MOTIVATIONS AND BARRIERS ASSOCIATED WITH THE ADOPTION OF BATTERY ELECTRIC VEHICLES IN BEIJING: A MULTINOMIAL LOGIT MODEL APPROACH

Gil Tal[1]
Institute of Transportation Studies
University of California Davis
Davis, CA 95616
Phone: 530-754-9230
gtal@ucdavis.edu

Yan Xing
Institute of Transportation Studies
University of California Davis
Davis, CA 95616
Phone: 530-574-7821
yxing@ucdavis.edu

Yunshi Wang
Institute of Transportation Studies
University of California Davis
Davis, CA 95616
Phone: 916-612-8719
yunwang@ucdavis.edu

Shengyang Sun
Deutsche Gesellschaft für Internationale Zusammenarbeit (giz) Gmbh
Beijing, China 100125
Phone: +86-010-8527-5589 ext. 415
Shengyang.sun@giz.de

Submitted to the Committee on: Alternative Transportation Fuels and Technology

Word Count: 5726
Number of figures: 1
Number of tables: 5

[1] Corresponding author

ABSTRACT

The recent surge of the Chinese Plug-in Hybrid Electric Vehicle (PEV) market makes China the world's largest PEV stock. A series of supportive policies in China contributed greatly to the rapid PEV adoption by limiting regular vehicles and reducing the price of PEVs. However, the role these policies play in changing references and encouraging consumers to purchase PEVs rather than conventional vehicles is not fully known. Other factors, rather than incentives, that could help maintain the current adoption trend are still unclear. The latter is especially critical in understanding how the market reacts to a gradually decreasing level of incentives to achieve the next goal of 5 million PEVs on the road by 2020 in China. Therefore, in this study we explored these research questions through a cross-sectional study of the current PEV market on consumers in Beijing by employing a multinomial logit model. Beijing has high levels of PEV adoptions in addition to a specific policy stimulus. The model results show significant influences of stimuli, individual socio-demographics, attitudes, charging infrastructure, and charging experiences on the adoption of PEVs over conventional vehicles. The results may help find out key interventions for policy makers to promote more PEV adoptions in China as well as other countries.

INTRODUCTION

Recently, Plug-in Electric Vehicles (PEVs), including Plug-in Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs), have been getting more global attention and are emerging as an important element of the transportation sector in reducing local emissions and greenhouse gases (GHGs). According to the report of the Electric Power Research Institute (EPRI), PEVs help reduce greenhouse gas emissions as well as potentially improve ambient air quality. To achieve large-scale adoption of PEVs, which are currently costly and unfamiliar to the general public, considerable stimulus incentives, including monetary subsidies and non-monetary strategies, are provided in China and globally. As a result, some countries have achieved great increases of PEV sales. For instance, The Globe witnessed a great surge in PEV sales in China: 331,092 PEVs were sold in 2015 alone, a 340% increase over 2014. Additionally, sustained market growth was shown in 2016 with total Chinese PEV sales reaching 322,271 by the end of 2016. Since 2011, PEV sales in China have topped 764,748 making China the world's largest PEV stock (China Association of Automobile Manufacturers). However, despite the rapid global growth of PEVs in some countries, PEVs make up a marginal share of vehicle stock and sales compared to conventional fuel vehicles: PEVs only account for 0.15% of all vehicles on the world roads as of December 2016 (*1*). The experiences of China, therefore, deserve global consideration for its dramatic expansion of the PEV market, which may suggest great possibilities for increasing PEV adoption in other countries.

The factors that drove the recent surge of PEV sales in China stem from a series of supportive policies that create the vehicle supply and demand. In addition to subsidies and tax exemptions, PEV owners can take advantage of getting a free license plate (i.e. permission to purchase a vehicle) or/and no traffic restriction during weekdays in big cities with heavy traffic. However, what role these policies play in encouraging consumers to purchase PEVs rather than conventional vehicles is unknown. Furthermore, many of these incentives are not sustainable in the long-run: too many or long-duration subsidies may weaken the competitiveness of domestic auto industries; free license plates could induce more unnecessary vehicle demands, thereby worsening city traffic congestion by bringing more vehicles on roads. In fact, Chinese government has already implemented the policy to gradually remove the monetary incentives from PEV sales by the end of the year 2020. Therefore, it is critical to understand how the market will react to the gradual reduction of incentives. Additionally, other factors rather than incentives that may help maintain the current adoption trend to achieve the next goal of 5 million PEVs on the road by 2020 in China are still unclear. This study aims to explore these research questions by studying the current PEV market in Beijing due to its high number PEV adoptions as well as its specific policy stimulus. We surveyed electric vehicle owners in Beijing using an online survey of 2,467 households. Unlike previous studies that explore the impact of incentives using stated preference or similar methods with a sample of households that are not familiar with the technology or have not made the decision on buying a new electric car, this paper models the behavior of actual PEV buyers in the city. We explore potential factors influencing adoptions under experimental conditions – more specifically, individual's stated intention to buy a PEV under certain hypothesized circumstances.

