Effects of Charging Infrastructure Characteristics on Electric Vehicle Preferences of U.S. Private Car Owners: A Comparative Analysis between New and Used Car Buyers

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ABSTRACT

Used car market is a critical target of the mass adoption of electric vehicle (EV). However, most efforts of previous studies on EV adoption focused only on new car markets. In order to add to potential solutions for promoting EVs, this paper examines and compares the effects of charging infrastructure characteristics on preferences for electric vehicles of both new and used car buyers. This study conducted an online stated preference choice experiment among private car owners in the U.S., and the results of comparable binomial logistic models show that new and used car buyers generally share similar patterns in preferences for EVs with the exceptions for sensitivity towards purchase price difference, fast charging time, and home charging solutions. Results also show that price difference between an EV and a similar conventional car has a negative and significant influence on preferences for EV while used car buyers are roughly 1.3 times as sensitive to the price difference than new car buyers. Preference for EVs increases considerably with improvements on driving range and the effects on new and used car buyers are very close. The study also finds that better availability of charging infrastructure largely increases preference for EVs. The results further reveals that slow and fast charging has complementary effects on encouraging EV adoption.

Keywords: Electric vehicle adoption, Charging infrastructure, Sustainable transportation, Used car market

INTRODUCTION

Many jurisdictions worldwide have set ambitious goals for continued growth and mass adoption of electric vehicles (EVs) and significant new public and private investments in expanding EV markets are expected. To sustain market growth, EVs must be practical and attractive not only to new car buyers, but to used car buyers too. It is generally accepted that the relative attractiveness of EVs and other alternative fuel vehicles (AFVs) depends on several factors. These include up-front cost, operating costs including fuel (electricity) and maintenance, range, refueling/recharging time, the availability of refueling infrastructure, environmental impacts, and government incentives, as well as those factors that affect any vehicle purchase decision, such as vehicle size, performance, and features (Hoen and Koetse, 2014; Tanaka et al., 2014; Coffman et al., 2017; Liao et al., 2017). In the case of EVs, many of these factors are determined by the characteristics of the charging infrastructure, i.e. the number, type, locations, and pricing of charging stations.

Since charging infrastructure has a significant effect on the adoption of electric vehicles, prior research generally indicates that to make EVs more attractive to consumers, we should make charging opportunities ubiquitous, fast, and inexpensive. However, in a world with budget constraints, tradeoffs must be made between these goals. Fortunately, many charging needs can be satisfied through relatively inexpensive infrastructure such as home-based level 1 charging, workplace and other intracity charging provided mostly by less costly level 2 charging (TRB and National Research Council, 2015). Although they serve relatively few charging events, expensive, high power direct current fast charging (DCFC) and extreme fast charging (XFC) are a key to making EVs feasible for longer, interurban trips, which is necessary if EVs are to attract mainstream consumers (Fontaine, 2008; Botsford and Szczepanek, 2009; Jabbari et al., 2018).

Home and workplace charging are found to be the most frequently used and the most influential charging infrastructure that encourages consumers to purchase an EV (Dunckley and Tal, 2016; Hardman et al., 2018). Beyond private charging, Axsen and Kurani (2013) suggests that installation of public charging infrastructure may alleviate some of the functional concerns of car buyers. Neaimeh et al. (2017) found that fast chargers enabled battery electric vehicles (BEVs) to be used on journeys above their single-charge range, which would have been impractical using regular slow chargers. This suggests that fast chargers could help overcome perceived and actual range barriers, making BEVs more attractive to future users. While consumer preferences for EVs and EV charging infrastructure have been broadly studied previously, there is little consensus on how to direct investments in order to get the greatest public benefit per dollar spent on new charging infrastructure. Hardman et al. (2018) further indicate that in some areas of study, the literature is not sufficiently mature to draw any conclusions from, and suggests that more research is especially needed to determine how much infrastructure is needed to support the roll out of EVs.

