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Consumers' willingness to pay for alternative fuel vehicles: A comparative discrete choice analysis between the US and Japan

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ABSTRACT

This paper conducts a comparative discrete choice analysis to estimate consumers' willingness to pay (WTP) for electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) on the basis of the same stated preference survey carried out in the US and Japan in 2012. We also carry out a comparative analysis across four US states. We find that on average US consumers are more sensitive to fuel cost reductions and alternative fuel station availability than are Japanese consumers. With regard to the comparative analysis across the four US states, consumers' WTP for a fuel cost reduction in California is considerably greater than in the other three states. We use the estimates obtained in the discrete choice analysis to examine the EV/PHEV market shares under several scenarios. In a base case scenario with relatively realistic attribute levels, conventional gasoline vehicles still dominate both in the US and Japan. However, in an innovation scenario with a significant purchase price reduction, we observe a high penetration of alternative fuel vehicles both in the US and Japan. We illustrate the potential use of a discrete choice analysis for forward-looking policy analysis, with the future opportunity to compare its predictions against actual revealed choices. In this case, increased purchase price subsidies are likely to have a significant impact on the market shares of alternative fuel vehicles.

1. Introduction

President Barack Obama has called for 1 million alternative fuel vehicles to be on the road in the US by 2015.[1] Automobile manufacturers have just begun to make such vehicles available in the US marketplace, with approximately sixteen different models available at the time of this writing and total sales from 2011 through September 2012 just over 40,000 units.[2] Similarly, Japan's Ministry of Economy has set a goal of having 20% of new car sales be such vehicles by 2020, although sales at this time remain quite modest: for fiscal year 2010, 4816 electric vehicles or just over 1% were provided to the domestic market.[3] Clearly

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[1] See his "Presidential Memorandum—Federal Fleet Performance" dated May 24, 2011 available at http://www.whitehouse.gov/the-press-office/2011/05/24/presidential-memorandum-federal-fleet-performance.

[2] Sixteen models are listed as eligible for the federal tax credit on the government website http://www.fueleconomy.gov/feg/taxevb.shtml. The sales figures for electric vehicles are from the Electric Drive Transportation Association at http://www.electricdrive.org/index.php?ht=d/sp/i/20952/pid/20952.

[3] See pp. 7 and 25 of The Motor Industry of Japan (2012). In calendar year 2010 there were 4,212,267 new passenger vehicle registrations, and 3,524,788 in 2011.

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there is a long way to go to reach these goals. The current vehicles are largely either electric (EV) or plug-in hybrid electric (PHEV), although other alternative fuels such as hydrogen or natural-gas powered vehicles could become more significant in the future.[4] Particularly, PHEVs have recently received considerable attention in the transportation literature (Musti and Kockelman, 2011; Graham-Rowe et al., 2012; Krupa et al., 2014). The US, Japan, and other countries are using and considering various public policies to help achieve these goals for cleaner vehicles.

In recent years, Japan has provided a variety of incentives to purchase green vehicles, including exemptions from its acquisition tax at purchase and some reductions in its tonnage tax, both totaling about 5.7% of the purchase price.[5] In the US, there is currently a federal tax credit of up to $7500 for the purchase of qualifying vehicles, and the President has announced that he would like to expand this credit to $10,000. What effect is a policy change like this likely to have? The analysis presented in this paper suggests that, other things being equal, such an increase is likely to have a significant impact. Of course, other things may not be equal. For example, some US states like California have additional tax credits that could be raised or lowered over time. The California Clean Vehicle Rebate Project currently provides a rebate of up to $2500 per vehicle (Center for Sustainable Energy, 2013), but it is not clear for how long such incentives will continue. Thus our analysis is not a forecast, but an investigation of the extent that different purchase factors matter to consumers.

Given the early stage of development for alternative fuel vehicles, empirical revealed preference data from actual purchases have not been sufficiently accumulated. Therefore, we adopt a stated preference (SP) method. SP data come from survey responses to hypothetical choices, and take into account certain types of market constraints useful for forecasting changes in consumer behaviors. The responses may be affected by the degree of contextual realism as perceived by the survey respondents.