LITERATURE REVIEW AND CONCEPTUAL MODEL

The diffusion of innovations theory provides a useful conceptual basis for understanding vehicle choice behavior and the adoption of electric mobility as a new technology spreads over time and space in a society. Diffusion of innovations theory (*2*) focuses on explaining how and why an innovation spreads through certain channels among adopters over time. The main elements in diffusion of innovations are the innovation, adopters, communication channels, time, and social system, which play important roles in the adoption of an innovation. Innovation indicates the new idea, practice, or object of interest; adopters are

the analysis unit such as individuals, organizations, etc.; communication channels are the patterns by which the information of innovation transfers from one unit to another; time indicates the necessary period of time for innovations to be adopted; and the social system includes all external and internal influences in a society. Based on this theory, we constructed a conceptual model that models BEV adoption as affected by multiple levels of factors which are grouped as (1) **vehicle attributes**, (2) **individual factors**, and (3) the **social system**. Vehicle attributes include characteristics of BEVs such as the benefit and cost, etc. Individual factors consist of socio-demographics and attitudes including preferences, beliefs, and life styles etc. Within the social system, several types of influences are categorized and defined as *external influences*, i.e. infrastructure settings, political conditions, societal norms and culture in a community, and *internal influences* measures interpersonal networks with near-peers in a society (in the theory of diffusion of innovation, the analogous counterparts of external and internal influences are *social structure* and *communication structure*). It should be noted that this conceptual framework does not include the time effect and diffusion channel due to the limit of the cross-sectional design of our study.

Literature on Factors Associated with PEV Adoption

Most of studies on the factors associated with PEV adoption employed quantitative methods including chi-square test(3), ordinary least squares (OLS) regression(*4, 5*), binary logit model(*6*), or a mixed logit (MXL) model (*7*), etc. The data of these studies can be categorized into two types: aggregate data at the national level (*4*) and disaggregate data at an individual level (e.g.(*5, 6*), with data from the latter being collected mostly through stated preference surveys. Qualitative methods were used in some studies (*3, 8*) to reveal inherent understanding or explanation mechanisms underlying actual experiences based on limited sample sizes.

Various potential factors associated with vehicle choice for PEVs have been tested in previous studies. Guided by our conceptual model, revealed factors associated with PEV adoptions in previous literature review of research can be grouped into the attitudes including preference, beliefs, and life style etc. rather than being exhaustively named individually. ***Vehicle attributes*** correlates to choice of PEVs: the high purchase price of PEVs, limited driving range, and long charging time deter people from owning PEVs (*5, 8*). Results from a consumer trail of MiniE BEVs found that participants valued the high performance nature of the vehicle (acceleration), the road handling, and the low environmental impacts of the vehicle (*9*). ***Individual socio-demographics*** include gender, age (*5, 7*), income, education level (*4, 7*), number of driving license holders in a family, and the number of vehicles (*6*) are all found to significantly influence consumers' choice of PEVs. Attitudes including preference, beliefs, and life style etc. are also important in explaining PEV adoption and are included in the individual socio-demographics explanatory category. For example, one study (*10*) predicted that early adopters would have "green" or environmentally-friendly life styles, and fuel cost concerns. Another paper (*11*) shows that early adopters generally have a stronger environmental attitude and fun/enjoyable driving style of BEV is viewed as an important advantage of BEV ownership. Other factors such as people's environmental awareness and interest in PEVs (*12*), beliefs, pro-environmental identity and lifestyle, knowledge of environmental problems, concern for the environment (*13*), concern for energy independence and climate change(*14*), vehicle confidence, environmental beliefs, and perception of electric vehicles (*8*) etc. all affect PEV market penetration.

The ***social system*** also shows its importance on the decision to adopt a PEV. ***External influences*** including charging infrastructure are significantly associated with PEV adoption (*4, 8, 12, 15, 16*). Additionally, the awareness of electric vehicle charging stations in the community also correlates to the intention to purchase a PEV(*5*). Public policies pertaining to PEVs have been found to be important in previous studies on the adoption of PEVs: Consumer adoption of PEVs is encouraged by government environmental regulations(*13*), tax incentives or manufacturer rebates(*14*), or policy measures to decrease the purchase costs (*17)*. An assessment of BEV adoption in 30 countries shows a statistically significant

relationship between incentives and BEV sales (*4*). However, a recent study found that consumers in China are found to be more receptive to BEVs than those in the U.S. regardless of financial subsidies (*18*). Although the importance of ***internal influences*** on PEV adoption is suggested by the conceptual model, to the best of our knowledge, few studies have explored its impact on PEV adoption empirically.

Overall, previous research provides important insights into the factors associated with PEV adoption. However, empirical knowledge is still limited about the importance of some key variables such as preference for new technology such as PEV. Additionally, internal influences represented by interpersonal networks with near-peers in a society where PEV spread has not been measured in previous studies, and therefore empirical testing of their impacts on PEV adoption is greatly lacking. Furthermore, factors facilitating the rapidly increasing PEV sales in China have not been effectively explored empirically. The issues mentioned above are all research topics in this study, and are expected to be addressed by applying discrete choice modeling based on an original survey conducted in Beijing, China.

METHODOLOGY

Sample Administration

The data was collected through an online survey widely conducted by the Beijing Transport Institute in Beijing, China. 2,467 BEV owners were recruited based on their interest in the survey (which was advertised online) and then invited to participate in an online or WeChat survey. A 30 Yuan (about $5) incentive was provided to every individual who finished the survey. With 1,467 uncompleted responses, a response rate of 41% was finally achieved. Various BEV models, including Beijing Auto EV, JAC iEV, BYD E6, etc. were included in this survey, among which the 2015 models account for about 97.8% of the total BEV share and 96.8% of total PEV market share for Beijing in 2015.

