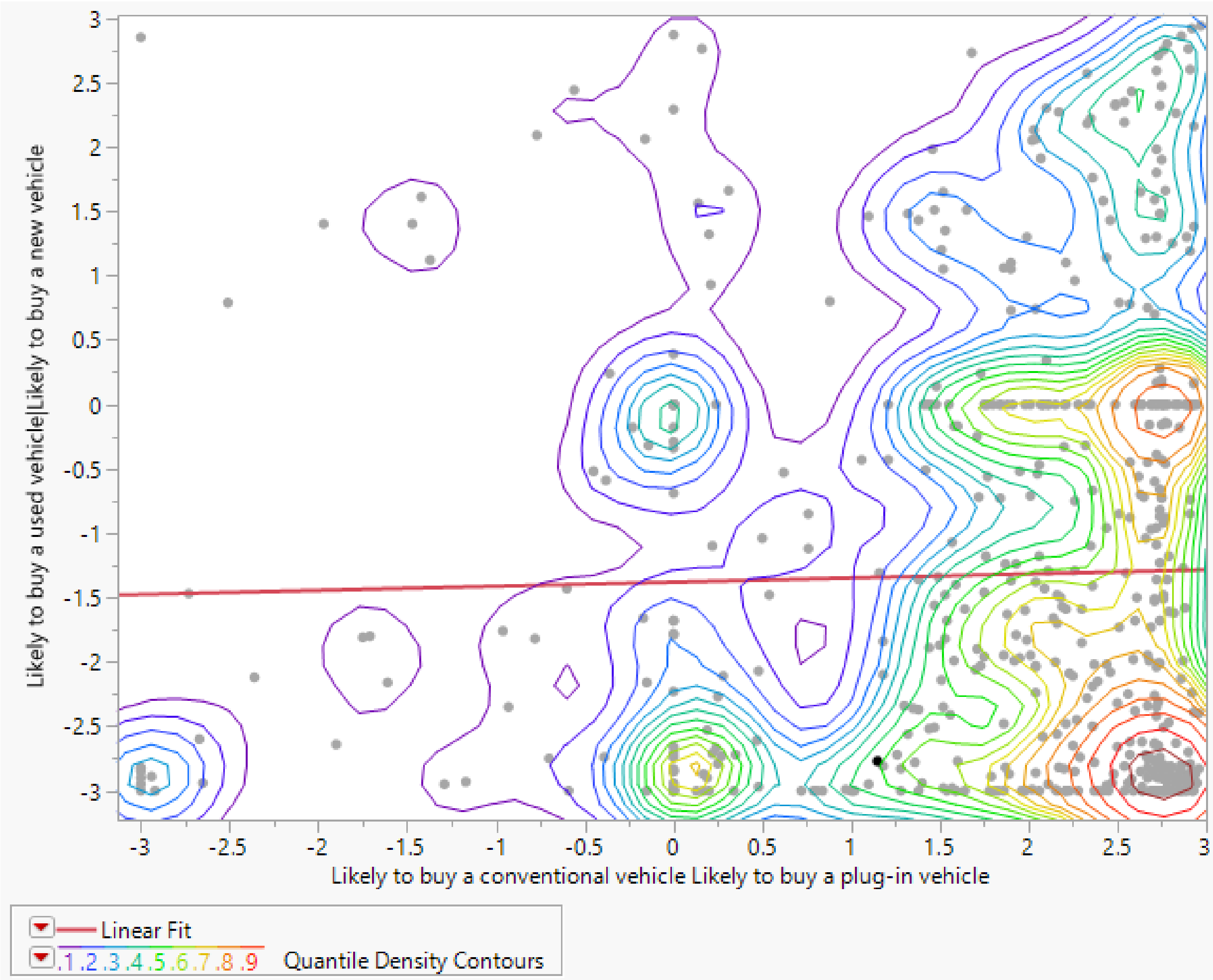


Figure 2-11. Density map of likely to buy new or used over likely to buy ICE or PEV

Overall, early adopters of used PEVs were in the market for a used PEV and in more than 28% of the cases, for a specific PEV. Only 3.9% started the purchase process not interested in PEVs. We see almost zero buyers who were looking for new ICE and purchased a used PEV but we do have small group who started the search looking for used ICE and ended up purchasing a used PEV (Figure 2-12).

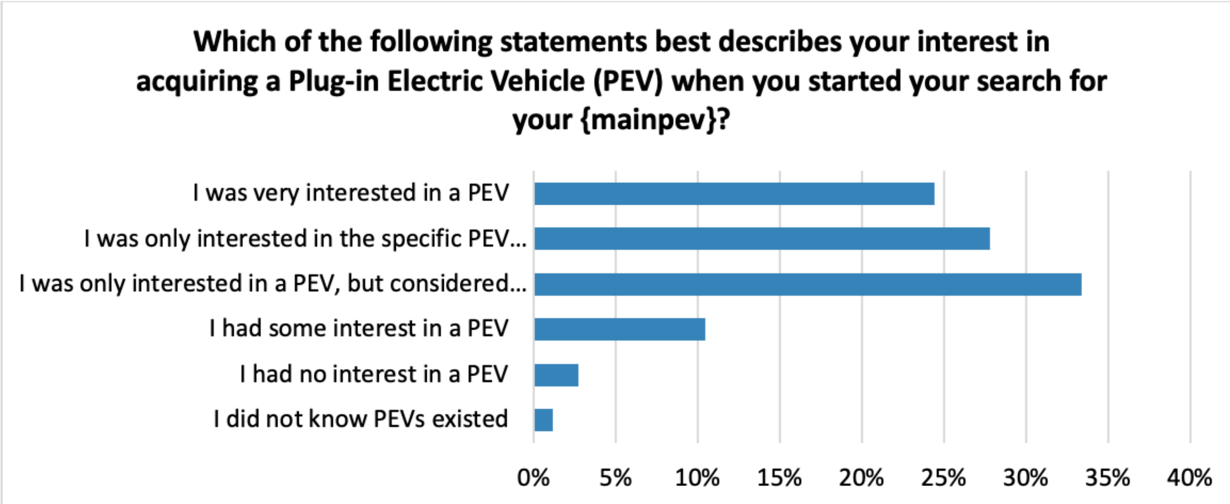


Figure 2-12. Interest in PEVs when starting the purchase process

2.2.5 Purchase Preference: Knowledge of incentives and Battery Condition

As presented previously, the price paid for a used PEV varied as a factor of the vehicle characteristics and the purchase timing. Next, we will explore the potential impact of the buyer attributes. We compared the price of a used PEV to that of a similar new vehicle at the time of purchase after subtracting purchase incentives and subsidies, but not all buyers were informed about the price difference between the MSRP and the actual price of a new PEV as those incentives are not available for used PEV buyers. 40.5% of the used PEV buyers had no knowledge about the federal tax credit for the purchase of a PEV, though higher awareness rates were observed for the PEVs eligible for the maximum $7,500 tax credit (Figure 2-13). The used PEV buyers are not eligible for the tax credit but not having the knowledge about it may bias the decision to purchase a used car by over-estimating the price of a similar new PEV.

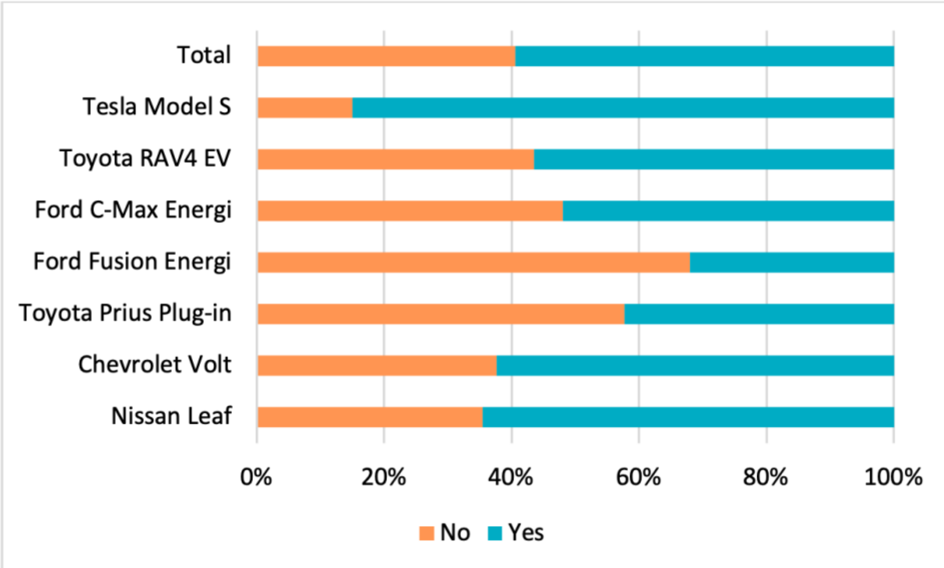


Figure 2-13. Knowledge about the potential federal tax credit for new PEVs

The knowledge about the federal incentives was higher for purchasers in 2013 when most used PEVs were purchased after only a year or two on the road and lower in 2014-2015. This may reflect the fact that buyers of newer used PEVs had more knowledge on the actual price of the new alternative than buyers of two or three years old cars (Figure 2-14). If this trend continues we can expect that future buyers of used PEVs will have even less knowledge about the opportunities open to new buyers and by that overpay for their used car comparing the price to the vehicle MSRP rather than the price the original owner paid or the price of similar new car.

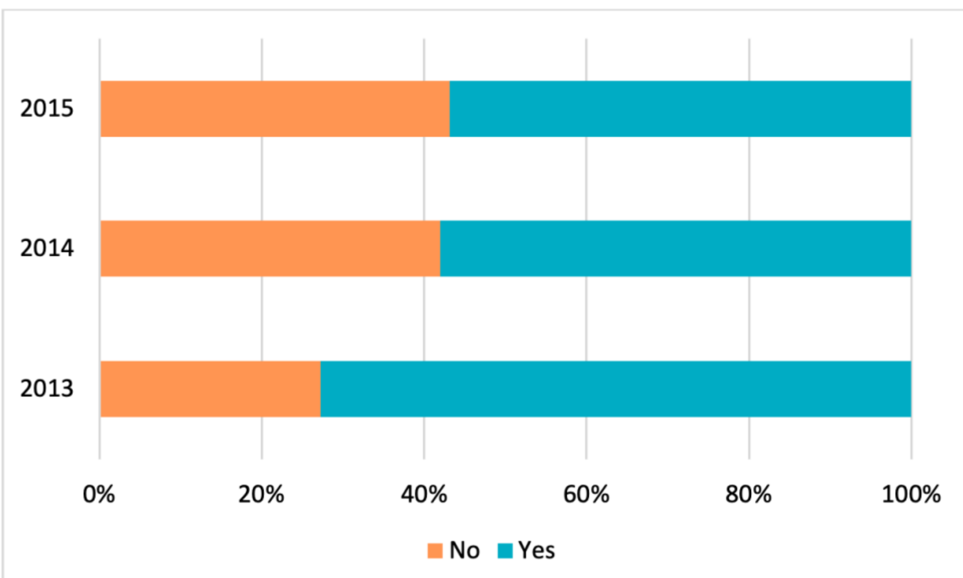


Figure 2-14. Knowledge of the Federal Tax credit by purchase year

We found that used PEV owners that got their vehicle at a dealership, even those that sell the same brand as new PEVs, had the least awareness about the federal tax credit. Furthermore, the differences in awareness between the two dealership options and the private owner option are statistically significant at the level of 0.05 (Figure 2-15).