Most studies on the demand for clean-fuel vehicles have used the SP method. Past studies on clean-fuel or electric vehicles are summarized in Table 1. Early studies on clean-fuel vehicles include those of Beggs et al. (1981) and Calfee (1985) in response to the oil crisis of the 1970s. The zero-emission vehicle mandate in California also stimulated a series of studies on EVs. Studies on the potential demand for EVs in California include Bunch et al. (1993), Segal (1995), Brownstone and Train (1999), Brownstone et al. (2000), and Hess et al. (2012). Many demand studies for clean-fuel vehicles focus on an individual country: the US (Hidrue et al., 2011), Canada (Ewing and Sarigöllü, 2000; Potoglou and Kanaroglou, 2007; Mau et al., 2008), Germany (Ziegler, 2012; Achtnicht et al., 2012; Hackbarth and Madlener, 2013), Norway (Dagsvik et al., 2002), Japan (Ito et al., 2013), South Korea (Ahn et al., 2008), and China (Qian and Soopramanien, 2011). Very few studies conduct a comparative discrete choice analysis across multiple countries. One exception is Axsen et al. (2009), which investigates SP data in the US and Canada. However, to the best of our knowledge, no comparative discrete choice analysis on the demand for clean-fuel vehicles between the US and Japan has been conducted.[6]

This paper contributes to the existing literature in three ways. First, we conduct a comparative discrete choice analysis on alternative fuel vehicles between the US and Japan based on the same online stated preference survey with a large sample in both countries. Second, we also carry out a discrete choice analysis across the four US states (California, Texas, Michigan, and New York) for a state comparison. Third, our analysis is policy-relevant in the sense that we account for EVs, PHEVs, and conventional gasoline vehicles to represent consumer choice among conventional and new technologies, and to simulate how these choices may be affected by public policies in the context of the US and Japan.[7]

Our main findings are as follows. Regarding the comparison between the US and Japan, we find that US consumers are more sensitive to fuel cost reductions and to alternative fuel station availability than are Japanese consumers, while consumers in both countries are equally sensitive to the driving range on a full battery and to emissions reduction. With regard to comparative analysis across the four US states, we find that consumers' willingness to pay (WTP) for a fuel cost reduction in California is considerably greater than in the other three states. The WTP values for other attributes are very similar across those states except for Michigan. We then conduct a numerical evaluation of EV/PHEV market shares based on the estimates obtained in the discrete choice analysis. In a base case scenario with relatively realistic attribute levels, conventional gasoline vehicles still dominate both in the US and Japan. However, in an innovation scenario with a significant purchase price reduction, we observe a high penetration of alternative fuel vehicles both in the US and Japan.

The remainder of this paper is organized as follows. Section 2 explains the online stated preference survey method and the experimental design. Section 3 describes the discrete choice model used for estimation. Section 4 reports the estimation results and measures the WTP values of the attributes. Section 5 presents the diffusion analysis and its implications for the future spread of alternative fuel vehicles. Section 6 presents a brief illustration of the potential of discrete choice analysis as a tool for forward-looking policy analysis. Finally, Section 7 concludes the paper.

[4] An EV uses one or more electric motors with batteries for propulsion, while a PHEV combines an internal combustion engine and electric motors with batteries that can be recharged via an external electric power source at home or at a public charging station.

[5] See p. 45 of The Motor Industry of Japan (2012).

[6] Karplus et al. (2010) used a computable general equilibrium (CGE) model to investigate the prospects for PHEV market entry in the US and Japan, particularly focusing on the production structure of the PHEV sector with cost share parameters. They, however, did not use SP data/discrete choice analysis on the demand for clean-fuel vehicles.

[7] Our work is in line with other studies that use a discrete choice analysis for forward-looking policy discussions (e.g., Ewing and Sarigöllü, 1998; Horne et al., 2005; Daziano and Bolduc, 2013).

Table 1
Summary of past SP studies on clean fuel or electric vehicles (an extension of the summary in Horne et al., 2005 and Hidrue et al., 2011).