Although we designed the survey to be available to all PEV owners, it is possible that individuals who like their PEVs were more inclined to complete the survey. Furthermore, because our survey had the added barrier of being online, non-response bias is also a concern in this study. For example, respondents who bought Beijing Auto EV 200 in 2015 account for only 6.3% in the survey, but made up 44.7% of the 2015 market share in Beijing (Table 1). However, because the focus of our study is on explaining mode choice as a function of other variables rather than on describing the simple univariate analyses, these differences are not expected to materially affect the results (*19*).

TABLE 1 Percent of 2015 PEVs by Model in the Survey and Their Respective Market Share in 2015

BEV	Model	Range* (km)	Sample number	Percent of 2015 BEVs in Survey	2015 Beijing Market share**
Domestic					
Beijing Auto EV			206	49.88%	54.63%
	E150 EV	150	130	31.48%	1.72%
	EV200	200	26	6.30%	44.66%
	Wiwang307	150	1	0.24%	7.88%
	Other		49	11.86%	0.38%
JAC			16	3.87%	19.75%
	iEV5	170	7	1.69%	14.70%
	iEV	152	9	2.18%	5.05%
BYD	e6	400	64	15.50%	7.30%
Qirui	EQ	200	6	1.45%	3.24%

Dongfeng	Qichen	175	10	2.42%	2.24%
Changan	Changan	200	17	4.12%	1.35%
Jili	Zhidou/EC7-EV	120-253	1	0.24%	0.60%
Shanghai Auto	Rowe	200	8	1.94%	0.09%
Joint					
BYD & Mercedes Benz	Denza	300	32	7.75%	3.67%
BMW	Zhinuo 1E	150	20	4.84%	1.08%
Beijing Hyundai	Shouwang EV	160	12	2.91%	0.49%
International					
Tesla	Model S	480-557	18	4.36%	3.21%
BMW	i3	185	3	0.73%	0.11%
Total			413	100%	97.77%

*Source: Blue Book of New Energy Vehicle: Annual Report on New Energy Vehicle (2016)
**Source: From China Automotive Technology and Research Center (CATARC)

Variable Definitions in the Survey

Conventional vehicle purchases must be through a lottery pool for license plates to register new vehicles in Beijing. The probability of getting a license plate is very low considering increasing vehicle demands, e.g. it was only 0.15% in early 2016 (*20*). However, there is a separate lottery pool for BEVs only, but not PHEVs, with a 100% winning probability to get a license plate—meaning a free license plate is provided by Beijing government. In cities where vehicle ownership is restricted, a free license plate is not only the sufficient condition for purchasing a vehicle, but also viewed as a great monetary subsidy. Although there is no clear market price to measure the value of a license plate for conventional vehicles in Beijing, an approximate estimate could be drawn from another comparable city, Shanghai, where vehicle buyers acquire license plates through the controlled auction. The average auction price of a Shanghai license plate for a conventional vehicle is 89,400 Yuan (about $13,343), reported by Shanghai Municipal Transportation Commission in June 2017.At least one study (*20*) shows that getting a free license plate is the most important factor for motivating PEV purchases in Beijing.

To explore the effect of a free license plate as well as other potential factors associated with PEV adoption in the Beijing market, an experimental choice set was designed for each respondent. In the survey, respondents were asked to make a choice about a potential vehicle purchase if the incentive of a free license plate was taken away, using the question: "What would you choose if the free license plate was no longer offered in return for purchasing a PEV, but other incentives were kept the same?" Four choices were offered: 1. Would buy a PEV. 2. Would buy a conventional fuel vehicle. 3. Would not buy any vehicle. 4. Other. The distribution by category is shown in Table 2. In this sample, almost half (about 44%) of respondents would no longer choose a BEV, 35% would choose to purchase a conventional car, 71 people would not buy any vehicle without the incentive of a free license plate, and 2% of the respondents were undecided and would turn to other choices, probably renting or borrowing a car, etc. In total, only about 56% PEV owners would choose a BEV again. Because the latter two categories ("Not to buy" and "Other") of the four choices share the common characteristics that the respondents would not buy any vehicle, we combined them as one group. The dependent variable was thus derived from this survey question as a set of 3 alternatives consisting of nominal categories: 1—Would buy a PEV; 2—Would buy an ICE; 3—Would not buy or Other.

Based on our conceptual model, the explanatory variables fall into three categories: (1) **vehicle attributes**, (2) **individual factors**, and (3) **the social system** (Table 2). Because at least one study (*21*) found that experience with a BEV improves perceptions, intent to purchase, and the likelihood of

recommending a BEV to others, this study is based on stated preference responses from individuals who have already become PEV adopters, the influence of their practical experience with PEVs on their choice of PEVs should be controlled for in the experimental scenario. Therefore, an additional category, BEV experiences measured by driving and charging behavior, was also included. The **vehicle attributes** category includes vehicle price and battery range. **Individual factors** fall into two categories: *socio-demographics* and *attitudes*. The former includes vehicle ownership, household income and education levels, household size, decision maker's gender and age level, and the number of children younger than 12 in the household. The latter consists of various attitudinal variables. We assume that the decision makers' attitudes do not change much from the time that they purchased their BEV. Therefore, attitudes toward the license plate, national and local subsidies, environment protection and energy savings were all measured in the model. The value of the variable "Price of License Plate" reflects the extent of mobility need by measuring the amount of money individuals would pay for a license plate. The attitudinal variables also include the preference for PEV and the perceptions of PEV. The **social system** is categorized into *external influences* which include charging infrastructure and political conditions and *internal influences* which are measured by measuring the behaviors of acquaintances and neighbors around the community.