Moreover, it has been almost a decade since the first release of commercially available EVs in 2010, and as more early adopters sell and replace their EVs, the used market for EVs will expand. However, most previous studies have focused on new car buyers and new EV markets, while less attention is paid to used EV adoption and secondary EV markets. A study in the Netherlands shows that secondhand AFV buyers are roughly twice as price sensitive as new AFV buyers, while preferences for other attribute levels including driving range, charging time, and detour time for charging are very comparable for buyers of new and secondhand cars (Hoen and Koetse, 2014). A study examining the status of the nascent secondary EV market in California shows that short-range used EV owners are charging their vehicles less than they could and early used EV buyers have significant knowledge gaps, such as being unaware of new EV purchase incentives, which reduce their ability to compare price options (Tal et al., 2017).

According to an Edmunds report (Edmunds, 2019a, 2019b), nearly 70% of all U.S. vehicle sales in 2018 were for used vehicles. Therefore, used EV sales have the potential to be very significant in the market as a whole (Tal et al., 2017). To reach the goal of mass adoption of EVs, the used car market is a critical target. To shift used car buyers towards used EVs, it is necessary to understand used car buyers' preferences for and concerns about used EVs. Used car buyers are more likely to be low-income people who cannot afford a brand new EV, and garage orphans who do not have off-street home parking space or accessible electricity outlets for home charging (Seattle Office of Sustainability and Environment, 2014). Used EVs tend to be less expensive and so would be favored by potential used car buyers who want to adopt new technology at an affordable price, but the barrier of charging, especially home charging, still exists in most cases. Nevertheless, how the availability of charging infrastructure affects use car buyer's preference for used EVs and how those effects are different than on new car buyers are rarely investigated in prior studies.

To fill in the gaps, this study conducted a stated preference choice experiment among new car buyers and used car buyers in the U.S. via an online survey to examine the effects of charging infrastructure characteristics on preferences for EVs. This study further attempts to provide potential charging solutions to encouraging garage orphans to adopt EVs. This study contributes to the existing literature in several ways. First, it is one of the earliest nationwide investigations of preferences for used EVs in the U.S., which could provide a more comprehensive analysis and a broader insight into EV adoption. Second, this study reduces choice burden of respondents by showing two purchase options, a conventional car versus an EV, allowing for collecting data of better quality and more accurate model results. Third, this study focuses on charging infrastructure in more detail including location, type, and charging duration, enabling a more reliable inference of the effects of charging infrastructure characteristics on EV adoption, and could function as a reference for charging network design and infrastructure planning.

The rest of the paper is organized as follows. The next section explains the survey design and the data collection process, including attributes and attribute levels used in our choice experiment. Data analysis and model results are presented in the results and analysis section. The final section discusses findings and summarizes the paper with potential suggestions for future studies.

SURVEY DESIGN AND DATA COLLECTION

The choice experiment of this study is set in a context where respondents are buying their next personal car. Before the choice experiment, respondents answered questions about their socio-economic background and were asked about their preferences for a new car or a used car for next car purchase, and then were directed to scenarios of new car options or used car options accordingly.

Choice tasks designed in this study provide two purchase options, a conventional car powered by gasoline, and an electric version – assuming everything else identical – of the conventional car, which runs solely on electricity. While existing studies show that financial, technical, infrastructure, and policy attributes all affect consumers preferences for EVs, this study focuses on attributes of the charging infrastructure. Key attributes included in the study are purchase price, driving range, walking distance of the nearest slow charging options to home and to work, fast charging time, fast charging availability in town, and fast charging availability on highway. The gasoline car option is the reference alternative with all attribute levels fixed throughout the entire experiment. All attributes and levels of the choice experiment are summarized in **Table 1.**