Study	Econometric model	Number of attributes, and levels	List of attributes used								
			Purchase price	Operating cost	Driving range	Emissions data	Fuel availability	Fuel type	Performance	Vehicle type	Other incentives
Beggs et al. (1981)	Ranked logit	8, NA	*Price*	*Fuel cost*	*Range*	–	–	–	*Top speed, acceleration*	*Number of seats, air conditioning*	*Warranty*
Calfee (1985)	Disaggregate multinomial logit	5, NA	*Price*	*Operating cost*	*Range*	–	–	–	*Top speed*	*Number of seats*	–
Bunch et al. (1993)	Multinomial logit and nested logit	7, 4	*Purchase price*	*Fuel cost*	*Range*	*Emissions level*	*Fuel availability*	*fuel type*	*Acceleration*	–	–
Segal (1995)	First choice model	7, 2–3	*Price*	*Fuel cost*	*Range, refueling duration*	–	*Refueling location, refueling time of day*	*Fuel type*	–	–	–
Brownstone and Train (1999)[1]; Brownstone et al. (2000)[1]	Multinomial logit and mixed logit; joint SP/RP MIXED LOGIT	13, 4	*Price*	*Home refueling cost, service station refueling cost*	*Range*	*Emission reduction*	*Fuel availability, home refueling time*	–	*Top speed, acceleration*	*Vehicle size, body type, luggage space*	–
Ewing and Sarigollu (2000)	Multinomial logit	7,3	*Price*	*Fuel cost, repair and maintenance cost*	*Range*	–	*Charging time*	–	*Acceleration*	*Commuting time*	–
Dagsvik et al. (2002)	Ranked logit	4, NA	*Price*	*Fuel cost*	*Range*	–	–	–	*Top speed*	–	–
Potoglou and Kanaroglou (2007)	Nested logit	7, 4	*Price*	*Fuel cost, maintenance cost*	–	*Emission reduction*	*Fuel availability*	–	*Acceleration*	–	*Incentives*
Horne et al. (2005)[2]	Multinomial logit	6, 2–5	*Purchase price*	*Fuel cost*	–	*Emissions compared to current vehicle*	*Stations with proper fuel*	–	*Power compared to current vehicle*	*Express lane access*	–
Ahn et al. (2008)	Multiple discrete-continuous extreme value	6, 2–5	–	*Fuel price, maintenance cost*	*Fuel efficiency*	*Engine displacement*	–	*Fuel type*	–	*Body type*	–
Mau et al. (2008)	Multinomial logit	6, 3	*Price*	*Fuel cost*	*Range*	–	*Fuel availability*	–	–	–	*Subsidy, warranty*
Axsen et al. (2009)	Multinomial logit; joint SP/RP multinomial logit	5, 3	*Price*	*Fuel price*	*Fuel efficiency*	–	–	–	*Horsepower*	–	*Subsidy*
Hidrue et al. (2011)	Latent class	6, 4	*price*	*Fuel cost*	*Range*	*Emission reduction*	*Charging time*	–	*Acceleration*	–	–
Qian and Soopramanien (2011)	Multinomial logit and nested logit	6, 3	*Price*	*Fuel cost*	*Range*	–	*Fuel availability*	*Fuel type*	–	–	*Policy incentives*
Ziegler (2012)	Multinomial probit	5, 3	*Price*	*Fuel cost*	–	*Emissions*	*Fuel availability*	–	*Horsepower*	–	–
Achtnicht et al. (2012)	Logit	6, 7	*Price*	*Fuel cost*	–	*Emissions*	*fuel availability*	*Fuel type*	*Horsepower*	–	–
Hess et al. (2012)	Mixed multinomial logit, nested, cross-nested logit	12, 2–15	*Purchase price*	*Fuel cost per year, maintenance cost per year*	*Driving range, miles per gallon equivalent*	–	*Fuel availability, refueling time*	*Fuel type*	*Acceleration*	*Vehicle type, age of vehicle*	*Incentive*
Ito et al. (2013)	Multinomial logit and nested logit	9, 4	*Price*	*Fuel cost*	*Range*	*Emission reduction*	*Fuel availability, refueling time*	*Fuel type*	*Acceleration*	*body type, Manufacturer*	–
Hackbarth and Madlener (2013)	Mixed logit	8, 3	*Price*	*Fuel cost*	*Range*	*Emission reduction*	*Fuel availability, refueling time, charging time*	–	–	–	*Policy incentives*
This study	Mixed logit	6, 2–4	*Purchase price*	*Fuel cost*	*Driving range*	*Emission reduction*	*FUEL availability, home plug–in construction*	–	–	–	–