TABLE 2 **Description of Variables Tested in the Model**

Variable name	Mean (s.d.) or Percent (%)*	Description
Dependent Variable		
Choice of PEV	56.1:35.0:8.9	The choice of PEV even without the incentive of getting a free license plate. 1=PEV, 2=ICE, 3=Not buy or Other.
Vehicle Attributes		
Vehicle Price	27.0(5.9)	The MSRP price in 10,000 Yuan of the vehicle in 2015.
Range	213.8(57.6)	The battery range of the vehicle.
Individual Factors		
Socio-demographics		
Vehicle Ownership	1.4(0.6) 1.36(0.58)	The number of vehicles in the household.
Income Level	5.9:21.5:25.3:30.3:9.9:4.0:1.2:1.9	Monthly household income level in Yuan. 1=Less than 2,999, 2=3,000-5,999, 3=6,000-9,999, 4=10,000-19,999, 5=20,000-29,999, 6=30,000-39,999, 7=40,000-49,999, 8=50,000 and above.
Education Level	7.5:18.0:53.4:16.0:5.0	The highest education level of the family members. 1=High school or under; 2=2- or 3-year college; 3=Bachelor; 4=Master; 5=Ph.D.
Edu-Income**	11.0(6.8)	Generated by multiplying Education level and Household annual income level.
Household Size	3.6(1.2)	The number of family members living in the household.
Female	40.3	The gender of the respondent who is also the PEV driver is female. 1=Female, 0=Male.
Age Level	15.3:40.3:33.0:10.0:1.3:0.1	The age level of the respondent who is also the PEV driver. 1=Younger than 25, 2=26-30, 3=31-40, 4=41-50, 5=51-60, 6=60 and over.
Kid Less than 12	0.6(0.7)	Number of kids younger than 12 years old in the household.
Attitudes		
Important License Plate	53.0:7.1:9.0:10.1:20.8	How important was the free license plate offered for PEV buyers in your decision to buy a PEV compared with the other incentives including purchase subsidy, purchase tax redemption, etc.? 1=Not important at all, 2=The fourth important, 3=The third important, 4=The second important, 5=The most important factor.
Important Subsidy	55.7:10.4:10.7:12.6:10.5	How important was the subsidies offered for PEV buyers in your decision to buy a PEV compared with the other incentives

Variable name	Mean (s.d.) or Percent (%)*	Description
		including free license plate, purchase tax redemption, etc.? The scale is same as above.
Important Environment & Energy	52.1:9.1:8.6:10.0: 20.2	How important was it in your decision to buy a PEV that PEVs are important for protecting environment and saving energy compared with incentives including free license plate, purchase subsidy, purchase tax redemption, etc.? The scale is same as above.
Price of License Plate	2.8(3.2)	The amount of money (in 10,000 Yuan) the respondent would spend to buy a license plate if license plates offered for PEVs were not free.
Like PEV	10.6:4.6:26.3:34.8 :23.6	I like this PEV more and more and would recommend it to my relatives and friends.***
PEV Better	10.6:8.7:27.0:33.2 :20.6	With the subsidies, PEVs are better than conventional fuel vehicles at same prices. The scale is same as above.
Less Cost	8.7:4.8:19.9:38.6: 28.0	PEVs cost less than ICEs for same distances driving. The scale is same as above.
Maintenance Less	9.1:4.2:20.4:39.2: 27.2	The maintenance cost of PEV is less than that of ICE if batteries are not considered. The scale is same as above.
Less Rely Gas	8.6:3.5:18.8:38.9: 30.2	PEVs help people rely less on fuel. The scale is same as above.
Less Pollute	7.7:4.3:18.0:33.2: 36.8	PEVs help reduce air pollution and greenhouse gas emission. The scale is same as above.
Hi Tech	7.7:8.1:25.9:33.0: 25.3	Most PEV drivers are people who like to try something new and high-technology. The scale is same as above.
The Social System		
External influences: Charging infrastructure		
Charge Home	65.5	Usually charge at home (including shared charging poles in community). 1=Yes, 0=No.
Charger Available	12.1:15.0:26.7: 26.9:19.4	It's easy to find a charging place around the community***.
External influences: Political conditions		
Subsidy	9.4(1.4)	The subsidies for different vehicle type in 2015
Internal influences: Interpersonal networks with near-peers		
Acquaintances Buy	8.1:5.8:26.1:37.9: 22.1	My relatives (or colleagues, friends, neighbors etc.) have purchased or plan to purchase a PEV***.
PEV around	9.0:7.6:26.7:34.2: 22.5	I often see PEVs on roads, being charged, or parking in the community. The scale is same as above.
Experiences: *Driving and charging behavior*		
Average Daily EVKT	31.4 (25.5)	The average daily driving distance, which was generated from the odometer readings reported on the survey day divided by the total days since purchasing the PEV.
PEV Commuting	59.2	The usage of the PEV is for work commuting for one of the four main drivers in the household. 1=Yes. 0=No
Charging Frequency	9.7(8.9)	Charging frequency per week.