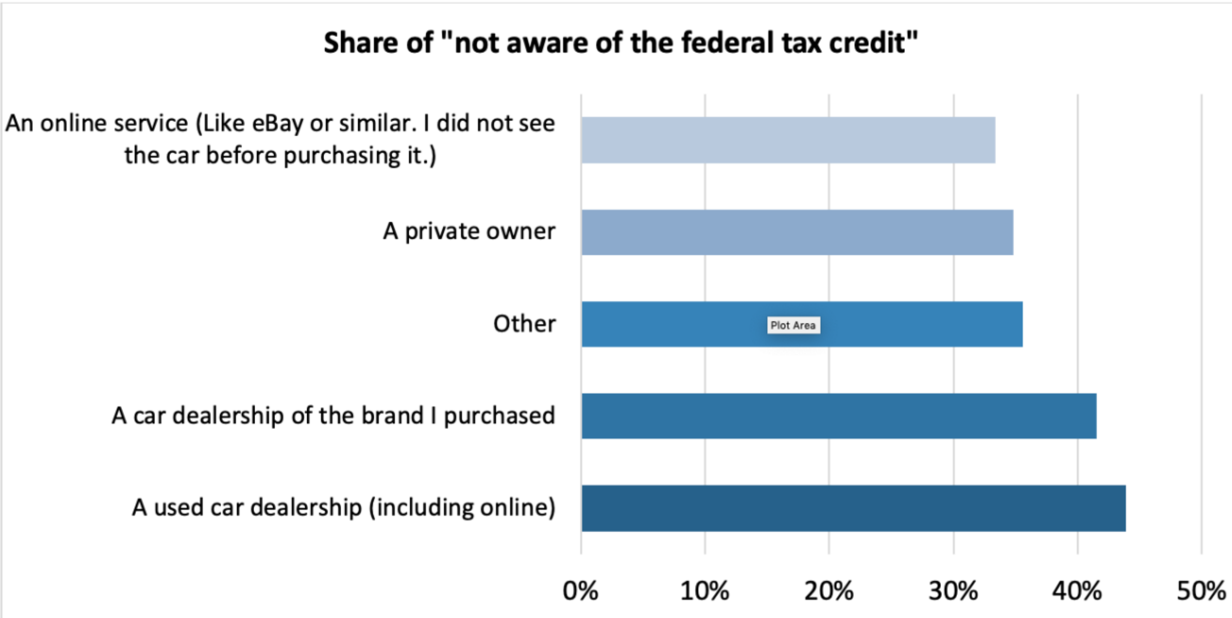


Figure 2-15. Knowledge of the Federal Tax credit by purchase location

The knowledge about the California PEV Clean Vehicle Rebate is lower than the knowledge about the federal tax credit which reflects the lower value of the state incentive and potentially lack of knowledge about it. Only 45% of the used PEV buyers knew that if they bought a new PEV they could receive a $1,500 to $2,500 rebate from California.

Used PEV buyers had a long list of concerns ranking range, price and charging infrastructure as the top three (Figure 2-16). When ask to rank the three most important concerns range was number one but only 30% rank it in the first three options reflecting high number of PHEV buyers. Price, as second, was only selected by 15% which may reflect more knowledge than “admitted”.

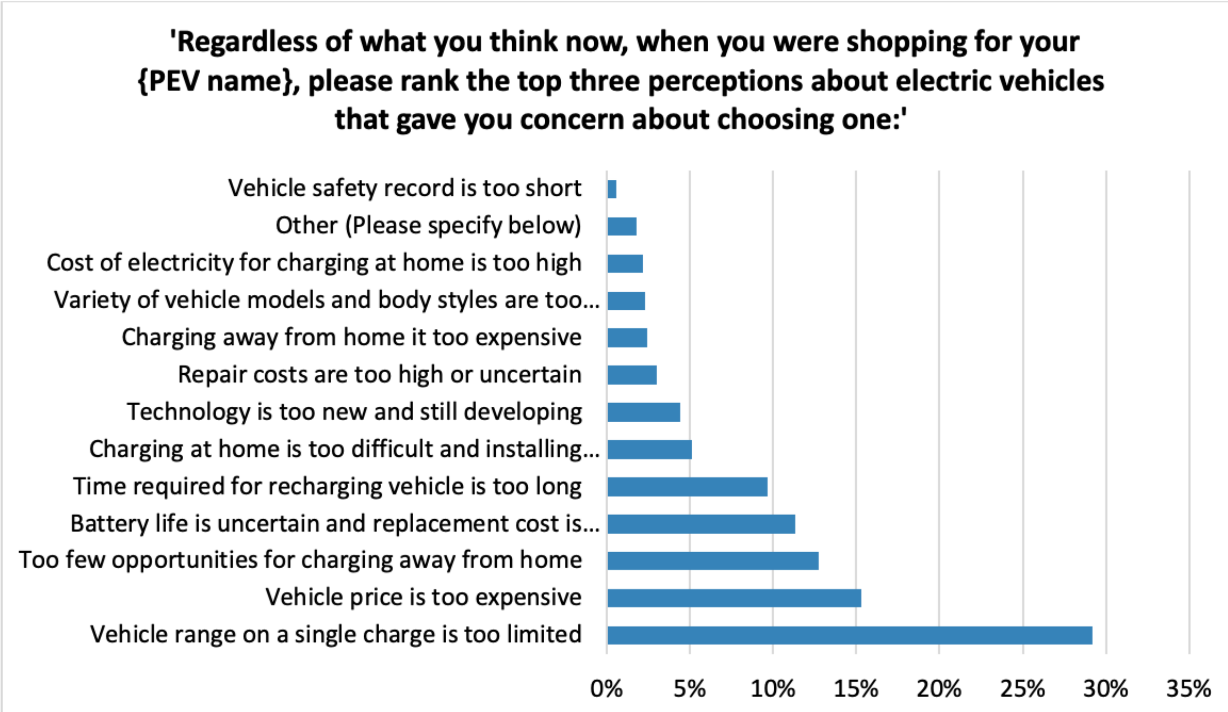


Figure 2-16. Initial perspectives on PEVs

Regardless of the initial perspectives, 77% of used PEV buyers would repeat their purchase if they needed to do it again and only 3% would not buy a PEV after their experience with one. 9% would buy a new PEV if they needed to do it again, maybe as result of the additional knowledge on potential incentives (Figure 2-17). In other words, 95% of used PEV owners are satisfied with the plug-in technology.

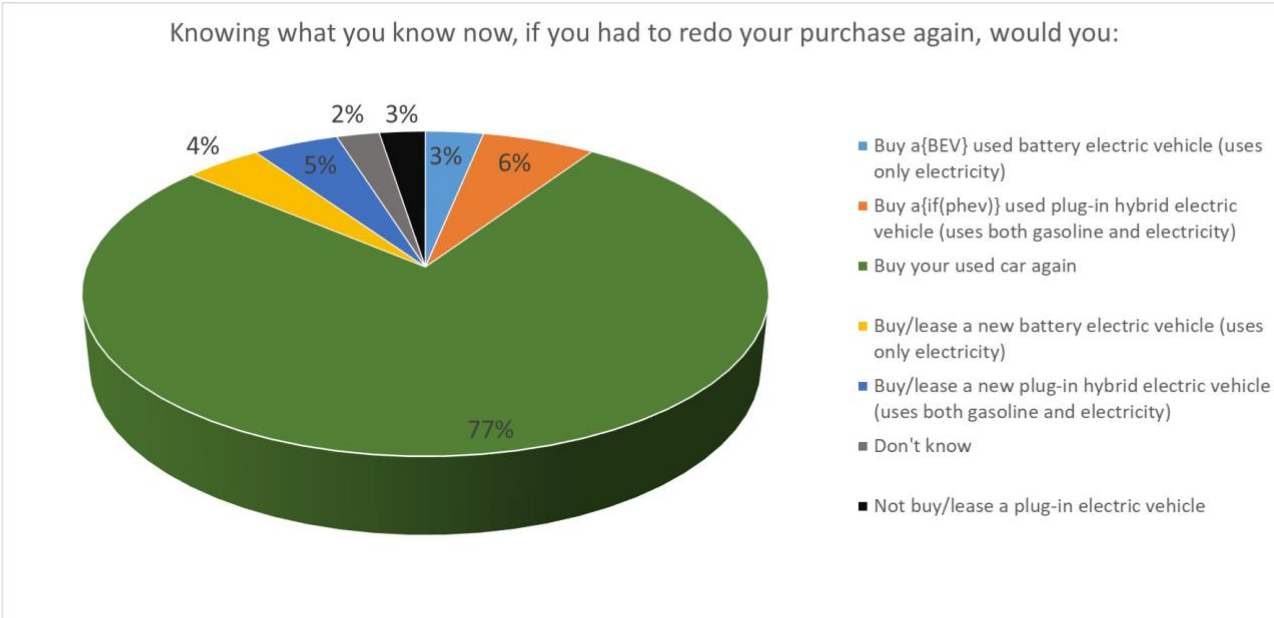


Figure 2-17. Would you purchase the PEV again?

The average self-reported odometer reading of used PEVs at the time of purchase was 23,400 miles. As described above, most of these vehicles entered the used PEV market after 2-3 years of usage by the original owner. The median odometer reading was 21,500 miles, with 90% of the vehicles having less than 40,000 miles as shown in the cumulative distribution function (CDF) plot (Figure 2-18).

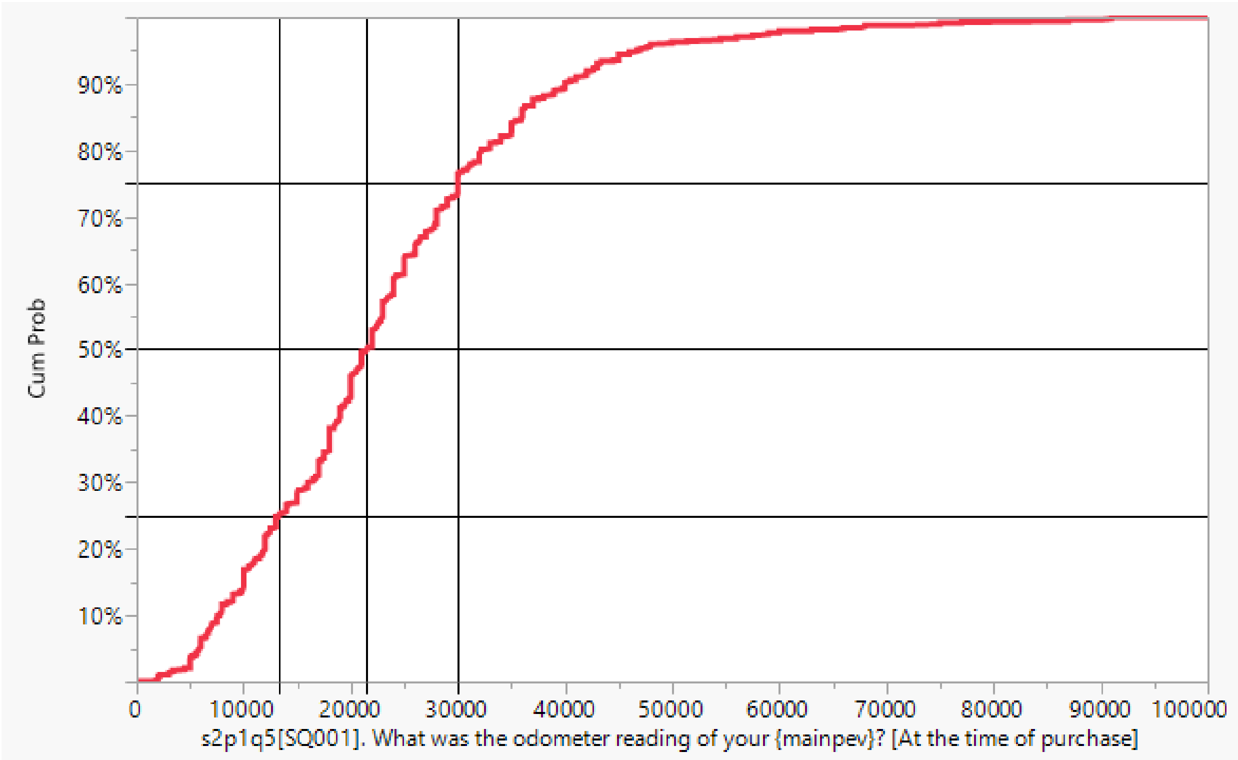


Figure 2-18. Self-reported odometer reading of used PEVs at time of purchase

The vehicles being relatively new, still being under warranty and having low mileage is reflected in awareness about the battery condition as only 15% report a capacity lower than 90% of the original (Figure 2-19), and most buyers did not check the battery condition other than asking the seller (Figure 2-20).