[1] The two papers used the same data.
[2] They conducted the survey within the context of vehicle type and commuting mode decisions. We extract the former part.

2. Survey and design

This section explains the stated preference survey method and the experimental design. The survey was conducted online in February 2012 by consumer research companies both in the US and Japan that employ random sampling techniques to ensure representative populations. We surveyed random samples of 4202 and 4000 consumers in four US states and Japan, respectively. Specifically, we focused on California (West), Texas (South), Michigan (Midwest), and New York (Northeast) as states from four different regions in the US, with a sample size of just over 1000 from each state. These states were chosen because they represent different regions, but also because they each have different electricity systems overseen by state regulators and differing clean vehicle policies.[8] While we present our findings separately for each state, we also average the responses across the four-state US sample to compare them with the Japanese responses. It should be understood that this four-state average is not intended to be statistically representative of the full US.[9] In the case of Japan, which is under one regulatory system, our sample of 4000 consumers covers all prefectures so as to represent an average Japanese population.[10] The samples were randomly selected by the consumer research companies to ensure that the actual population distribution, age distribution, and gender distribution were properly reflected.

Our survey focuses on consumer preferences for particular attributes of vehicles that affect their purchase decisions. In the marketing literature, using this type of survey to model consumer choice is often referred to as a conjoint analysis. If an excessive number of attributes and levels are included, respondents find it difficult to answer the questions. On the other hand, if too few are included, the description of the alternatives becomes inadequate. Since the number of attributes becomes unwieldy if we consider all possible combinations, we adopted an *orthogonal planning method* to avoid this problem (see Louviere et al., 2000, Ch. 4, for details).

There are pros and cons for a consumer considering purchasing an EV or PHEV. Driving an EV or PHEV can significantly reduce expenses on gasoline or other fuels, and pollution is much lower than from conventional gasoline vehicles. On the other hand, the purchase prices of these vehicles are relatively high when compared to standard gasoline vehicles (at present, an additional $10,000 or more). Furthermore, the driving range on a full battery is still very limited, and finding a charging station can be time consuming. Given these facts, we focus on the following six key attributes in this study: (1) purchase price premium, (2) fuel cost reduction (percentage) as compared with gasoline vehicles, (3) driving range on full battery, (4) emissions reduction (percentage) compared with gasoline vehicles, (5) alternative fuel station availability (expressed as a percentage of existing gas stations), and (6) home plug-in construction fee. Note that the driving range on a full battery is concerned with consumer preference for the physical attribute of the EV/PHEV battery ("range anxiety") rather than implying a preference for fuel efficiency. After conducting several pretests, we determined the attribute levels of the EV/PHEV conjoint analysis as summarized in Table 2. We did not consider other attributes such as fuel type, performance, vehicle type, and other policy incentives as shown in Table 1. That is, the survey holds constant other attributes by providing a simple description of a hypothetical vehicle that does not vary apart from the six studied attributes.

Fig. 1 displays an example of one of the questions used on the EV/PHEV conjoint questionnaire. There are three alternatives: Alternative 1 denotes EV; Alternative 2 denotes PHEV; and Alternative 3 refers to gasoline vehicle purchases. There are sixteen questions in total that look like Fig. 1 except with different attributes. In addition, they are divided into two versions of eight questions each by using a blocking methodology. All respondents are asked one of the two versions at random.