TABLE 1 Attribute levels used in choice experiment

Attribute	Alternative	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7
Price (US Dollar)	Gasoline car	0.85 *budget[1]						
	EV	1.0 *budget	0.85 *budget	0.7 *budget				
Fuel Cost (Per 100 Miles)	Gasoline car	$12						
	EV	$4						
Driving Range (Miles)	Gasoline car	400						
	EV	400	300	200	100			
Slow Charging to Home (Minutes)	EV	0	1	2	3	5	10	20
Slow Charging to Work (Minutes)	EV	0	1	2	3	5	10	20
Fast Charging Time	EV	5min	15 min	30 min	1h			
Fast Charging Density in Town	EV	5min	10 min	15 min	Not available			
Highway Fast Charging Spacing (Miles)	EV	30	50	70	Not available			

1 Respondent's anticipated highest amount of money they would spend on their next car purchase

To avoid situations where the car purchase prices are too high for respondents to afford to buy, resulting in ineffective detection of the effects of other attributes on preferences, respondents were asked about their anticipated highest amount of money they would spend on their next car purchase in advance, for which they were provided 8 price categories in a drop-down menu to choose from. Purchase prices in the choice experiment were pivoted around this maximum price, and prices would never exceed a respondent's selected budget limit.

Driving range is one of the most important attributes of an EV and is very much likely to be related to car buyers' demand for charging infrastructure. According to the driving range of current EV models in market, and considering the continuous improvement of battery technology, this choice experiment applies the driving range of EV from 100 miles to 400 miles while keeping the driving range of the gasoline car fixed at 400 miles.

Charging infrastructure availability in prior work has been operationalized as refueling distance, detour time than to gas station, percentage of the number of gas stations, presence in often visited place in previous studies (Chorus et al., 2013; Hoen and Koetse, 2014; Jensen et al., Tanaka et al., 2014; Valeri and Danielis, 2015), however, those measures are not conducive to providing specific implications to decision makers for infrastructure investment (Liao et al., 2018). While Liao et al. (2018) tried to address this by noting the difference of distribution of charging stations in urban areas and on highways, they only specified fast charging stations and excluded slow charging options in their study. Therefore, this study includes both slow charging and fast charging solutions to enable policymakers to make tradeoffs between these different charging solutions.

Slow charging availability was presented as walking distance to home and to work measured in minutes, to examine car owners' preferences for public slow charging and their willingness to walk. We assume car owners park their EV at a nearby slow charging station and then walk back home or to work while waiting for a slow charge. The choice experiment also explained to respondents that it normally took 4 to 10 hours to charge an electric car from empty to full using slow charging.

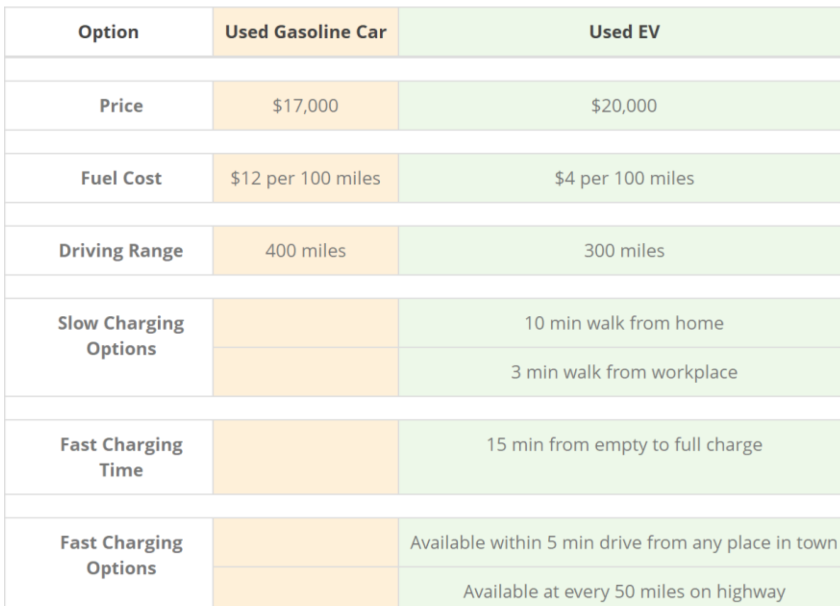
Similar to (Liao et al., 2018), fast charging options were shown in terms of in-town density and highway spacing, measured in driving distance to a fast charging station from any place in town, and as distance between two fast charging stations along highway, respectively. In this way, an optimal charging infrastructure distribution for both slow vs. fast charging, and in-town vs. highway, can be estimated.