Note: * Mean (s.d.) for continuous variables and percent for discrete variables. For binary variables, the percentage of the variable taking the value of 1 is shown.
**This variable was created because the correlation between Education Level and Income Level is significantly high (correlation is 0.521) at 1% significance level.
***5 point Likert-scale. 1=Strongly disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly agree

Model Selection

The dependent variable is a set of 3 alternatives consisting of nominal categories: 1—Would buy a PEV; 2—Would buy an ICE; 3—Would not buy or Other. Therefore, a multinomial logit model (MNL) was

used, which is appropriate if the IIA (the Independence of Irrelevant Alternatives) holds for the three nominal categories. We developed a "best" MNL model (also known as the most parsimonious model, i.e. all explanatory variables in the model are significant), and then employed the Hausman-McFadden method to test the IIA assumption, checking to see if models with a subset of the full choice set would still give estimates of parameters that were not significantly different from the model estimates on the full choice set. Each of the three alternatives were eliminated respectively and were used to re-estimated the model to test whether the coefficients of this model are statistically equivalent to the best MNL model on the full choice set. Although two of the tests suggest the non-violation of IIA, a computational error (negative chi-square) occurred for one test statistic after dropping the alternative "Would buy an ICE" (Table 3). This is possible because the inversion of the small difference between estimates of the two closely related variance-covariance matrices (V^R and V^U) may be non-positive-definite or nearly singular, especially when $\beta^R = \beta^U$ (*22*). This (common) computational problem when conducting the Hausman-McFadden test therefore suggests the non-violation of the IIA assumption but this conclusion is inconclusive.

TABLE 3 Hausman-McFadden Test for IIA

Hausman-McFadden test	Category 1 dropped	Category 2 dropped	Category 3 dropped
Chi-square	7.946	-1129.2	1.638
p-value	0.540	NA*	0.999
Conclusion	Non-violation of the IIA	Suggest the non-violation of the IIA assumption but is inconclusive	Non-violation of the IIA

*NA=Not available

Another approach, the nested logit (NL) model test, was employed to test whether the NL model, a more general model by relaxing the IIA assumption, is significantly better than the best MNL model. It is notable that the three categories share common elements, specifically, respondents in the category 1 and 2 have the common need for mobility; both respondents in category 2 and 3 would not buy PEVs if free license plate was no longer offered; and respondents in categories 1 and 3 share the common characteristic of declining ICEs. Therefore, three conceptually logical NL models (the corresponding NL structures are shown in Figure 1) were tested. The results shown in Table 4 indicate that both likelihood-ratio tests, comparing the goodness of fit of the NL models and the best MNL model, and the t-tests, testing whether the IV parameters of the three NL models are not significantly different from one, support that all nests should be collapsed and the MNL structure is appropriate for this study. Therefore, a MNL model was applied to explore the factors associated with PEV adoption in an experimental situation.

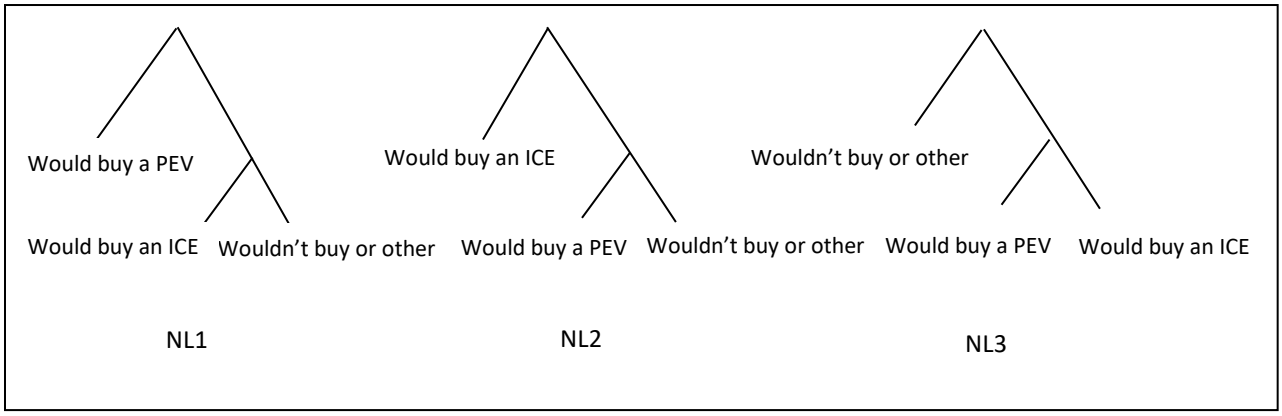

FIGURE 1 Nested Logit Model Structures

TABLE 4 Nested Logit Tests of 3 Nested Logit Model Structures

NL test	NL1 test	NL2 test	NL3 test
Likelihood ratio test			
Chi-square	0.012	0.041	0.020
p-value	0.914	0.839	0.888
t test			
IV parameter $\hat{\theta}$	1.091	0.952	0.957
Standard error of $\hat{\theta}$	0.569	0.225	0.313
Test statistic $\frac{\hat{\theta}-1}{s.e.(\hat{\theta})}$	0.160	-0.212	-0.137
95% critical value for t-distribution (two-tailed)	1.96	1.96	1.96
Conclusion	Fail to reject Ho: IV parameter is 1	Fail to reject Ho: IV parameter is 1	Fail to reject Ho: IV parameter is 1