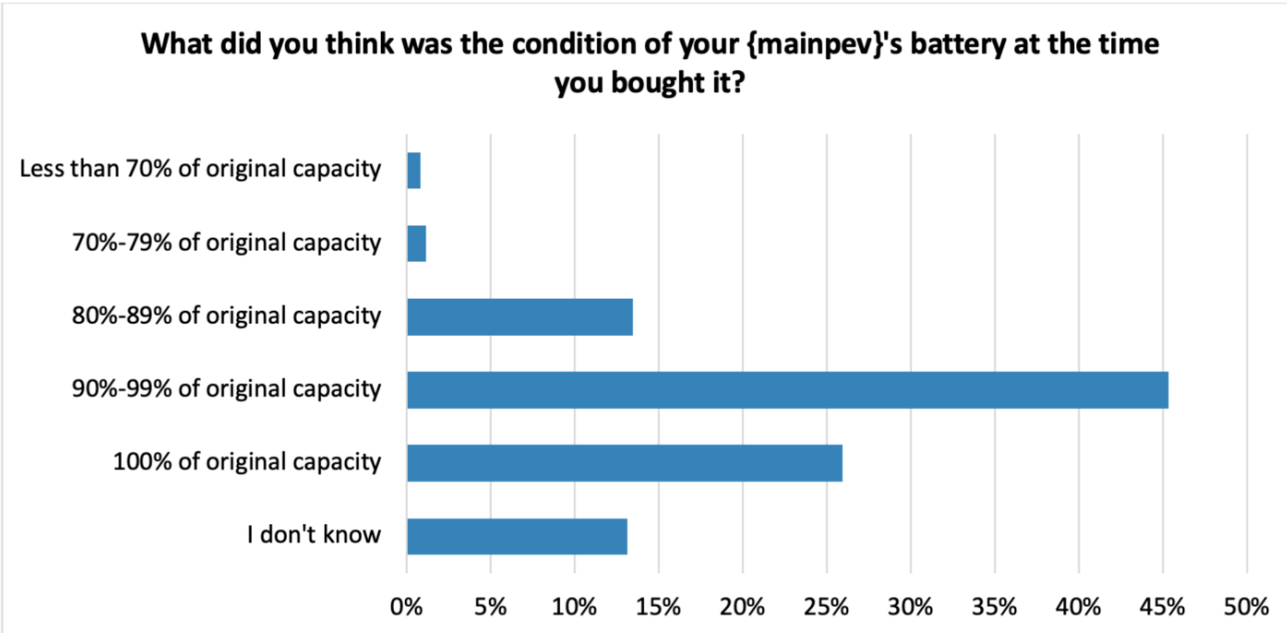


Figure 2-19. Self-reported battery condition at time of used PEV purchase

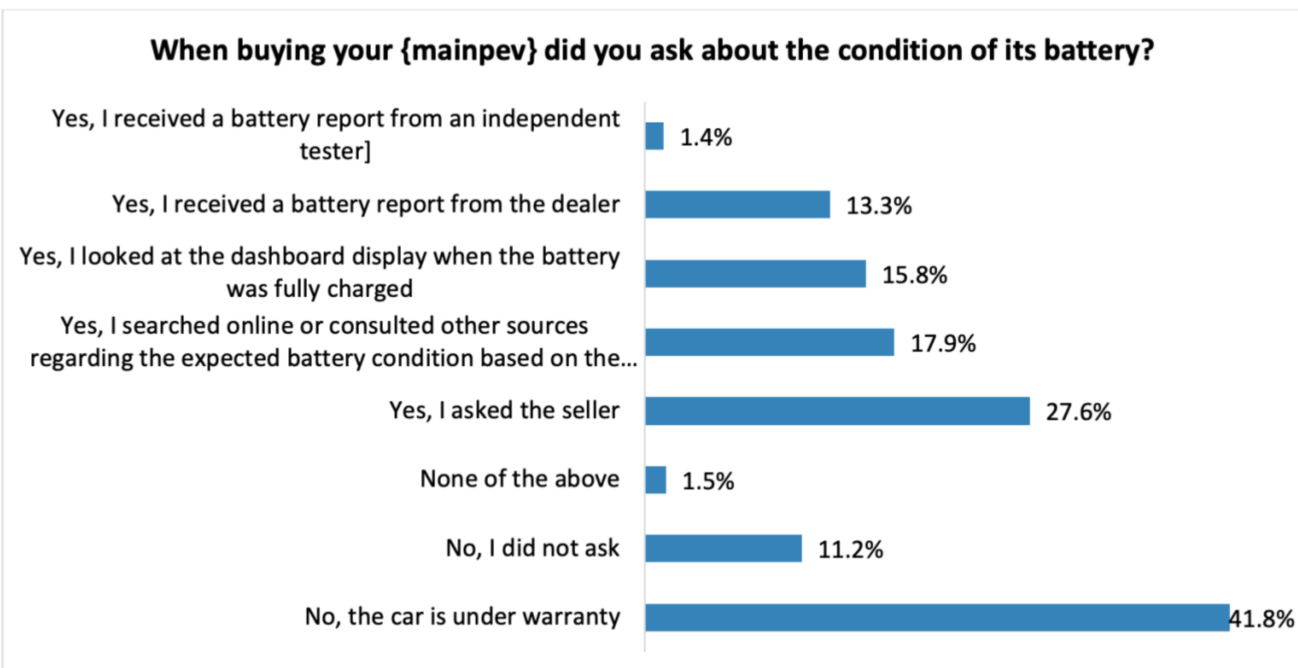


Figure 2-20. How did buyers check on the condition of the battery?

2.2.6 Vehicle Usage

We estimated the vehicle usage based on the reported odometer reading at the time of vehicle purchase, the time of survey, and the number of months of reported ownership. We excluded outliers with less than 1,000 or over 50,000 miles per year and owners who report lower accuracy than 3,000 on their odometer report. The results, in Table 2-4, suggest high usage of the used PHEVs with the annual median miles greater than 15,000 for the Ford Fusion.

Table 2-4. Used PEV Annual miles

PEV	N	Mean	Std Dev	Median	Median
Ford Fusion Energi	25	17839	9336	15692	12600
Toyota Prius Plug-in	89	15584	9376	13678	12700
Ford C-Max Energi	24	14412	7696	12621	10800
Tesla Model S	38	14403	9490	12798	11200
Chevrolet Volt	167	13611	7126	12000	10800
Toyota RAV4 EV	23	9929	7323	8075	10500
Nissan Leaf	188	8649	6233	7836	9400

When comparing usage of the used and new PEVs (data from UCD electric vehicle mile travel (eVMT) survey data) in the last two columns of Table 2-4, one can see that used PHEVs are driven more than their new PHEV counterparts, but used BEVs (other than the long-range Tesla) are driven less. When comparing charging behavior (Figure 2-21) we see that many of those high usage PHEVs are being used as hybrid vehicles only or being plugged in less than 5 times per month. As expected, the Prius with the short-range battery has the greatest percentage of respondents that are not plugging in regularly (more than 30%), with 18% not plugging in at all.

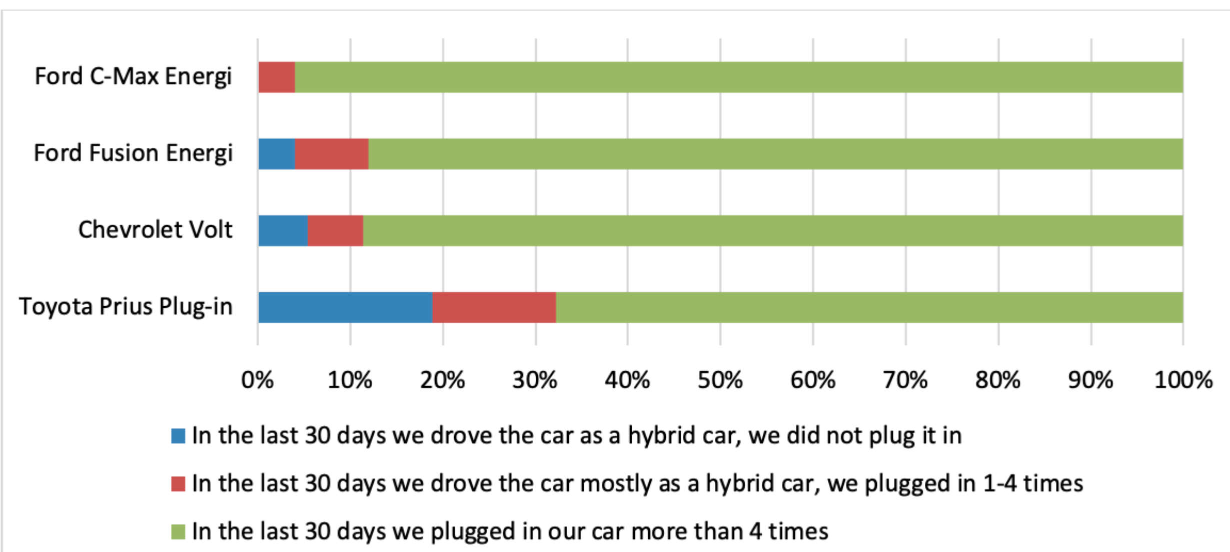


Figure 2-21. Used PHEV owners who are not plugging in at all or less than 4 times a month

Additionally, it helps to compare the used PEV consumers to the original owners. In the eVMT project recruitment survey, we used a similar question, asking for charging 4 or less times per month and categorizing it as “not plugging in” and as shown in Figure 2-22 the new PHEV owners are more likely to plug in their car.

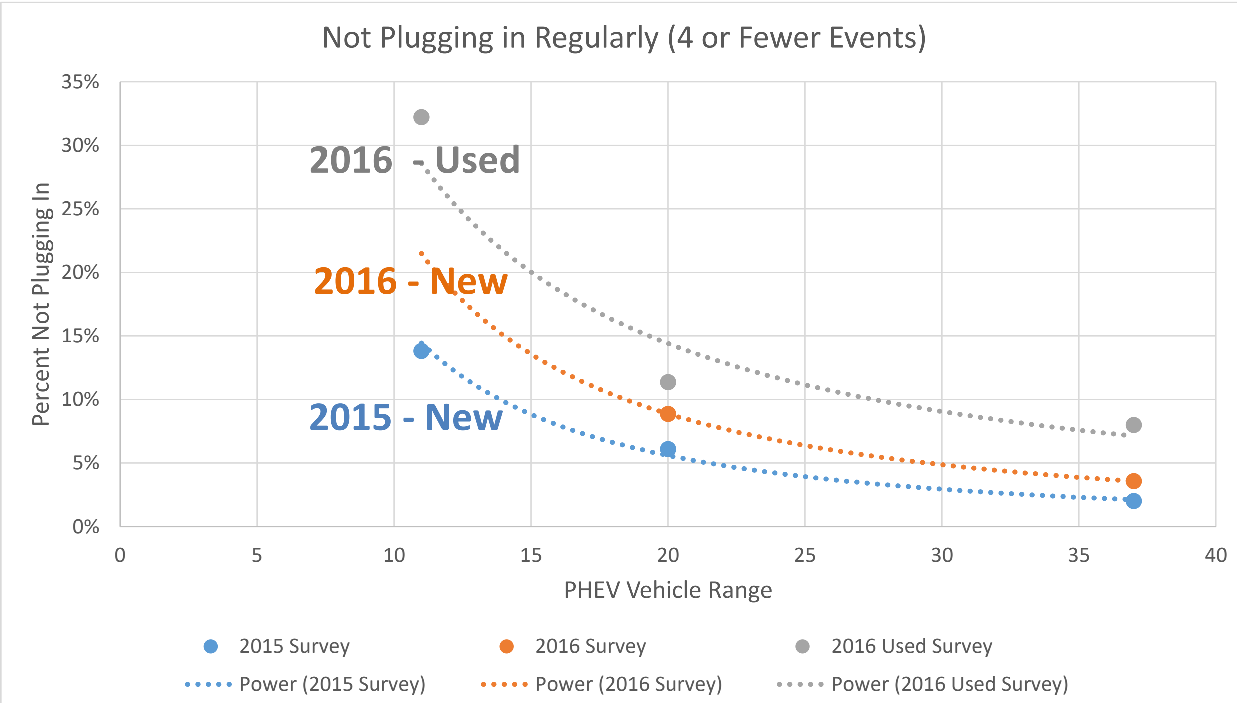


Figure 2-22. Percent of survey respondents rarely plugging in as a function of PHEV electric range

As the benefit of plugging in is limited by vehicle range and battery capacity, some users don’t bother plugging in. in figure 2-22, we show results from 3 different surveys used to recruit household for the eVMT project. The results are consistent with the premise that increasing vehicle electric range in PHEVs increases the likelihood of plugging in. Also, the plugging in of PHEVs with short ranges is more vulnerable than longer range PHEVs with different EV driving characteristics.

Excluding those that reported not plugging-in, 44% of our sample plugged in only at home. Over 50% of the shorter-range PHEV drivers (of those who plugged in at all) plugged in only at home. Overall, we saw more out of home (work and public) charging for the BEVs and the longer-range Volt. Fewer than 10% of all households charge away from home only, while most of the vehicles that are used as plug-in vehicles are being charged both at home and away from home (Figure 2-23).