On top of location and density of fast charging, fast charging time is also shown in choice tasks. Many previous studies such as (Chorus et al., 2013; Hackbarth and Madlener, 2013) did not distinguish between slow and fast charging and applied a wide range of charging times (usually 10 min – 8h). Rarely did they investigate the impact of a shorter charging time, where most of them have a lower bound of 10 minutes of full charge. Therefore, considering that extreme fast charging has made great technical progress, this study applies fast charging times ranging from 5 minutes to 1 hour, aiming to enable a more reliable inference of the effects of reduced charging time on EV adoption, and to anticipate the benefits of advanced fast charging technologies.

The choice tasks were generated using an orthogonal design with 240 fractional factorial scenarios extracted from the full factorial combinations. Each respondent was randomly assigned to 6 of the 240 tasks. **Figure 1** shows an example of a choice scenario for respondent who prefer to buy a used car and would spend at most $20,000 for his or her next personal car purchase.

The survey was designed and implemented in SurveyMonkey, an online survey tool, and was distributed through Amazon Mechanical Turk (MTurk), a crowdsourcing system which has become increasingly popular as a tool for research, where the working population is found to be diverse across several notable demographic dimensions such as age, gender, and income (Ross et al., 2010). Respondents recruited were qualified as car owners who have completed 100 tasks on MTurk with a minimum 95% acceptance rate, and were sampled in proportion to population in the four time zones in the U.S. Data collection was conducted from June 28 to July 9, 2019 and overall, 983 respondents completed the full survey with valid responses. **Table 2** summarizes the socio-demographics and basic characteristics of parking situation and personal car usage of the sample. **Table 2** also presents socio-demographic characteristics of the U.S. population reported by American Community Survey 2017 (5-year estimates) for comparison.

Table 2 shows that respondents intending to buy a used car reported a slightly lower level of education, lower income, and were less likely to be employed than the overall sample Compared to the national population, our sample contains a higher proportion of employed people and people with higher education levels. Household income level of $25,000-$74,999 might be overrepresented in out sample.78% of all respondents are identified as garage orphans (respondents who answered they only had on-street home parking space or had no accessible electricity outlet for home charging), while this proportion is even higher among used car buyers (82%).



Option	Used Gasoline Car	Used EV
Price	$17,000	$20,000
Fuel Cost	$12 per 100 miles	$4 per 100 miles
Driving Range	400 miles	300 miles
Slow Charging Options		10 min walk from home
		3 min walk from workplace
Fast Charging Time		15 min from empty to full charge
Fast Charging Options		Available within 5 min drive from any place in town
		Available at every 50 miles on highway

Figure 1. Screenshot of an example choice task

Table 2 Background characteristics for the 983 respondents.

Variable	Value	Used Car Buyers	All Respondents	National Population
Time Zone	Eastern	46.7%	47.8%	47.6%
	Central	28.9%	28.8%	29.0%
	Mountain	5.4%	6.0%	6.3%
	Pacific	18.8%	17.4%	17.1%
	Total count	**533**	**983**	
Gender	Female	50.7%	49.6%	49.2%
	Male	49.3%	50.4%	50.8%
Education level	Less than bachelor's degree	49.9%	45.9%	69.1%
	Bachelor's degree and higher	50.1%	54.1%	30.9%
Employment Status	Employed	82.0%	84.7%	58.9%
	Not employed	8.8%	6.3%	4.3%
	Other	9.2%	9.0%	36.8%