3. Model specification

This section describes the estimation model. Conditional logit (CL) models, which assume independent and identical distribution (IID) of random terms, have been widely used in past studies. However, the property of independence from the irrelevant alternatives (IIA) derived from the IID assumption of the CL model is too strict to allow flexible substitution patterns. A nested logit (NL) model partially relaxes the strong IID assumptions by partitioning the choice set and allowing nested alternatives to have common unobserved components compared with non-nested alternatives. However, the NL model is not suited for our analysis because it cannot deal with the distribution of parameters at the individual level (Ben-Akiva and Bolduc, 2001). The best model for this study is an error component multinomial logit (ECML) model, which accommodates differences in the variance of error components for each alternative. This model is flexible enough to over-

[8] Michigan, the historic home state of the US motor vehicle industry, is also a state in which electricity service is provided largely by vertically-integrated utilities subject to rate-of-return regulation. Texas is a state with substantial retail and wholesale electricity competition, and the competitive retailers may market to induce customers to purchase plug-in electric vehicles. New York has wholesale competition and some retail competition (although not as much as Texas). California has significant wholesale competition, but not retail competition. In terms of clean vehicle policies, California adopted in 2004 emission standards that commit to a 30% reduction in GHG emissions by 2016, and it offers rebates of up to $2500 per vehicle for the purchase of qualifying alternative fuel vehicles. New York adopted the California emission standards in 2005, but does not offer financial incentives for the purchase of clean vehicles. Michigan and Texas do not have state emission standards or financial incentives.

[9] These four states contain approximately 30% of the US population. To the extent that higher electricity prices discourage interest in alternative fuel vehicles, our sample may slightly understate the overall interest of the US population. While the average residential electricity bill in the four states ($105.26) is close to the US average ($110.55), the average retail rate of $.144 per kWh in the four states is higher than the US average of $.115 and the average monthly consumption amount (763 kWh) is lower than in the US as a whole (858 kWh). These figures are from the US Energy Information Administration 2010 report on electricity sales and revenue.

[10] Japan is a more compact and homogeneous country, approximately equivalent in area to California but with a population of 128 million.

Table 2
Attribute levels of conjoint analysis.

	EV (Electric vehicle)				PHEV (Hybrid electric vehicle with a plug-in function)				Gasoline Vehicles			
	Level 1	Level 2	Level 3	Level 4	Level 1	Level 2	Level 3	Level 4	Level 1	Level 2	Level 3	Level 4
Purchase price/price premium	$1,000 higher	$3,000 higher	$5,000 higher	$10,000 higher	$1,000 higher	$3,000 higher	$5,000 higher	$10,000 higher	about $20,000 (fixed)			
Fuel cost (compared with conventional gasoline vehicles)	60% off	80% off			40% off	60% off			0% off (as conventional)	10% off	20% off	30% off
Driving range	100 miles	200 miles	300 miles	400 miles	700 miles	800 miles	900 miles	1000 miles	400 miles	500 miles	600 miles	700 miles
Emission reduction (compared with conventional gasoline vehicles)	70% reduction	80% reduction	90% reduction	100% reduction	50% reduction	60% reduction	70% reduction	80% reduction	No reduction	10% reduction	20% reduction	30% reduction
Alternative fuel availability (% of existing gas stations)	10%	30%	50%	70%	10%	30%	50%	70%	–			
Home plug-in construction fee	No fee	1,000 US$			No fee	1,000 US$			–			

Note: Among the respondents including those who are interested in alternative fuel vehicles, approximately 75% of the US respondents and 85% of Japanese respondents are thinking of "under $30,000" for purchasing a future vehicle as shown in Table 3. Therefore, we assume the conventional purchase price for a gasoline vehicle at $20,000 in the choice experiment for simplification. This simplification may induce bias in estimation and a limit on this analysis, but can decrease the cognitive burden of the respondents in the survey task.