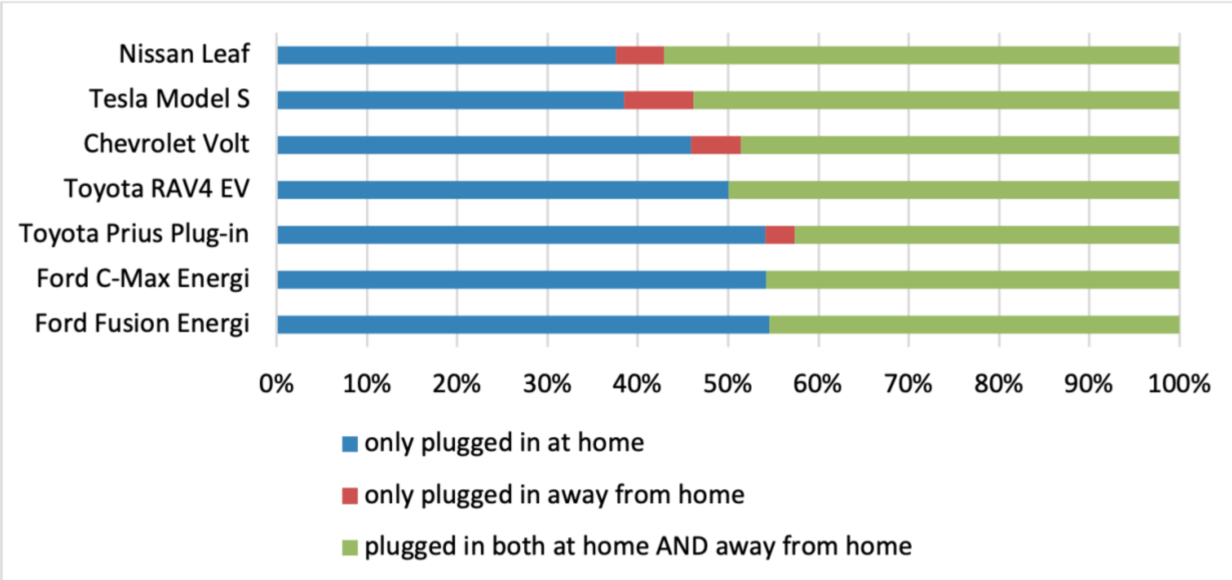


Figure 2-23. Self-reported charging location of the used PEV in the last 30 days

Installing a level 2 charger at home (208v-240v home chargers capable of 9+ miles per hour of charging) can cost between few hundred dollars to few thousand dollars, depend mostly on the need to upgrade the house electrical system. Level 1 charger (120v charger that is usually connected to a regular plug and capable of adding around 3 miles per hour of charging) cost nothing as most owners just use the charger supplied with the car. Figure 2-24 and Figure 2-25 show that used PEV owners have similar levels of level 2 chargers at home compared to new PEV owners despite a lower level of installation support. Some of the original owners received the charger as part of the Federal EV project, or from the OEMs; others received government or utilities subsidies. We see five used PEV owners converted a level 1 into level 2 charger but a statistically similar total number of new and used PEV owners utilize level 1 chargers. All households who did not charge at all in the last 30 days report having level 1 availability at home.

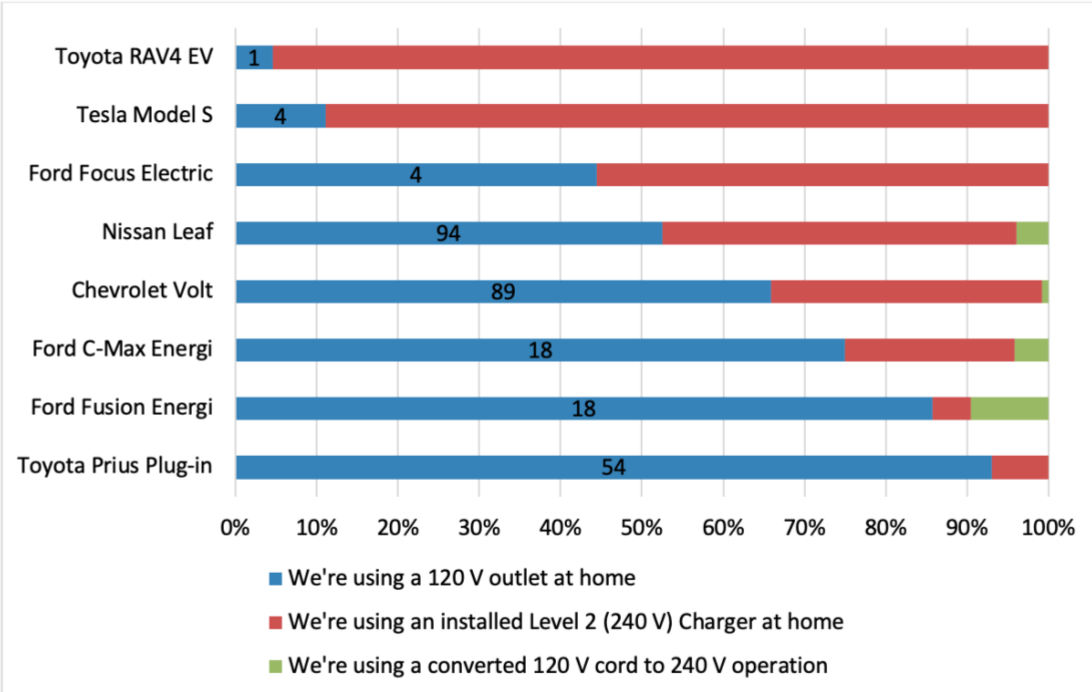


Figure 2-24. Used PEV owner self-reported charging equipment at home

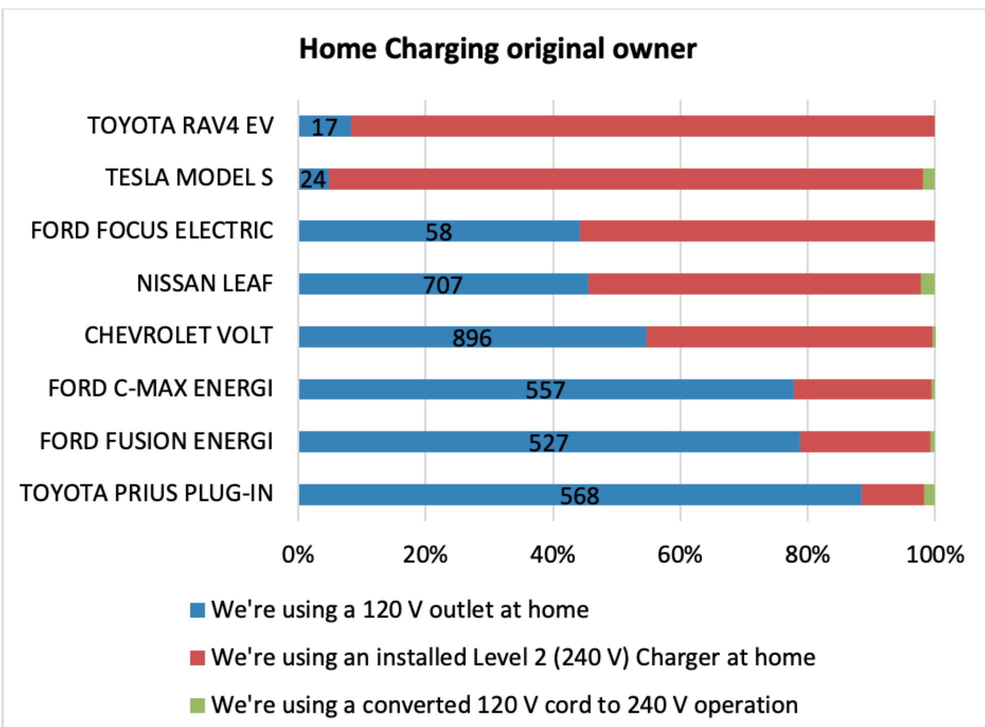


Figure 2-25. New PEV owner self-reported charging equipment at home in 2015

We asked the respondents for the primary reason people did not install a level 2 charging station at home. Most used PHEV owners reported that it is not necessary. Out of the 34% who answered that they can benefit from a home charger, 7% reported that they are not authorized to install and 29% report that it is too expensive because of charger cost (18%) or installation cost (11%). Based on the response presented a policy that subsidizes chargers for used PEV owners would benefit up to half of the buyers who find it needed and currently either pay for the full cost or not installing a charger. A major challenge in implementing this kind of policy will be knowledge and awareness about it, as used PEV buyers have less interaction with potential data sources provided by the OEM or while applying for the new PEV incentives.

2.3 Survey Conclusions

The used PEV buyers sampled in 2016 purchased relatively new cars with low mileage, low prices, and still under warranty. Most of these used PEVs were 2 or 3 years old, with a median self-reported odometer reading of 21,500 miles at the time of purchase. The survey reflects gaps in knowledge about the pricing and incentives of new PEVs, battery conditions and other topics that reduce the potential value of used PEVs. Some used PEV buyers may have paid more than what they would have paid knowing what the actual price of a new similar cars is. Others may have been more likely to have bought a new PEV if they had all the knowledge. Not asking about battery conditions may result in purchasing a car with shorter range that expected and lower satisfaction over time.

Furthermore, this survey shows that used PHEV buyers, and more so for the shorter-range PHEVs, during this time period were tending to drive their cars as hybrids without charging them as much as the original buyers. This phenomenon can be the result of the cost of installing a charger at home, but it more likely reflects differences in purchase motivation. The high price of the plug-in Prius in the used market together with the low charging rates may reflect used buyers who purchase the car for the HOV sticker rather than for the EV benefit. The purchase of used PEVs may be the outcome of temporary shortage in PHEV HOV permits at the time of the survey but still it proves that that carpool sticker is a good incentive for some PEV owners.

Used PEV-owning households have lower incomes than new PEV-owning households, but still much higher than the average car owning households in California. The mean household income reported by used PEV owners is $173,400 versus an average of $227,000 as reported by new PEV owners in a 2015 survey. Therefore, more needs to be done to broaden the used PEV market to all Californians.

Most used PEV buyers reported having access to a level 1 charger at home, with 44% exclusively charging at home. Despite this, a significant fraction of used short range PHEV owners utilize their vehicles as conventional hybrids without plugging it in suggesting that the potential climate and air quality benefits of these vehicles are not being realized and that there may be a role for additional public programs, such as education campaigns and incentives for chargers.

About half of the survey respondents have purchased only used vehicles previously and are generally much more likely to buy a used vehicle over a new one. Used PEV buyers were interested in acquiring a PEV at the start of their shopping process, with about a third reporting they were only interested in the specific make and model they purchased. Overall, early used PEV buyers are satisfied with their vehicles - 95% would repeat their purchase or get another PEV.

Future work, that will focus on more mature market will be able to look at used PEV market with much higher supply as large number of PEVs are coming back from 2 and 3 years lease agreements. This market will also include older cars or high mileage cars that are out of the OEM warranty and may attract different buyers and be used in different settings. We suggest repeating this survey on the used PEV market once it has matured in order to examine three main topics: 1) The impact of the secondary market on the spatial distribution of PEVs and the derived demand for home and work infrastructure. This topic will also have contributed to quantifying the expected impact of the used market on GHG and criteria pollutant emissions reduction. 2) How the secondary market responds to the presence of incentives in the market in general, and how the patterns of trade may differentially benefit certain income and ethnic communities. 3. The extent to which activity in the secondary market affects new PEV sales. Of particular interest may be the impact of the residual value on the private and lease markets, and the rate of PEV trade between California and other states. Combining this study with three other surveys of new and used ICE buyers and new PEV buyers can improve our general understanding of vehicle purchase within all groups in California and will allow a better understanding of the three topics discussed above.

3 Econometric Analysis of the Used PEVs Market

3.1 Introduction

In this chapter we take a retrospective view of developments in the used PEV market. Recent years have been characterized by high growth rates in adoption of electric vehicle technology. The used PEV market has evolved with a two- to three-year lag relative to the new car market. As new PEV sales in California increased to a roughly 2.5 percent market share by 2013, cars leased in 2011 and 2012 began to reach the end of their lease agreements. A robust used car market developed, and consumers were able to choose between new and used electric vehicles. Given the similarity between new and used PEVs, they became substitutes for each other in the eyes of buyers, very much in the same way that someone today might choose between a new Honda Civic or an older model. Any market forces that influence the price that consumers pay in either the new market will, as a result of the substitutability between these market segments, influence patterns of trade in the used market. In this chapter, we examine some of these patterns.