MODEL RESULTS

The PEV specific variable "Vehicle Price" is significant (p=0.034) with a negative coefficient of -0.017 with the MNL model applied on the full dataset, which means high-end PEV users are less likely to buy PEVs if there is no free license plate offered. However, if Tesla owners were removed from the dataset, the variable Vehicle Price is no longer significant (p=0.323), with both the significance and the relative importance of the other variables remaining the same These findings may indicate that Tesla owners, still a marginal share in the Chinese PEV market, have a price distortion effect. Therefore, to avoid the distortion of explanatory variables such as Price, number of Vehicles in households, etc. (Tesla owners presents significantly different socio-demographics from other PEV owners), and considering that Tesla owners only account for 3.2% of the total respondents, this group of individuals were treated as extreme values and excluded from the data set.

The final data included in the final model are from 968 individuals, and consist of 543 BEV owners who would still choose BEVs, 339 individuals who would choose an ICE instead, and 86 individuals who would choose not buy a car or Other, under the scenario of removing the incentive of a free license plate but keeping other incentives the same. The best-fitting MNL model for vehicle choice is shown in Table 5. The McFadden ρ^2 measure is based on the Market Share model, i.e. the model contains constant terms only, for this model are 0.131, which indicates that about 13.1% of the information contained in the data has been explained by this model relative to the Market Share model. Although this value is small, which may imply important explanatory variables are still lacking, it is still fair for a disaggregate model with 3 alternatives and a relatively large sample size. Analogous to the adjusted R-square of linear regression models, the adjusted ρ^2 ($\overline{\rho}^2$) is 0.110, which corrects for the number of estimated parameters.

Individual Factors: Socio-Demographics

Socio-demographic factors are associated with vehicle choice. **Household annual income** level is correlated with PEV adoption: people with lower income level are more likely to still buy PEVs or not to buy vehicles, whereas people with higher income level intend to buy a conventional vehicle if no free license plate is offered for purchasing a PEV. This result reveals that a free license plate is an important

factor in motivating PEV buyers, especially for people with higher income. If this incentive was taken away, people with lower income level may still adhere to PEVs due to subsidies applied on them and their low running and maintenance cost; whereas higher income people intend to purchase a conventional vehicle instead. Additionally, people with larger **household sizes** are more likely to not buy a vehicle or make an "Other" choice instead of buying a car, which is likely due to the association between the variable "Household Size" and vehicle ownership (r=0.208, p=0.000). If no free license plate is offered for PEVs, the high cost and difficulty to get a license plate discourage households, especially larger size families which own more vehicles thus have no urgent mobility demands, to purchase vehicles. An interesting finding is that **female** decision makers are more likely to be conservative and not buy any vehicle. In contrast, males still have the propensity to purchase PEVs or conventional vehicles, even if no free license plate is offered.

Individual Factors: Attitudes

Accounting for socio-demographics, attitude factors show great influence on explaining choice of PEVs even without the incentive of free license plate. The more **important the free license plate** offered for PEV was in the decision to buy a PEV, the more likely it was that people would choose conventional vehicles if this incentive was removed. This finding implies the important role the incentive of free license plate plays in PEV adoption. PEV owners who were motivated more by **subsidies for PEVs** are associated with a lower likelihood of purchasing a PEV without the free license plate offered, which may indicate that a license plate has potential value and is currently viewed as a big subsidy in the Beijing vehicle market. The belief that PEVs are important for **environment protection and energy saving,** which was a reason for purchasing a PEV originally, positively correlates to choice of PEVs under this experimental scenario. The model results also show that people who would **pay higher price for a license plate**, which is associated with a higher urgency level of mobility need, are more likely to buy PEVs under the scenario that license plates for PEVs are not free but are available in the market. This finding indirectly reflects the extraordinary difficulty that people face in Beijing to get a license plate – people with more urgent mobility demands would rather even pay for them if they are available in the market. The **affection for PEVs** is positively associated with choice of PEVs or choosing not to buy a vehicle. In other words, people who grow to like PEVs more through driving experience are less likely to buy conventional vehicles. **PEV owners who agree that PEVs with the subsidies are better than conventional fuel vehicles at similar prices** are more likely to still choose PEVs. On one hand, this finding indicates the important role the configuration, performance, as well as quality of PEVs play in PEV adoption; on the other hand, it shows the critical role of monetary and none monetary incentives for current market. A counter-intuitive result is shown in that the more people agree that the **cost of maintenance (excluding battery) of PEV is less than that of a conventional vehicle,** the more likely it is that the PEV owners would not choose PEVs. It is possible that although some long-time PEV users may experience a lower cost of maintenance, this statement may raise their concern for the high cost of replacing the battery; additionally, based on the feedback of further in-depth interviews with some PEV users in Beijing, some worried about vehicle safety without having the same regular maintenance requirements as conventional vehicles.