Household income level	Under $25,000	17.3%	12.6%	21.3%
	$25,000-$49,999	35.1%	31.1%	22.5%
	$50,000-$74,999	23.8%	25.6%	17.7%
	$75,000-$99,999	11.1%	13.8%	12.3%
	$100,000-$149,999	9.3%	12.2%	14.1%
	$150,000 and up	3.5%	4.5%	12.1%
Vehicle ownership	1	56.7%	53.6%	45.8%
	2	32.5%	36.3%	27.2%
	3	8.4%	8.2%	6.3%
	4 or more	2.4%	1.8%	2.2%
Age		Min: 19 ; Mean: 40.1 ; Median: 37 ; Max: 75	Min: 19 ; Mean: 40.3 ; Median: 37 ; Max: 76	Median:38
Used car owner	Yes	87.6%	64.9%	
	No	12.4%	35.1%	
Garage orphan	Yes	82.2%	77.5%	
	No	15.6%	19.4%	
	Other	2.2%	3.0%	
EV owner	Yes	3.8%	7.3%	
	No	96.2%	92.7%	
Monthly long-distance trip	0	33.6%	28.9%	
	1	27.0%	26.7%	
	2	19.5%	23.6%	
	3	8.1%	8.6%	
	4 or more	11.8%	12.2%	

RESULTS AND ANALYSIS

To identify how preferences for EVs differ between new car and used car buyer, we estimated separate choice models for used car buyers and new car buyers. The outcome variable in this study is the stated choice between a gasoline car and an electric car. Thus, a binomial logit model was employed in this study with the gasoline car set as the reference alternative. To convey the model results to a broader audience, we simulated counterfactual scenarios to examine and visualize the effects of variables of interest. Simulation is performed with the Simcf R package and visualized using the tile package.

Table 3 shows the estimation results of the final models for new and used car buyers. The two models include the same set of variables except for home related slow charging availability. To examine whether the effects of slow charging will be affected by fast charging availability and vice versa, interactions between slow and fast charging are also added to the models. The results of the two binomial logit models are sensible, with all coefficients having the expected sign and most variables significant at the usual critical significance levels. The results also show similar patterns in preferences for EVs between new and used car buyers, which is consistent with conclusions by Hoen and Koetse (2014).

TABLE 3 Model results

Variables	**New EV Buyer Model**		**Used EV Buyer Model**	
	Estimate	Std. Error	Estimate	Std. Error
Constant	0.6978	0.5568	1.2396	0.4664**
Vehicle related variables				
Price Difference[1] (in $1,000)	-0.0877	0.0114**	-0.1176	0.0165**
Driving range of EV (mile)	0.0039	0.0004**	0.0035	0.0003**
Charging infrastructure variables				
Charging is available at home: 1; Else: 0	0.6529	0.2270**	-	-
Walking distance from home to nearest slow charging (min)	-	-	-0.0603	0.0125**
Walking distance from work to nearest slow charging (min)	-0.0422	0.0133**	-0.0263	0.0110*
Fast charging time (min)	-0.0006	0.0020	-0.0048	0.0018**
Driving time to fast charging in town ≤ 15 min drive: 1; Else: 0	0.6979	0.1375**	0.3545	0.1426*
Number of fast charging stations per 100 miles of highway	0.0476	0.0380	0.0220	0.0338
Individual characteristic variable				
Age	-0.0877	0.0246**	-0.0827	0.0206**
Age^2	0.0009	0.0003**	0.0007	0.0002**
Male	0.2740	0.0843**	0.2215	0.0749**
Person has an EV: 1; Else: 0	0.7091	0.1454**	0.4833	0.2027*
Interactions				
Charging is available at home: 1; Else: 0 **&** Driving time to fast charging in town ≤ 15 min drive: 1; Else: 0	-0.3430	0.2696	-	-
Walking distance from home to nearest slow charging (min) **&** Driving time to fast charging in town ≤ 15 min drive: 1; Else: 0	-	-	0.0286	0.0143*
Walking distance from work to nearest slow charging (min) **&** Driving time to fast charging in town ≤ 15 min drive: 1; Else: 0	0.0307	0.0152*	0.0097	0.0129
Number of Observations	2,700		3,198	
Log-likelihood	-1660.83		-2056.54	
AIC	3349.7		4141.1	