We seek to answer two main questions. First, to what extent do financial subsidies for new PEV purchases influence the flow of PEVs between states? The hypothesis here is that if a state offers purchase subsidies that apply only to new PEVs and not used, then this will cause used

PEVs to depreciate in value within that state but be relatively more valuable in states with no new PEV purchase subsidies. The re-sorting of used PEVs across states results from the activity of auto dealerships who purchase the used PEVs from previous owners or reclaim ownership after the expiry of a lease. Rather than selling the car on their own used car lot, dealers will often sell the car to another dealer via an auction clearinghouse. To examine the relationship between subsidies and purchases across states, we examine data from the largest use car auction market in the country (Manheim). These exchanges bring together sellers and buyers, the vast majority of whom are auto dealerships, who offer used cars for sale and bid on their purchase. The highest bidder purchases the car from the seller, so long as the highest bid exceeds a reservation price. The sales records from these auction transactions, along with the location of the buyers and sellers, offer an opportunity to study flows in the used car market.

Second, we look for evidence that low-income or minority ethnic groups face abnormally high barriers to purchasing PEVs in the state of California. We use micro data from Experian that allows us to observe both the reported transaction price of the used PEVs and a measure of the distance traveled from customer to dealer. We examine whether low-income or minority ethnic groups are facing different barriers in the PEV market than in the markets for ICEs or HEVs.

While we discuss some caveats to interpreting our results, we find evidence that is consistent with there being few systematic barriers that are adversely inhibiting access to PEVs differentially across ethnic and income groups.

3.2 Understanding Used PEV Trade: Data and Methodology

To study the flow of used EVs, we use data from the largest vehicle auction exchange in the country: Manheim. The dataset from Manheim contains the universe of electric vehicles transacted in their continental US exchanges between January 4, 2010 and July 6, 2015.[2] We also were provided with EV type: hybrid electric vehicle (HEV), plug-in-hybrid electric vehicle (PHEV), and battery electric vehicle (BEV). In what follows, we maintain disaggregated PHEVs and BEVs, but sometimes refer to them jointly as PEVs. In total, we observe 235,261 HEV and PEV sales. After removing observations with missing odometer readings, invalid model years, VINs, and origin and destination data we are left with 232,796 auctioned HEV and PEV vehicles. We further exclude: (1) any vehicles that were bought from a Manheim auction house or sold to a buyer outside of the contiguous 48 US states, and (2) three models (Honda FIT, Smart Fortwo and Chevy Spark) for which we do not observe whether the specific vehicle is a traditional hybrid, plug-in hybrid or battery electric vehicles. This leaves a total of 201,451 observations across all years of the sample, and 82,997 observations after January 1, 2014.

Descriptive statistics of the Manheim data can be seen in Table 3-1 and Table 3-2. Table 3-1 lists the top three vehicle models by transaction frequency on the Manheim exchanges during the

[2] The specific location of Manheim exchanges in the United States can be found here: https://publish.manheim.com/en/locations/us-locations.html

sample period January 1, 2014 through July 6, 2015. This sample period was selected to reflect the fact that there were very few used PEV transactions before 2014.

Table 3-2 summarizes the maximum financial purchase incentives for BEVs and PHEVs offered by states during the years 2014-2015 and the flows of vehicles in and out of each state.[3] Several states offered some form of PEV rebate incentives. When the incentive column reads "Sales Tax", this reflects a waiver of the sales tax for PEV purchases in that state. Rebate levels range from up to $1,500 per new PEV purchased in Utah and Louisiana to up to $6,000 in Colorado.[4] Two important distinctions should be noted. First, most states offer incentives only on new PEV purchases, and these states comprise the upper panel in the table. Colorado, New Jersey, and D.C. offer incentives for both new and used PEV purchases. The presence of used EV rebates is relevant since the relative value of new and used PEVs in a state is affected significantly if new PEVs are subsidized but used PEVs are not. During the years 2014-2015, only the state of Washington offered a subsidy for hybrid electric vehicles.

Table 3-1. Counts by Vehicle Type on Manheim Exchanges, January 1, 2014 – July 6, 2015

	BEV		PHEV		HEV	
Rank	Model	%	Model	%	Model	%
1	Nissan Leaf	94.9%	Chevrolet Volt	58.8%	Toyota Prius	30.7%
2	Ford Focus	2.5%	Ford C-Max	23.1%	Toyota Camry 4C	7.4%
3	Smart ForTwo	1.9%	Ford Fusion	9.1%	Toyota Civic	7.1%
Other		0.7%		9.0%		54.8%
Total		6,970		3,700		72,327

Table 3-2 begins to illuminate the potential role of BEV and PHEV purchase incentives on the flow of vehicles in the secondary market. The columns labeled "Ex" list the total number of vehicles of that type exported from the state, and the columns labeled "Net" present counts of net flows (exports minus imports) of each type of car. Thus, a state is a net exporter if "Net" is negative, and a net importer if it is positive. As can be seen in the "New Incentive Total" row, used BEVs tend to flow out of states with new PEV rebates, and the opposite pattern is exhibited in the HEV market. This is most clearly seen when examining the aggregate flows by incentive/non-incentive designation. There was a net flow of 745 BEVs out of incentive states – roughly half the size of total export volume – as compared to a net flow of 2830 HEVs *into* PEV incentive states –roughly a third the size of total export volume. The PHEV flows are mixed.

[3] The source of the subsidy data is the Alternative Fuels Data Center: https://www.afdc.energy.gov/laws

[4] Subsidies listed in Table 3-2 are available for both BEV and PHEV vehicle types in all states, with the exception of California (the maximum PHEV subsidy is $1,500), Utah (the maximum PHEV subsidy is $1,000), Georgia (there was no financial subsidy on PHEVs during the sample period), and New Jersey (which did not extend the sales tax waiver to PHEVs). The differences in BEV and PHEV subsidies are reflected in the analysis that follows.

California is an interesting case, since it is the state with the largest net exodus of BEVs. Presumably this is due to the high quantity of new BEVs in California in the years preceding 2014 (i.e. California had a high supply of used BEVs in 2014 and 2015), and also the presence of new BEV subsidies under the CVRP that served to make close substitutes for used BEVs less expensive. These summary statistics may reflect any number of forces. For this reason, we do not suggest reading too much into the summary statistics for any individual state, since there may be (unobservable and unrelated to EV subsidies) reasons for idiosyncratic patterns in the data. A primary objective of the empirical work that follows is to control for a wide class of potential confounders.

Table 3-2: PEV purchase incentives and net flows by state in 2014-2015

	Incentive		BEV		PHEV		HEV		EV	
State	Maximum	S.177	Ex	Flows	Ex	Flows	Ex	Flows	Ex	Flows
AR	$2500 Rebate	0	0	6	0	6	0	123	0	135
CA	$2500 Rebate	0	708	-595	95	16	1891	820	2694	241
GA	$5000 Credit	0	322	-225	127	-62	2334	-326	2783	-613
LA	$1500 Credit	0	4	4	2	1	144	-23	150	-18
MA	$2500 Rebate	1	1	29	38	-15	457	-30	496	-16
MD	$3000 Credit	1	2	118	45	46	1053	537	1100	701
SC	$2000 Credit	0	2	11	1	28	166	347	169	386
TX	$2500 Rebate	0	146	-68	86	-50	1439	-11	1671	-129
UT	$1500 Credit	0	2	99	3	64	58	704	63	867
WA	Sales Tax	0	303	-124	25	4	324	689	652	569
New Incentive Total			**1490**	**-745**	**422**	**38**	**7866**	**2830**	**9778**	**2123**
CO	$6000 Credit	0	85	18	21	16	311	300	417	334
DC	Sales Tax	0	0	2	0	0	0	147	0	149
NJ	Sales Tax	1	62	514	86	-53	2536	-1077	2684	-616
New/Used Incentive Total			**147**	**534**	**107**	**-37**	**2847**	**-630**	**3101**	**-133**
Non-Incentive States			**1186**	**568**	**828**	**287**	**16888**	**3519**	**18902**	**4374**

Positive flow values reflect net imports, negative ones net exports.
Only observations entirely in the contiguous US between 1/1/2014 and 7/6/2015 were used.
Section 177 ZEV non-incentive states include: CT, ME, NY, OR, RI, and VT.

Some readers may be interested in the potential role of the ZEV mandate. Under the ZEV mandate provisions, OEMs gain ZEV credit for cars sold in any of the Section 177 ZEV states, and so it is unclear what incentive this creates for OEMs to sell in one state or another within the Section 177 ZEV designation. It is thus also unclear what effect we would predict this to have on flows in the used market. It does appear that the presence of new PEV incentives affects flows in the used market irrespective of Section 177 ZEV status (net BEV flows are lower in incentive states than no-incentive states).

We continue by documenting spillovers from the new into the used vehicle market using a regression approach. Variation in our variable of interest is largely cross-sectional during our study period. Some states offered incentives, other states did not. As such, our main empirical concern is omitted variables correlated with both a state offering an incentive for new vehicles and the likelihood with which used vehicles are exported from that state. Our empirical strategy will be to compare the pattern of trade in BEVs and PHEVs to the pattern of trade in HEVs, and in particular examine how these patterns relate to the presence of new BEV and

PHEV incentives in the originating state. This strategy rests on an underlying assumption that if there were no state incentives, the pattern of trade in BEVs and PHEVs would look similar to the pattern of trade in HEVs. The credibility of our estimates thus rests on the validity of HEV flows as a counterfactual against which to compare PEVs, and there are at least two reasons to believe in their validity. First, during the period of study, an HEV rebate was only available in Washington state. The presence of HEV rebates could influence the flow of HEVs in similar ways that we hypothesize for PEVs, and so their absence is encouraging. Second, the states that exhibited high HEV adoption are similar states to those that exhibited high PEV adoption. We presume that this is a function of underlying similarity in preferences among buyers of PEVs and HEVs.

Our regression specifications are similar across two dependent variables of interest: net exports and the price of a vehicle at auction. We regress each dependent variable on sets of fixed effects, vehicle characteristics and incentive "treatments" as shown in the following equation (3.1):

$$y_{imst} = \alpha + \sum_{j \in \{PHEV, BEV\}} (\gamma_j + \delta_j * I_{sj}) + \theta * X_{imst} + \varepsilon_{imst}$$

where *i*, *m*, *s* and *t* denote vehicle, model, state and time, respectively; γ_j equals one if the vehicle is either a PHEV or a BEV; and, I_{sj} equals one if there is a new subsidy available in state *s* for vehicles of type *j*. A wide array of potential covariates is represented by X_{imst}. The regression constant is estimated by α, and ε_{imst} reflects random estimation error. θ and δ_j are parameters to be estimated.

3.2.1 Understanding Used PEV Trade: Results and Discussion

We estimate the coefficients of interest, δ_{PHEV} and δ_{BEV}, conditioning on covariates as shown in equation 3.1. This effectively compares the differences in means of the outcome variables for BEVs and PHEVs to HEVs in states that offer a new incentive and states that do not offer an incentive for each vehicle type. We enrich the specification to include state-of-origin fixed effects, state-of-destination fixed effects, month-year fixed effects, make-model fixed effects and vehicle characteristics such as vehicle mileage and age at time of auction.[5] This approach will yield consistent estimates of the treatment effect under the assumption that the correlation between unobservable determinants of EV and hybrid demand does not differ between new-incentive and no-incentive states. State-of-origin fixed effects account for model and time-invariant differences across state wholesale auto markets – as noted above, these are likely important to include.

[5] In the regression output tables, "fixed effects" is abbreviated "FE".

Table 3-3. Effect on Used BEV and PHEV Quantities Exported

	(1)	(2)	(3)	(4)	(5)
PHEV	-0.00925	0.0129	0.0156*		
	(0.00687)	(0.00660)	(0.00667)		
PHEV*New-Incentive	0.0108*	0.00987*	-0.000706	-0.00361	-0.00382
	(0.00471)	(0.00416)	(0.00485)	(0.00483)	(0.00482)
BEV	0.115***	0.129***	0.129***		
	(0.00527)	(0.00510)	(0.00520)		
BEV*New-Incentive	0.0276***	0.0284***	0.0408***	0.0462***	0.0457***
	(0.00680)	(0.00644)	(0.00681)	(0.00674)	(0.00672)
Vehicle mileage					4.79e-08
					(2.77e-08)
Vehicle age at sale					-0.0176***
					(0.000594)
Origin FE	X	X	X	X	X
Destination FE		X	X	X	X
Month-year FE			X	X	X
Model FE				X	X
Vehicle Covariates					X
Observations	202341	202341	202341	202341	202341
Adj. R-Squared	0.202	0.389	0.389	0.402	0.406

Standard errors are in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
The sample includes all BEV, PHEV, and HEV sales.
The dependent variable is 1 if the buyer was in a different state than the auction house.
New-Incentive is 1 if the sales state offers only new-vehicle incentives on BEV or PHEV.