External Influences: Charging Infrastructure

The **accessibility of charging infrastructure, indirectly measured by the perception of the charging infrastructure around the community,** is significantly associated with PEV adoption: PEV owners who feel they can find a charging place around the community are more likely to choose PEV. One assumption was that charging availability at home would be a key factor in purchasing a PEV. However, the results show that people who can **plug in their PEV at home** prefer to buy both PEV *and* conventional vehicles rather than not to buy vehicles. This may be due to a design flaw in the survey: the survey question

measuring availability of home charging fails to identify respondents owning private charging poles from those having shared charging poles or using a fly line, i.e. a long charging cable through windows for home charging; the inconvenience of home charging with the two latter charging methods may lead to the choice of conventional vehicles.

Experience: Charging Behavior

Charging behavior is also found to be associated with PEV adoption. People with higher **frequency of charging behavior** are less likely to choose a conventional vehicle. They may realize the economic benefits of PEV by using it more frequently; or alternatively, the frequent charging behavior indirectly indicates the accessibility and availability of nearby charging infrastructure.

TABLE 5 Results of the MNL Model for PEV Choice

Explanatory	**Would buy a PEV**		**Would not buy or Other**	
Variable	**Coefficient**	**p-value**	**Coefficient**	**p-value**
Constant	-0.351	0.370	-1.851 **	0.006
Individual Factors: Socio-demographics				
Income	-0.159 **	0.004	-0.262 **	0.006
Household Size			0.332 ***	0.000
Female			0.435 *	0.067
Individual Factors: Attitudes				
Important license plate	-0.181 ***	0.000	-0.133 *	0.076
Important subsidy	-0.152 **	0.002		
Important Environment & energy	0.194 ***	0.000		
Price of license plate	0.074 **	0.003		
Like PEV	0.238 *	0.050	0.414 *	0.014
PEV better	0.477 ***	0.000		
Maintenance less	-0.562 ***	0.000	-0.281 *	0.097
External influences: Charging Infrastructure				
Charger available	0.269 ***	0.000		
Charge home			-0.641 **	0.007
Experience: *Charging behavior*				
Charging frequency	0.027 *	0.012	0.030 *	0.053
Number of observations	968			
LL(MS)	-877.805			
LL ($\hat{\beta}$)	-763.03			
ρ^2 MS base	0.131			
$\bar{\rho}^2$ MS base	0.110			

Note: Base category: Would buy an ICE.
*10% significance level, ** 5% significance level, *** 1% significance level.
Blank means the alternative specific variable was allowed to enter the model but was excluded for its insignificance.

DISCUSSION

This analysis of individuals' vehicle choice based on the stated preference data provides new and potentially important insights into factors associated with PEV adoption. The findings reveal that the supportive policies, free license plates and subsidies on PEV purchase, significantly facilitate PEV adoptions. About 44% respondents in Beijing stated that they would not buy BEVs if no free license

plates were offered for the purchase, though it suggests some people are still interested in PEVs as a suitable option for their transportation needs even without this incentive. Considering a stated preference bias may exist, the actual percentage of people who would reject PEVs if there were no incentive of a free license plate should be even higher. The model results also reveal the influences of the free license plate on specific groups of consumers: if free license plates were not offered, people with higher income and people who viewed the free license plate as the most important factor in their decision to purchase the BEV would be more likely to purchase conventional vehicles instead. Additionally, controlling for driving and charging experiences of these PEV owners, although the impact of subsidy on PEVs does not show in the model results, the significance of the variable that PEV is better with subsidies indirectly suggests the importance of subsidies on PEV. Further, the Multinomial Logit model, controlling for the influence of this incentive, shows that other factors such as individual socio-demographics, attitudes, charging infrastructure, and charging experiences play important roles in influencing PEV adoptions. The attitude of affection for BEVs strongly encourages people to adopt a BEV; so does the attitude of environment and energy concern. The results also indicate BEV adoption in China could be driven by mobility need: under the experimental scenario that the license plate was no longer free but could be purchased in market, the price people are willing to pay for it (reflecting the extent to which they need a vehicle) was positively associated with BEV adoption. Among external influences, accessibility of the charging infrastructure, including both private charging poles and charging infrastructure outside, plays an important role in encouraging the choice of a BEV. However, the internal influences do not show significant direct influences on PEV adoption in this model. It is possible that the interpersonal network may work as a mediator indirectly through the attitude of affection, e.g. being encouraged by behaviors of near-peers favoring PEVs; people living in a PEV supportive interpersonal network may be more apt to more and more like PEVs and feel positively towards PEVs over time, which positively correlates to PEV adoption.