1 Purchase price of EV minus purchase price of gasoline car
Note: *p<0.05;**p<0.01

Individual-Related Variables

In terms of car buyer's characteristics, results show that age plays an important role with non-linear effects as both linear and quadratic effects of age are significant. The model indicates that younger and older car buyers might be more likely to buy an EV than middle aged people, all else equal. The model also suggests that on average, male car buyers are more likely to buy EVs than female buyers and car buyers who are EV owners are significantly more likely to choose an EV for their next car purchase than individuals who currently do not own an EV.

Vehicle-Related Attributes

Using the marginal effects analysis, **Figure 2** shows that as EV price gets relatively higher than the regular car, car buyers get less likely to buy the EV, but the sensitivity towards price difference varies between new and used car buyers. **Figure 2** shows that on average, for a $1,000 increase in the price premium of an EV, the probability of buying EV decreases by 0.02 for new car buyers and by 0.03 for used car buyers. In other words, used car buyers are roughly 1.3 times as sensitive as new car buyers to an increase in purchase price difference.

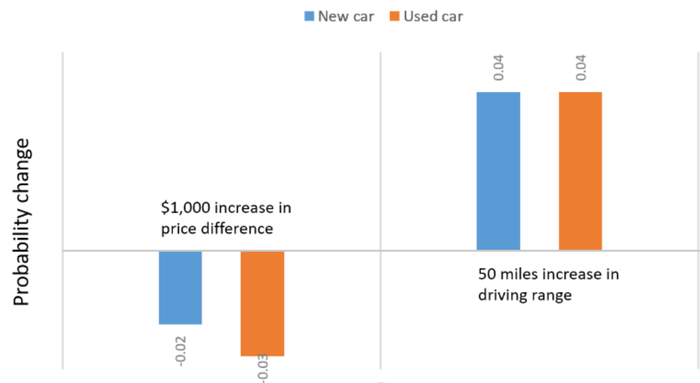


Figure 2 Marginal effect of price difference and driving range

As for driving range, **Figure 2** shows that a 50 mile increase in EV driving range increases the probability of buying EV by about 0.04 for both new and used car buyers, which suggests that increasing the driving range of EVs increases the probability of buying EV significantly and the effects are quite similar for both new and used car buyers.

Charging Infrastructure

Through preliminary modelling, it appeared that new car buyers' preferences are not significantly affected by the walking distance of slow charging option for home charging solution. Rather, new car buyers are sensitive to whether they have a charging option at their current home parking space or not. On the other hand, for used car buyers, proximity of slow charging option to home has significant positive effects on their preferences for EVs.

Considering these differences and better data fitting, in the final models, home charging attribute is thus modeled in two ways: a home charging availability dummy variable for new car buyers; and walking distance from slow charging to home for used car buyers. While we also tried to capture any non-linear effect of the proximity of slow charging infrastructure, as well as other charging infrastructure related variables, the non-linear terms did not show significant influence at a 0.05 significance level. Also, by comparing log-likelihood and Akaike Information Criterion (AIC) values, those terms barely improved the model. Therefore, we only included linear teams in the final models. Preliminary model results are available from the authors upon request.

As for work charging options, based on the estimation results in **Table 3**, new and used car buyers respond similarly to the negative effects of the proximity to workplace slow charging. When comparing the effects of the proximity of slow charging to home and to work, the coefficients of the used car buyer model show that the proximity to home has a larger effect than the proximity to work. Marginal effect analysis shows that 1 minute reduce in walking time from slow charging to home increases the probability of buying EV by 0.009, while it is 0.004 for one unit change in proximity to work. This suggests that for the purpose of charging, used car buyers' sensitivity to walking distance from slow charging to home are roughly twice the sensitivity to walking distance from slow charging to work.