Table 3-3 displays results from the base specifications. The coefficients should be interpreted as percentage changes. For example, the coefficient in column 1 associated with "BEV*New-Incentive" reflects a 2.76% increase in exports. Moving left to right, it's clear that including month-year fixed effects absorbs important variation in the seasonality of PHEV transactions originating in states with new PEV incentives. The coefficient goes from positive and significant (columns 1 and 2) to zero (column 3). The specifications in columns 4 and 5 are preferred, since the inclusion of model fixed effects absorbs compositional differences between incentive and non-incentive states in the types of PHEVs and BEVs that are sold. Including vehicle covariates (mileage and age at sale) are intended to further absorb otherwise unobserved determinants of demand for PEVs.

Interestingly, the new BEV incentives appear to have more effect on the trade patterns of used BEVs than new PHEV incentives have on used PHEVs. There is no statistical effect on export quantities of used PHEVs, but a 4.5-4.6 percent increase in the rate of export of used BEVs from states with new PEV incentives. This is consistent with the theoretical prediction that subsidies on one subset of products (new BEVs) will depress the value of close substitutes for those products (used BEVs). Mileage has an insignificant effect on the probability of export, and the negative coefficient on vehicle age at sale reflects a lower probability of export among older cars.

Table 3-4 displays estimated differences in used vehicle price levels. Columns 1-3 show that used PHEVs are on average approximately $2300-$3100 *more* expensive than used HEVs, and used BEVs are on average $1200-$2100 *less* expensive than their used HEV counterparts. These estimates do not condition on car model, and can be thought of (very roughly) as comparing the price of Nissan Leafs to Toyota Priuses across states with a different incentives status. The presence of a new-PEV incentive has mixed effects on used PHEV prices, and uniformly decreases the transaction price of used BEVs. It is interesting to note that the effect of new PEV subsidy on used PHEV prices flips its sign between columns 2 and 3, where month-year effects are added. This implies seasonality in the purchase timing of PHEVs that does not appear to be present for BEVs.

Table 3-4. Effect of Incentives on Used BEV and PHEV Prices

	(1)	(2)	(3)	(4)	(5)
PHEV	2298.3***	2316.2***	3072.5***		
	(93.18)	(93.63)	(91.62)		
PHEV*New-Incentive	-163.9	-171.2	805.5***	377.2***	413.1***
	(93.15)	(92.02)	(101.9)	(66.14)	(42.33)
BEV	-2126.1***	-1994.5***	-1212.1***		
	(53.80)	(56.45)	(55.85)		
BEV*New-Incentive	-517.2***	-369.7**	-663.3***	-256.8**	-392.1***
	(120.3)	(120.0)	(125.0)	(79.36)	(51.14)
Vehicle mileage					-0.0404***
					(0.000859)
Vehicle age at sale					-1153.8***
					(12.23)
Origin FE	X	X	X	X	X
Destination FE		X	X	X	X
Month-year FE			X	X	X
Model FE				X	X
Vehicle Covariates					X
Observations	202341	202341	202341	202341	202341
Adj. R-Squared	0.0697	0.0902	0.105	0.683	0.868

Standard errors are in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
The sample includes all BEV, PHEV, and HEV sales.
New-Incentive is 1 if the sales state offers only new-vehicle incentives on BEV or PHEV.

Columns 4 and 5 display a comparison within models (e.g. between the price of Leafs in incentive states to the price in non-incentive states). The presence of incentives leads to a roughly $400 *increase* in used PHEV prices, and an average $250-$400 reduction in the price of used BEVs. The price increase is difficult to explain and is a result worthy of future investigation. The price decrease for used BEVs is what theory would predict. The drop in treatment effect between columns 3 and 4 suggests that lower-price BEVs are sold in incentive states. This explanation is further supported by conditioning on odometer reading and vehicle age, revealing that used BEVs in incentive states are older and have been driven more (-663.3 is a larger negative coefficient than -392.1, and the difference is explained by the types of models that are purchased-model fixed effects-and mileage and age at sale). If incentive states are populated with more early adopters of BEVs, this provides additional justification for including hybrid controls if it is true that states with early BEV adoption are also states with early hybrid adoption.

3.3 Do Disadvantaged Subpopulations Experience Barriers to EV Adoption? Data and Methodology

Policy makers consider PEVs to be an important element of reducing urban air pollution, lowering carbon emissions and reducing overall petroleum consumption. Federal, state and local governments offer incentives to encourage consumer adoption of these vehicles. In this section, we analyze new and used vehicle purchase data from Experian to compare purchase patterns across vehicle types and buyer attributes. Experian combines several sources of data, ranging from DMV registration records (for car type, transaction price and purchase timing) to public records on the buyer's dwelling. Experian also has access to names and addresses of the purchaser (we do not). They use these fields to match other publicly available data (e.g. credit scores, magazine subscriptions, etc.), and use these to estimate gender (presumably based on first name), ethnicity (presumably based on a combination of first and last names), and income (based on home characteristics and purchase patterns).

We use several relevant fields – car type (VIN), transaction date and price, buyer ZIP, and Experian estimates of ethnicity and income – from Experian for the state of California between December 29, 2010 and January 1, 2016. The sampling methodology used by ARB over-weights PEVs relative to HEVs, and HEVs relative to ICEs. The data include the universe of PEVs and a random subset of "comparable" cars (which exclude, for example, pickup trucks, SUVs and luxury cars). Table 3-5 displays observation counts by vehicle type and new/used classification in the Experian dataset for California. Table 3-6 lists the top models of each vehicle type. Note that the analysis that follows, as well as these summary tables, exclude leased vehicles. The rationale is that leased car prices are potentially interpreted (by consumers) and reported differently than cars that are purchased outright.

Table 3-5. Experian California Data Summary Statistics, Excluding Leased Vehicles

Vehicle Technology	New	Used	Total
ICE	63,028	92,395	155,423
BEV	31,073	10,233	41,306
PHEV	40,522	8,844	49,366
HEV	10,712	7,431	18,143
Total	145,335	118,903	264,238

Only observations within CA between 12/29/2010 and 1/1/2016 were used.

Table 3-6. Experian California Data Top Vehicle Types, Excluding Leased Vehicles

	BEV		PHEV		HEV		ICE	
Rank	Model	%	Model	%	Model	%	Model	%
1	Tesla Model S	55.3%	Toyota Prius	42.2%	Toyota Prius	53.1%	Toyota Camry	11.7%
2	Nissan Leaf	26.7%	Chevrolet Volt	38.3%	Toyota Prius C	11.8%	Honda Civic	11.1%
3	BMW I3	3.9%	Ford Fusion	10.6%	Toyota Prius V	9.3%	Honda Accord	10.9%
4	Chevrolet Spark	3.6%	Ford C-Max	8.4%	Toyota Camry	8.5%	Toyota Corolla	9.8%
5	Smart ForTwo	2.8%	Cadillac ELR	0.5%	Ford Fusion	5.6%	Nissan Altima	8.8%
Other		7.7%		0%		11.7%		47.7%
Total		41,306		49,366		18,143		155,423

Only observations within CA between 12/29/2010 and 1/1/2016 were used.

A primary motivation for examining PEV adoption in disadvantaged subpopulations stems from basic observations about who has been buying these cars in the recent past. Adoption of PEVs and HEVs by African-American, Hispanic and low-income consumers has lagged adoption by Asian, non-Hispanic white and high-income consumers (see Figure 3-1 and Figure 3-1. Purchases by Ethnicity

).[6] As a result, incentives have tended to accrue disproportionately towards high-income households (Borenstein and Davis, 2015). Understanding the low rate of adoption for certain demographic groups is of particular interest to California legislators – SB350 requires CARB to study barriers to zero-emission transportation options faced by low-income consumers. The

[6] Note that for HEVs and ICEs, these figures reflect the proportions in our dataset, which is a non-random subsample of the California vehicle population. Therefore, they should not be interpreted as representative of the California population.

Clean Vehicle Rebate Project (CVRP) and Enhanced Fleet Modernization Program (EMFP) Plus Up target these groups – the programs offer more lucrative incentives to low income consumers or consumers who live in disadvantaged communities.