SUMMARY AND CONCLUSIONS

The results offer meaningful insights into ways to increase PEV adoption. Planners usually focus on tangible strategies, such as improving charging infrastructure, to promote PEV sales. Changing attitudes toward PEVs has not traditionally fallen within the realm of the promoting strategies. This study, however, points to the importance of the attitude toward PEVs on PEV adoption which may lead other potential ways to get more people to choose PEVs. Although limited, the available evidence of Beijing BEV market suggests that "soft" strategies may have a measurable impact on PEV adoption, given a certain number of charging infrastructure to start with. The empirical results imply that planners need to consider comprehensive programs that affect PEV adoptions on all three levels—individual attitudes, charging infrastructure, and incentives. One concern under China's current plan to reduce incentives gradually is that the PEV demand will decrease before a self-sustained market can be achieved. In this situation, the findings of this study suggest that the increasing trend may be maintained through programs such as interventions designed to provide helpful information about the benefits and costs of PEVs by media advocacy programs. Practically, governments, local communities, and scientific institutions can play synergetic roles in advocating PEVs as an environmentally and economically beneficial mode of transport to build a positive image of PEV that may help attract more PEV adopters who seek to be more protective of the environment and energy efficient, or help foster the attitude of affection for PEVs. Meanwhile, programs focused on building a good network of charging infrastructure that works to attract more PEV consumers are also necessary. These programs, together with incentives, should help expand the PEV market in China. This also may be an effective strategy for other countries, if only ones with similar economic status.

Although we designed the survey to be relevant to all PEV owners, this is a marginal population that can be hard to reach. Out of the PEV owners recruited for the survey, it is possible that individuals who do not like PEVs were less inclined to complete the survey. Because our survey had the added

barrier of being online, non-response bias may be another concern in the survey. Moreover, our model is limited by the experimental design in which a stated preference bias may exist. Some issues cannot be resolved without further research, such as improvements in survey methodology to achieve time series rather than cross sectional data. Nevertheless, this study still tentatively provides a critical understanding of potential determinants of PEV ownership, which will aid in the formation of policies directed toward increasing PEV adoptions globally.

References

1. Cobb J. “The world just bought its two-millionth plug-in car.” hybridCARS 16 Jan. 2017. http://www.hybridcars.com/the-world-just-bought-its-two-millionth-plug-in-car/. Accessed June 5, 2017.
2. Rogers E. Diffusion of innovations. 5th ed. New York: Free Press; 2003.
3. Bakker S, Trip JJ. Policy options to support the adoption of electric vehicles in the urban environment. Transportation Research Part D. 2013;25:18-23.
4. Sierzchula W, Bakker S, Maat K, van Wee B. The influence of financial incentives and other socio-economic factors on electric vehicle adoption. Energy Policy. 2014;68:183-94.
5. Carley S, Krause RM, Lane BW, Graham JD. Intent to purchase a plug-in electric vehicle: A survey of early impressions in large US cites. Transport Res D-Tr E. 2013;18:39-45.
6. Zhang Y, Yu Y, Zou B. Analyzing public awareness and acceptance of alternative fuel vehicles in China: The case of EV. Energy Policy. 2011;39:7015-24.
7. Hackbarth A, Madlener R. Consumer preferences for alternative fuel vehicles: A discrete choice analysis. Transportation Research Part D. 2013;25:5-17.
8. Graham-Rowe E, Gardner B, Abraham C, Skippon S, Dittmar H, Hutchins R, et al. Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: A qualitative analysis of responses and evaluations. Transportation Research Part A. 2012;46(1):140-53.
9. Turrentine TS, Garas D, Lentz A, Woodjack J. The UC Davis mini E consumer study. Institute of Transportation Studies; 2011.
10. Hidrue MK, Parsons GR, Kempton W, Gardner MP. Willingness to pay for electric vehicles and their attibutes. Resource and Energy Economics. 2011;33:686-705.
11. Lane BW, Sherman CP, Sperl J, Krause RM. Beyond eraly adopters of Plug-In Electric Vehicles? Evidence from fleet and household users in Indianapolis. TRB 2014 Annual Meeting; Washington D.C.2014.
12. Egbue O, Long S. Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. Energy Policy. 2012;48:717-29.
13. Lane B, Potter S. The adoption of cleaner vehicles in the UK: exploring the consumer attitude-action gap. Journal of Cleaner Production. 2007;15(11-12):1085-92.
14. Krupa JS, Rizzo DM, Eppstein MJ, Lanute DB, Gaalema DE, Lakkaraju K, et al. Analysis of a consumer survey on plug-in hybrid electric vehicles. Transportation Research Part A. 2014;64:14-31.
15. Skippon S, Garwood M. Response to battery electric vehicles: UK consumer attitudes and attributions of symbolic meaning following direct experience to reduce psychological distance. Transportation Research Part D. 2011;16(7):525-31.
16. Jensen AF, Cherchi E, Mabit SL. On the stability of preferences and attitudes before and after experiencing an electric vehicle. transportation Research Part D. 2013;25:24-32.
17. Peters A, Dutschke E. How do consumers perceive electric vehicles? A comparison of German consumer groups. Journal of Environmental Policy & Planning. 2014;16(3):359-77.
18. Helveston JP, Liu Y, Feit EM, Fuchs E, Klampfl E, Michalek JJ. Will subsidies drive electric vehicle adoption? Measuring consumer preferences in the U.S. and China. Transportation Research Part A. 2015;73:96-112.
19. Babbie ER. The practice of social research. Belmont, CA: Wadsworth Publishing Company; 1998.
20. Wang Y, Sperling D, Tal G, Fang H. China's electric car surge. Energy Policy. 2017;102:486-90.
21. Bühler F, Cocron P, Neumann I, Franke T, Krems JF. Is EV experience related to EV acceptance? Results from a German field study. Transportation Research Part F. 2014;25:34-49.
22. Small K. A., Hsiao C. Multinomial logit specification tests. International Economic Review. 1985;26:619-627.