Table 3 shows that denser distributions of fast charging options around town and on highway have positive effects on preferences for EV for both new and used car buyers. Model results also show that a shorter fast charging time significantly increases used car buyer's preferences for EVs while the effect is not significantly observed for new car buyers. We calculated the marginal effects which indicate that 1 minute decrease in fast charging time increases probability of buying EV of new car buyers by 0.0001. This relative small effect might suggest that within the range of fast charging time (5min – 1h) provided in this choice experiment, varying fast charging duration could barely change new car buyers' preferences for EV. This result is in line with results provided by Liao et al. (2018) who also found that the duration of fast charging does not significantly affect the utility of EV for new car buyers.

Furthermore, the interactions between slow and fast charging options show that they have complementary effects. Significantly, better access to in-town fast charging reduces the disutility of having to walk between charging locations and work or home. We simulated counterfactual scenarios to capture the effects while controlling for other variability. We simulated how the probability of buying an EV varies with slow and fast charging availability while holding everything else constant: price difference is zero, EV driving range is 400 miles, fast charging time is 30 minutes, and fast charging stations available every 50 miles on the highway. The car buyer is held as 40 years old, male, and owning no EV. For new car buyers, home charging is held unavailable and for used car buyers, work charging is held available at workplace.

Figure 3 shows that with a denser distributed fast charging (available within 15 min drive), the effects of slow charging proximity is smaller as the slope of the line between the dashed lines is flatter than in the shaded area (fast charging > 15 min drive). These patterns show that the negative effects of the distance of slow charging to work (for new car buyers) and to home (for used car buyers) are mitigated by a denser distribution of fast charging in town.

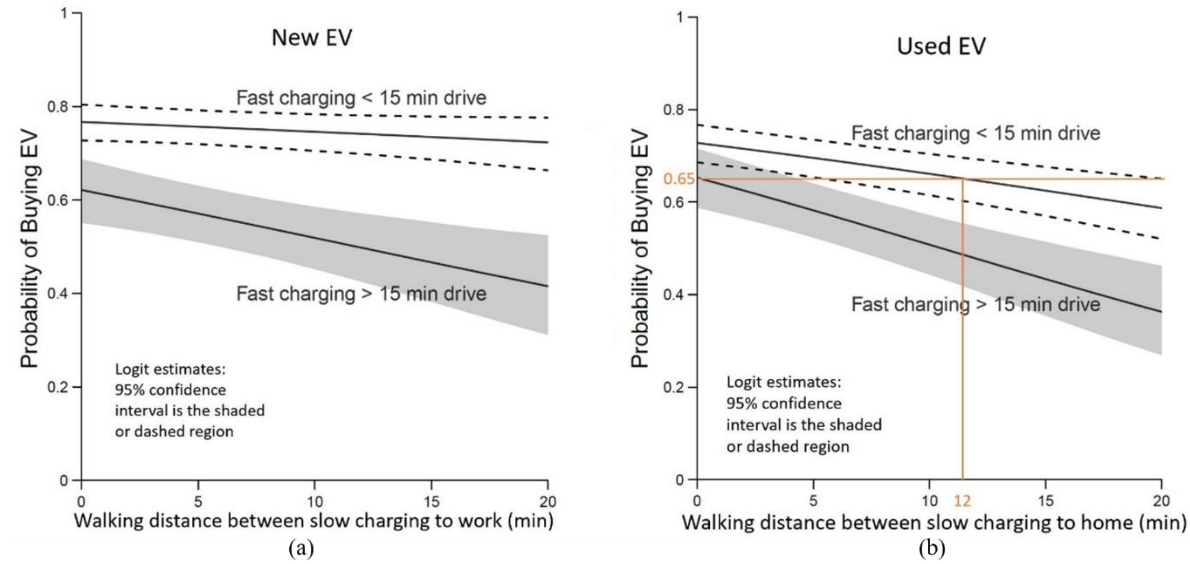


Figure 3 Interaction effects on fast charging on slow charging.