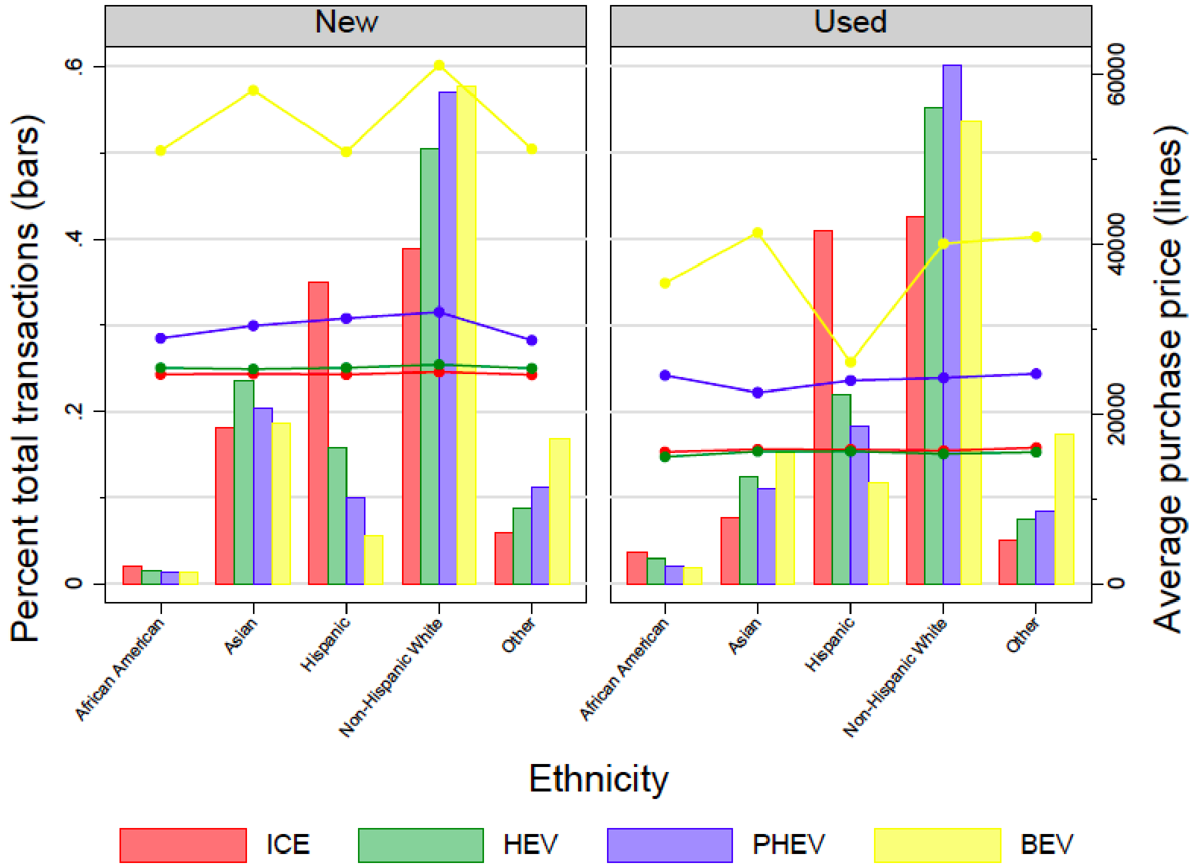


Figure 3-1. Purchases by Ethnicity

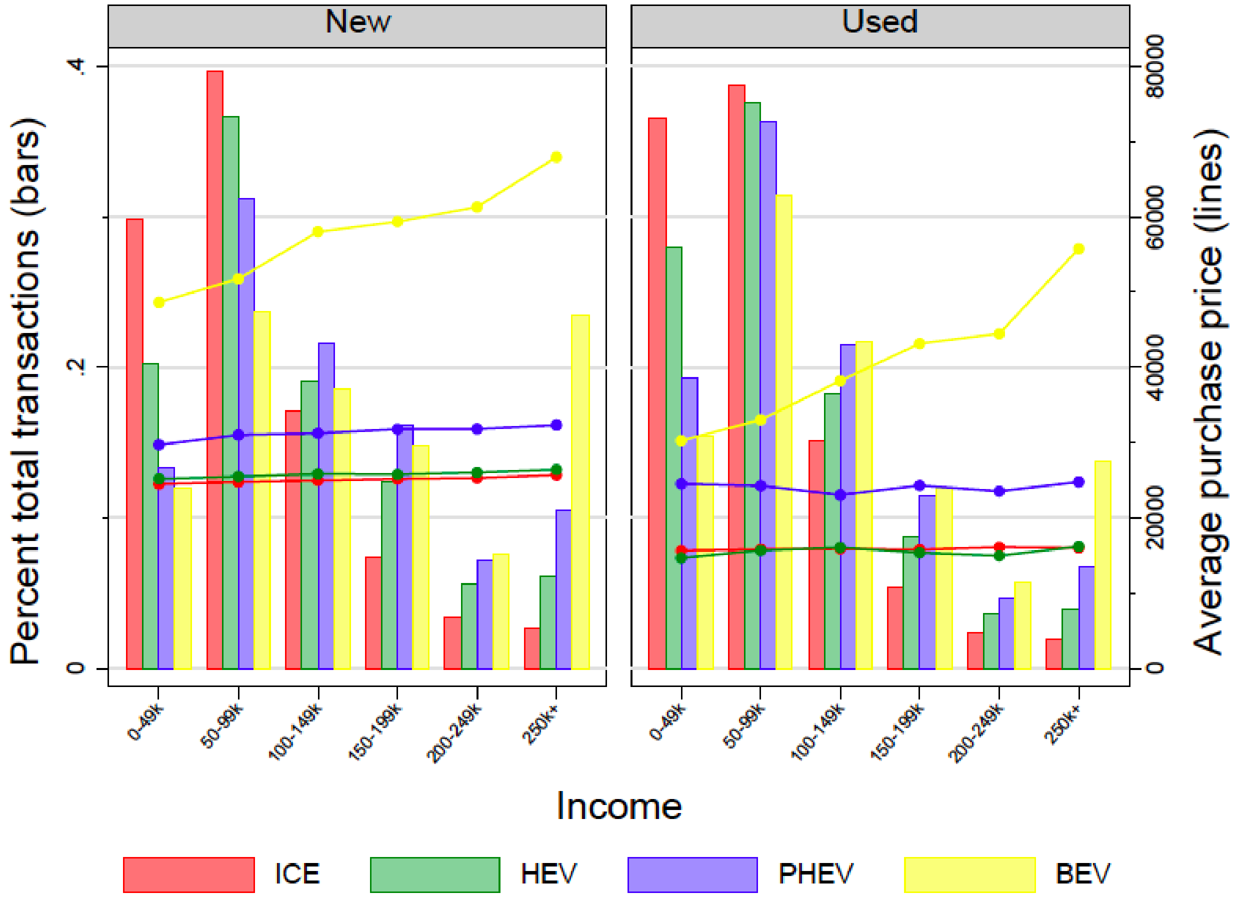


Figure 3-2. Purchases by Income

We analyze data for over 260,000 new and used California vehicle sales between 2012 and 2015. We see the price paid by the consumer, the location of dealership, the zip code of the buyer and buyer demographic characteristics (e.g., race, gender, income, age) for each transaction.[7] We test for the presence of two commonly asserted barriers to EV adoption: (1) price discrimination against low-income consumers; and, (2) limited selection of EVs at dealerships proximate to disadvantaged communities.

To test the presence of price discrimination, we compare the price premium (or discount) paid by different demographic groups when purchasing alternative-technology vehicles as opposed to comparable vehicles with internal combustion engines. We calculate how much more (or less) a particular demographic group paid relative to the average price paid all vehicles of the same make, model, model-year and trim. Price differences may be a result of compositional effects (e.g. non-Hispanic Whites buy different cars than Asians), differences in bargaining

[7] In the analysis, observations with missing data elements are automatically dropped.

power, or discrimination. Since we cannot separately identify these effects empirically, the results must be interpreted with this caveat in mind.

The empirical specification reflected in the price tables below is from equation 3.2:

$$P_{imzt} = \alpha_0 + \sum_{k\in\{ethn\}} \beta_k * I_{i\in k} + \sum_{k\in\{ethn\}} \gamma_k * I_{i\in k} * Inc_i + \sum_{k\in\{ethn\}} \sum_{j\in\{type\}} \delta_{kj} * I_{i\in k} * I_{j=m}$$

$$+ \sum_{k\in\{ethn\}} \sum_{j\in\{type\}} \mu_{kj} * I_{i\in k} * I_{j=m} * Inc_i + \theta * X_{imzt} + \varepsilon_{imzt}$$

where *i*, *m*, *z* and *t* denote buyer, car type purchased (ICE, HEV, PHEV, BEV), buyer location (zip) and month of sample, respectively. The covariate matrix X_{imzt} includes vehicle age, distance between buyer and dealer zip centroids, summations over the product of vehicle type and income, month-of-sale fixed effects, buyer zip code fixed effects, and car model fixed effects. The "Intercept" row in the tables that follow is comprised of the estimates of α_0 (Base Effect) and β_k's (the incremental average difference in price paid by various ethnicities for an ICE). Income effects by ethnicity are represented by γ_k. Price effects by ethnicity broken down by vehicle type come from δ_{kj}, and ethnicity-type-income effects from the estimates of μ_{kj}.

3.3.1 Do Disadvantaged Subpopulations Experience Barriers to EV Adoption? Results and Discussion

We present price results separately for new (Table 3-7) and used (Table 3-8) non-leased cars. The "Base Effect" intercept is the sales price paid for an ICE car by the average Non-Hispanic White buyer. The subsequent coefficients can be thought of as average changes in the transaction price for buyers of different ethnicities (moving across the columns) and incomes (various rows) for different vehicle types (rows). For example, Asians pay roughly $528 less for an ICE as non-Hispanic Whites and, all else equal, pay $16.50 less for every $10,000 of income. HEVs are on average $1,878 more expensive than ICEs, but Asians pay an additional $142. Since our data do include vehicle information at the model-year level but do not include more granular attributes (e.g. trim), these differences may be influenced by consumer preferences over unobserved vehicle attributes.

Our main research question of interest relates to the price of PHEVs and BEVs. Two patterns become relatively clear when examining the market for new cars in Table 3-7. First, low-income customers do not seem to face higher prices when negotiating a new PHEV or BEV. If anything, low-income customers across all ethnicities purchase these cars at a slight discount to high-income customers purchasing identical PHEVs and BEVs. There are differences in price paid by demographic group, but they suggest that non-Hispanic whites and Asians, not Hispanics and African Americans, pay a price premium when purchasing new PHEVs and BEVs.

Table 3-7. Transaction Price Differences (Income and Ethnicity by Vehicle Type – New Cars)

	Base Effect	African American	Asian	Hispanic	Other
Intercept	34,011.06	-75.59	-527.52	169.69	-589.17
	(1,838.33)***	(188.65)	(89.29)***	(84.39)**	(228.11)**
Income (USD 1000s)	1.62	-1.20	-1.65	-1.56	1.67
	(0.90)*	(1.73)	(0.63)***	(0.85)*	(1.64)
HEV	1,878.38	-336.79	142.05	-220.12	-179.65
	(242.09)***	(586.64)	(151.92)	(206.63)	(720.98)
HEV × Income	-1.14	2.67	1.58	2.46	1.81
	(1.01)	(3.91)	(0.93)*	(2.10)	(4.20)
PHEV	6,328.21	-4,311.78	63.29	-213.81	-4,412.02
	(339.50)***	(1,451.43)***	(149.98)	(152.02)	(1,000.60)***
PHEV × Income	-0.20	26.30	1.22	0.74	22.25
	(1.12)	(8.89)***	(1.01)	(1.58)	(4.88)***
BEV	4,902.43	-2,853.97	-684.96	-1,041.34	-2,646.26
	(1,565.94)***	(2,886.09)	(427.32)	(432.35)**	(2,005.70)
BEV × Income	1.70	15.91	-1.58	2.99	14.10
	(1.85)	(15.34)	(2.75)	(4.66)	(9.50)
N	133,649	2,238	25,788	26,779	13,239

Standard errors are in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The results are somewhat different in the used car market. Whereas in the new car market the price paid for PHEVs and BEVs is increasing in income, the opposite is true for non-whites buying PHEVs and for Hispanics buying BEVs. In those cases, increases in income are associated with *lower* prices. The income-unadjusted prices paid for PHEVs by African Americans, Hispanics and other ethnicities are significantly higher ($434 for African Americans and $2,627 for other ethnicities) than those paid by non-Hispanic whites. On the other hand, non-whites pay lower prices on average for used BEVs than non-Hispanic whites. These results show that, on average, low-income non-whites face higher prices in the used PEV market (relative to baseline) than they do in the new PEV market.

Table 3-8. Transaction Price Differences (Income and Ethnicity by Vehicle Type – Used Cars

	Base Effect	African American	Asian	Hispanic	Other
Intercept	20,892.85	-394.65	-395.85	285.38	202.87
	(3,026.10)***	(403.58)	(240.15)	(183.61)	(320.62)
Income (USD 1000s)	-0.55	4.13	4.40	0.05	2.32
	(1.34)	(4.62)	(2.66)	(2.19)	(3.27)
HEV	-745.31	1,519.07	780.20	254.17	1,440.80
	(760.86)	(1,285.54)	(868.14)	(677.09)	(1,251.75)
HEV × Income	3.91	-17.55	-7.61	2.51	-19.90
	(3.03)	(14.67)	(7.01)	(8.41)	(10.21)*
PHEV	2,614.86	434.49	-327.90	1,482.77	2,627.19
	(1,249.78)**	(1,876.73)	(1,594.23)	(443.65)***	(1,864.67)
PHEV × Income	4.95	-5.44	-2.09	-22.29	-24.22
	(3.69)	(14.74)	(9.60)	(5.50)***	(12.43)*
BEV	8,292.30	-171.56	-452.34	-349.29	-2,979.87
	(3,031.87)***	(2,593.64)	(910.72)	(765.96)	(1,521.50)*
BEV × Income	7.15	2.78	-1.86	-18.61	13.14
	(5.76)	(19.50)	(7.52)	(7.65)**	(9.81)
N	116,615	3,920	10,341	41,502	7,648

Standard errors are in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

To further assess barriers related to the availability of electric vehicles, we perform a similar comparison for distance traveled. Our data afford us the opportunity to calculate the distance traveled from the centroid of a buyer's home zip code to the zip centroid of the dealership at which they purchased their vehicle. If local dealerships in disadvantaged communities do not have sufficient supply of electric vehicles, we would expect that consumers in these communities who purchase electric vehicles would have to travel relatively further to make the purchase. In Table 3-9 and Table 3-10, we present regression results relating distance traveled to income and ethnicity by vehicle type for the new and used market, respectively. For consistency with the price analysis, we again restrict the sample to exclude leased vehicles in the new car market.

The average distances traveled for new ICEs differ significantly by ethnicity. African Americans and Asians travel more than three miles more than non-Hispanic whites. However, when we look at distance traveled to purchase new PHEVs and BEVs, there is not a statistically significant difference beyond what is observed for ICEs. There appear to be small differences in distance traveled by income for Hispanics buying BEVs (wealthier buyers travel farther) and other ethnicities for PHEVs (less wealthy buyers travel farther). This suggests that local availability does not explain the gap in adoption for new PEVs during this time period.

The patterns of distance traveled to buy used PHEVs and BEVs are somewhat different than to buy new ones. On average, people tend to travel 10.2 miles to buy used cars, which is 1.6 miles farther than they travel to buy new cars. People travel farther still to buy used PHEVs (3.8 miles farther) and BEVs (9.6 miles farther). Relative to this baseline, Asians and Hispanics travel even farther (3.5 and 2.0 miles respectively) for used PHEVs, but Hispanics and other ethnicities travel less distance for used BEVs (2.9 and 9.7 miles respectively). There are mostly no differences in distance traveled as a function of income across ethnicities, but Hispanics travel somewhat farther for PHEVs and BEVs as their incomes increase, and other ethnicities travel somewhat farther for BEVs as incomes increase. Interestingly, there are no measurable differences in distance traveled by African American used PHEV and BEV buyers relative to non-Hispanic whites.

Table 3-9. Differences in Distance Traveled to Dealer (Income and Ethnicity by Vehicle Type – New Cars)

	Base Effect	African American	Asian	Hispanic	Other
Intercept	8.6881	2.9761	3.3959	0.8176	2.4263
	(6.0576)	(0.9538)***	(0.5741)***	(0.4154)*	(0.6765)***
Income (USD 1000s)	0.0110	-0.0126	-0.0040	-0.0070	-0.0056
	(0.0030)***	(0.0099)	(0.0040)	(0.0032)**	(0.0056)
HEV	1.6928	-1.0607	0.5021	1.2192	0.1242
	(0.7203)**	(2.4603)	(0.9933)	(1.1078)	(1.4162)
HEV × Income	-0.0016	-0.0083	-0.0069	-0.0010	-0.0037
	(0.0046)	(0.0195)	(0.0073)	(0.0087)	(0.0115)
PHEV	4.5814	0.3214	-1.0451	-0.4445	2.4177
	(0.7025)***	(2.5047)	(0.6870)	(0.6678)	(1.5987)
PHEV × Income	-0.0059	-0.0088	0.0036	0.0014	-0.0177
	(0.0037)	(0.0181)	(0.0050)	(0.0055)	(0.0105)*
BEV	7.4807	6.8096	-3.6555	-1.4519	-3.2440
	(1.8743)***	(5.7662)	(2.5883)	(1.3362)	(2.2683)
BEV × Income	-0.0241	-0.0373	-0.0062	0.0169	0.0061
	(0.0073)***	(0.0292)	(0.0080)	(0.0101)*	(0.0121)
N	132,299	2,212	25,592	28,083	12,344

Standard errors are in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 3-10. Differences in Distance Traveled to Dealer (Income and Ethnicity by Vehicle Type – Used Cars)

	Base Effect	African American	Asian	Hispanic	Other
Intercept	10.2460	0.6933	1.6509	-0.6367	-0.0274
	(3.0308)***	(0.6549)	(0.5302)***	(0.3056)**	(0.7164)
Income (USD 1000s)	0.0111	-0.0126	0.0000	-0.0055	0.0031
	(0.0025)***	(0.0074)*	(0.0046)	(0.0029)*	(0.0070)
HEV	3.3890	-2.4759	-1.0002	-2.3721	-1.6345
	(1.0493)***	(2.1656)	(1.2341)	(1.6599)	(1.8497)
HEV × Income	-0.0114	0.0353	0.0057	0.0305	0.0009
	(0.0072)	(0.0221)	(0.0081)	(0.0212)	(0.0167)
PHEV	3.8348	-1.5828	3.5173	2.0043	-0.7913
	(1.3724)***	(2.5802)	(1.8590)*	(1.0918)*	(2.4189)
PHEV × Income	0.0039	0.0178	-0.0144	0.0183	-0.0102
	(0.0062)	(0.0267)	(0.0125)	(0.0100)*	(0.0161)
BEV	9.5873	0.4392	-0.6674	-2.8860	-9.6814
	(2.3840)***	(2.2605)	(1.2132)	(1.1858)**	(3.0438)***
BEV × Income	-0.0245	-0.0083	-0.0123	0.0383	0.0661
	(0.0073)***	(0.0142)	(0.0076)	(0.0127)***	(0.0202)***
N	112,479	3,803	9,807	40,816	7,218

Standard errors are in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The results of this work suggest that price discrimination and market access are not limiting adoption amongst these groups. In the new PEV market in particular, there is little evidence of minority ethnic groups paying higher prices or traveling longer distances to buy their alternative fuel cars. In the used car market, the results are more mixed. There do not appear to be any overall premiums in prices paid for used PEVs by non-white buyers. However, there are some differences when cutting the data by income and ethnicity. Low-income non-whites tend to pay more relative to baseline for used PHEVs than in the new car market, and the same is true for Asian and Hispanic buyers of used BEVs. While it's possible that these effects are compositional or result from sampling variation, it's also possible that there are more obstacles to market access in the used PEV market. Investments through the Low Carbon Transportation funds, including the CVRP and the EFMP Plus Up, are potentially important ways to increase adoption levels, and evaluating the effects of these policies is an important area of future research.

3.4 PEV Secondary Market

In this section, we take a retrospective look at activity in the secondary market for PEVs. First, we examine the effects of state-level new PEV incentives on the flow of used PEVs across states. There appears to be a relationship. When a new BEV incentive is available in a state, that state exhibits a higher rate of net exports of BEVs relative to the HEV comparison group. We do not uncover a similar effect in response to new PHEV incentives. Since the incentives created by new PEV incentives may also affect price of used PEVs, we examine this relationship as well. We find evidence that new BEV incentives decrease the equilibrium price of used BEVs by approximately $250-400. This is in the approximate range of the commercial cost of shipping a car from California to Arizona. The results for PHEVs are in the opposite direction, which is difficult to explain. We suspect that these results may be an artefact of the thin market for PHEVs, as well as potentially data coarseness (e.g. we currently are examining aggregate PEV incentives, which likely always apply to BEVs and only occasionally to PHEVs). Nonetheless, the results for BEVs align with theoretical prediction that if a close substitute (new PEV) experiences a drop in price (e.g. a rebate incentive), then the price and pattern of trade in close substitutes will be affected.

Second, we explore the possibility that low-income and minority ethnicity buyers of PEVs experience barriers to purchasing in the new and used market. The results are somewhat mixed, but overall lead us to conclude that there is no clear evidence of systematic barriers to low-income and minority groups. In new PEV markets, low-income customers pay approximately the same price for PEVs than do higher-income buyers. While there are differences in prices paid across various demographic groups, they suggest that non-Hispanic whites and Asians, not Hispanics and African Americans, pay a price premium when purchasing new PHEVs and BEVs. This may be due to differences in unobserved car attributes (e.g. trim). Moreover, local availability, as measured by distance traveled, does not appear to explain the gap in adoption for new PEVs.

In the used market, there is mixed evidence that is, in some cases, consistent with the presence of heterogeneous barriers across ethnic and income groups. Non-whites do not pay a premium for PEVs overall, but there does appear to be an interaction between ethnicity and income. Non-whites buying PHEVs, and Hispanics buying BEVs, on average face *lower* prices in the used PEV market as their income increases.

Some caveats are needed. First, we are unable to control for compositional effects within models. To the extent that different income or ethnic groups demand different trim levels, these will not be conditioned out of the estimates. Second, our data include only purchases that occurred. Barriers may lead to potential PEV buyers deciding not to buy, and these potential transactions are obviously not present in a dataset of transactions. We cannot rule this out, but it would also require a very particular distribution of preferences to retrieve the results that we do and at the same time have many potential buyers who are blocked by higher prices or proximity barriers.

4 Conclusion

The sample of used PEV buyers surveyed in 2016 was dominated by individuals who learned about and planned to buy the specific vehicle they purchased. The vehicles tended to be relatively new with low mileage, relatively low prices, and still under warranty. In the future, the used PEV market will contain more and older vehicles with higher mileage that are over the battery and powertrain warranty limits, and will likely have different dynamics. Used PEV buyers are more utilitarian than new PEV buyers as reflected by their high driving needs, but appear less committed to electric driving; the drivers of short range PHEVs show high rate of driving their cars as hybrids not plugging them in. As shown in our price analysis, HOV stickers have a high impact on the price paid and they may be negatively correlated with charging behavior. If given the chance, the majority of used PEV buyers would choose to repeat their purchase. Used PEV buyers had knowledge gaps regarding the potential cost of new PEVs and in most cases decided to purchase the used PEV under partial data and knowledge on battery condition, the price of similar vehicles, or incentives for new PEVs. The survey results may suggest that current buyers of used PEVs have similar socio-demographic and travel characteristics to new PEV buyers rather than used ICEV buyers but only a comparison study with used ICEV buyers can quantify this point.

The econometric portion of this research has two main parts. First, we examine the relationship between new PEV incentives and the flow of used PEV trade across states. Second, we seek to identify barriers to PEV purchase opportunities that may exist among low-income and minority ethnic populations. Our trade results show that states with purchase incentives for new BEVs exhibit lower used-BEV prices and a higher rate of used BEVs exiting the state. In 2014-2015, the presence of new BEV subsidies led to a 4.5-4.6 percent increase in the rate of BEVs leaving those states and a $250-400 price discount. While California is the largest exporter of BEVs, the flow of trade is not large effect in absolute terms. However, this may be something for policymakers to monitor as the volume of PEV trade increases in general.

There does not appear to be market access discrimination towards minority groups in the new or used PEV market. Results are more mixed for prices paid by minority groups in the used PEV market. Some non-white, low-income populations appear to pay higher prices in the used PEV market, relative to a baseline, than they do in the new PEV market. Further research is needed to rule out compositional effects (e.g. that minority used PEV buyers are selecting used PEVs with more expensive features than those chosen by non-Hispanic white buyers). In general, the results of this study support a continued effort to understand and potentially remediate barriers such as knowledge and education on the technology, incentives, and charging in the California used PEV market.

The findings of this study have a direct impact on a wide variety of policies. A large subset of early used PEV buyers are unaware of the existence of subsidies for new PEV purchases, which is particularly surprising given that they are a population that is largely self-selected as interested in PEVs. This finding suggests that there are still significant shortfalls in public communication about the availability of state and federal incentives. Furthermore, used PEV buyers appear to be plugging the cars in much less than they could be, suggesting the GHG-reduction benefits of the cars might not be as high as they could be. We also see that longer-range PHEV users tend to plug-in much more than shorter range cars. Lack of charging opportunity does not affect charging range most likely reflecting self-selection of vehicle choice and charging installation choice. Consumer education and outreach programs may help increasing charging range together with lower cost of electricity and the shift to longer range PEVs, and maybe higher-powered PHEVs, that yield higher benefit for each charging event. Current used and new PEV owners have much higher incomes on average than the general car-owning population. This is a natural reflection of the cost of PEVs and the very low availability of low cost new and used car. Nevertheless, this study suggest that California needs to do more to monitor the access to PEVs for all communities and to adjust policies to address environmental justice. The success of the new PEV market is key to create a large secondary market and the success of the secondary market is a key to create a large new PEV buyers with substantial portion of repeat buyers. Integrating the policies aimed to grow both new and used market may impact total market growth and PEV viability for households who cannot afford new cars including low-income households and households in disadvantaged communities.

5 References

Benmelech, Efraim, Nittai K. Bergman (2009). 'Collateral pricing'. *Journal of Financial Economics* 91(3): 339-360.

Borenstein, S. and L. Davis. "The Distributional Effects of U.S. Clean Energy Tax Credits". *Tax Policy and the Economy* 30.1 (2016): 191-234.

Brenna, Morris, Federica Foiadelli, Michela Longo, and Dario Zaninelli. "e-Mobility forecast for the transnational e-corridor planning." *IEEE Transactions on Intelligent Transportation Systems* 17.3 (2016): 680-689.

Bühler F, Neumann I, Cocron P, Franke T, Krems JF (2011) Usage patterns of electric vehicles as a reliable indicator for acceptance? Findings from a German field study. Transportation Res. Board, 90th Annual Meeting, Report 11-0227

Busse, Meghan R., Christopher R. Knittel, and Florian Zettelmeyer. "Are Consumers Myopic? Evidence from New and Used Car Purchases." The American Economic Review (2013): 220-256.

Chen, J., S. Esteban, and M. Shum (2013), 'When Do Secondary Markets Harm Firms?', The American Economic Review, 103, 2911–34.

Edmunds (2013). 4th Quarter-2013 Used Market Quarterly Report. http://www.edmunds.com/industry-center/data/used-car-market-quarterly-report.html.

Fudenberg, D., and J. Tirole (1998). 'Upgrades, tradeins, and buybacks', The RAND Journal of Economics, 29, 235–58.

Iwata, Kazuyuki, and Shigeru Matsumoto. "Use of hybrid vehicles in Japan: An analysis of used car market data." *Transportation Research Part D: Transport and Environment* 46 (2016): 200-206.

Majid, Kashef Abdul, and Cristel Antonia Russell. "Giving green a second thought: Modeling the value retention of green products in the secondary market." *Journal of Business Research* 68.5 (2015): 994-1002.

Nicholas, Michael A., Gil Tal, Thomas S. Turrentine (2016) Advanced Plug-in Electric Vehicle Travel and Charging Behavior Interim Report. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-16-10

Noparumpa, Tim, and Kanis Saengchote. "The Impact of Tax Rebate on Used Car Market: Evidence from Thailand." International Review of Finance (2016).

Propfe, Bernd, Martin Redelbach, Danilo J. Santini, and Horst Friedrich. 'Cost Analysis of Plug-in Hybrid Electric Vehicles including Maintenance & Repair Costs and Resale Values'. EVS26 (2012): Los Angeles, CA.