Figure 3 (b) also suggests that the combination of a dense distribution of in-town fast charging with slow charging available 12 min away from home, can provide the same utility as having ubiquitous home charging with sparsely distributed fast charging in town. These interaction effects shed light on potential solutions to encouraging garage orphans to purchase EV, especially for used car buyers. The combination of public slow and fast charging could possibly compensate the unavailability of home charging for garage orphans.

CONCLUSION AND DISCUSSION

This paper analyzed the results from an online stated preference choice experiment among private car owners in the U.S., aiming to examine and compare the effects of charging infrastructure characteristics on preferences for EVs of new and used car buyers. Most efforts of previous studies focused only on new car markets while the differences between new and used car buyers have been ignored. In addition, detailed analysis of charging infrastructure characteristics is provided to support the roll out of EVs. Our results show that while new and used car buyers share similar patterns in preferences for EVs, their sensitivity towards price difference between EV and conventional car, fast charging time, and home charging solutions are different. This study also finds that slow and fast charging have complementary effects in alleviating concerns for charging.

It is reported that most states in the U.S. offer incentives only on new PEV purchases while only a few states have incentives for both new and used PEV purchases (Turrentine et al., 2018). Findings of this study conclude that used car buyers are approximately 1.3 times as sensitive to the price difference as new car buyers, which indicates that used car buyers might respond to the same monetary incentive differently than new car buyers. It also worth mentioning that subsidizing one market may also affect the other market. For example, incentives on new EV may cut down the EV's residual value, reducing its resale price as a used car (Noparumpa and Saengchote, 2017; Tal et al., 2017). All these factors should be taken into consideration when proposing incentives on either new or used EVs.

Compared to used car buyers, when it comes to considering buying EVs, new car buyers are not significantly affected by the proximity of slow charging around home but respond to home charging availability. We speculate that this may be because they are more concerned about the safety of parking their brand-new car overnight outside home parking space than used car buyers. If this is the case, an effective public slow charging network would need to not only adopt an optimal density distribution, but also provide a parking environment that is safe for long time parking and charging. In this way, both used and new EV owners would make good use of the facilities. This study also finds that people's willingness to walk for parking and charging at public slow charging stations is likely to be difference for "near-home" and "near-work" charging where with the same variation in charging proximity, the effect of the change made to home parking is twice the effect of the change made to work parking. This suggests that in general, to increase EV adoption rate, slow charging infrastructure investment might need to prioritize residential areas and apply a denser distribution design. In addition to safety concerns, people's current parking behavior at home and at work may also play an important role in finding the optimal charging station distribution for different land use types.

While home and workplace charging are usually the top choices of charging for current EV owners, evidence from this study shows that the presence of fast charging significantly increases preferences for EV and could compensate it when home or workplace charging is less accessible. This indicates that a combination of public slow and fast charging could potentially be a charging solution for garage orphans whose home parking space is on street or possibly does not have a proper condition to access electricity for EV charging.

Since the study is based on a stated preference choice experiment, in order to reduce respondent's choice burden, among many charging infrastructure characteristics only a limit number of attributes of interest were included in choice tasks. Based on this limitation and findings of this study, we therefore recommend several future research opportunities regarding the impact of charging infrastructure on consumer preferences for electric vehicles. First, in addition to proximity, factors such as slow charging time and parking safety that affect car buyers' preferences for slow charging at public charging station can be explored. Second, this study did not distinguish charging cost of slow and fast charging. Investigating the effects of charging costs and how they interact with charging type and location would add to the design of a more effective charging network. Lastly, local context is very important for any infrastructure investment. Future research on EV charging infrastructure could build on this nationwide study to conduct local-specific analysis in detail.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study concept and design: T. Zou, D. MacKenzie, M. Khaloei; data collection: T. Zou; analysis and interpretation of results: T. Zou, M. Khaloei, D. MacKenzie; draft manuscript preparation: T. Zou, M. Khaloei. All authors reviewed the results and approved the final version of the manuscript.

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