A1	Vehicle1 EV (Electric vehicle)	Vehicle2 PHEV (Plug-in hybrid)	Vehicle3 Gasoline vehicles	Do not buy
Purchace price/price premium	$1,000 higher	$1,000 higher	about $20,000	Do not buy any of them
Fuel cost (compared with conventional gasoline vehicles)	60% off	40% off	10% off	
Driving range	200 miles	700 miles	400 miles	
Emission reduction (compared with conventional gasoline vehicles)	80% reduction	60% reduction	20% reduction	
Alternative fuel availability (% of existing gas stations)	50%	30%	-	
Home plug-in construction fee	No fee	1,000 US$	-	
	↓	↓	↓	↓
Please circle one choice→				

Fig. 1. Example of conjoint questionnaire.

come the limitations of CL models by allowing for random taste variation, unrestricted substitution patterns, and the correlation of random terms over time (McFadden and Train, 2000). In the ECML model, alternative specific random individual effects account for unobserved variations that are not accounted for by the other model components.

Assuming that parameter β_n is distributed with density function $f(\beta_n)$ (Train, 2003; Louviere et al., 2000), the ECML specification allows for repeated choices by each sampled decision maker in such a way that the coefficients vary across people but are constant over each person's choice situation. The logit probability of decision maker n choosing alternative i in choice situation t is expressed as

$$L_{nit}(\beta_n) = \prod_{t=1}^{T}\left[\exp(V_{nit}(\beta_n)) \Big/ \sum_{j=1}^{J} \exp(V_{njt}(\beta_n))\right], \quad (1)$$

which is the product of normal logit formulas, given parameter β_n, the observable portion of utility function V_{nit}, and alternatives $j = 1,\ldots,J$ in choice situations $t = 1, \ldots, T$. Therefore, the ECML choice probability is a weighted average of the logit probability $L_{nit}(\beta_n)$ evaluated at parameter β_n with density function $f(\beta_n)$, which can be written as

$$P_{nit} = \int L_{nit}(\beta_n) f(\beta_n) d\beta_n. \quad (2)$$

Accordingly, we can demonstrate variety in the parameters at the individual level using the maximum simulated likelihood (MSL) method for estimation with a set of 100 Halton draws.[11] Furthermore, since each respondent completes eight questions in the conjoint analysis, the data form a panel to which we can apply a standard random effect estimation.

In the linear-in-parameter form, the utility function can be written as

$$U_{nit} = \alpha' x_{nit} + \beta_n' z_{nit} + \varepsilon_{nit}, \quad (3)$$

where x_{nit} denotes an observable variable, z_{nit} is an alternative error component, α denotes a fixed parameter vector, β_n denotes a random parameter vector, and ε_{nit} denotes an independently and identically distributed extreme value (IIDEV) term. Here, for simplicity, we assume that the only random parameters included are the error components for each alternative. Further, we set the utility of the no-choice alternative to be normalized to zero (baseline) and the error component terms—as well as alternative specific constant terms—are added to all alternatives, including the no choice (baseline) alternative. Since the ECML choice probability is not expressed in a closed form, simulations must be performed for the ECML model estimation (see Train, 2003, for details).

4. Data description and estimation results

After briefly describing the data used in this study, we show the EV and PHEV estimation results in this section. First, Table 3 summarizes the basic demographic characteristics of the respondents in the four-state US and Japan samples.[12] Table 3 also shows the preferences for EV/PHEV utilization. As shown, 57% and 41% of the respondents in the US and Japan samples, respectively, indicate an intention to purchase a car within the next five years. Moreover, 60% and 53% of the respondents in the US and Japan, respectively, show an interest in alternative fuel vehicles.

[11] Louviere et al. (2000, p. 201) suggest that 100 replications are normally sufficient for a typical problem involving five alternatives, 1000 observations, and up to 10 attributes (also see Revelt and Train, 1998). The adoption of the Halton sequence draw is an important issue (Halton, 1960). Bhat (2001) found that 100 Halton sequence draws are more efficient than 1000 random draws for simulating an ECML model.

[12] 81% and 72% of the respondents replied that they are the primary handlers of household bills in the US and Japan, respectively. Some of the asymmetric gender distribution between the US and Japan in this survey might be attributed to some extent to who primarily handles household bills. While our interest is in geographic differences, an alternative modeling approach would be to explore the extent to which demographic differences can explain the stated preferences. We explore such an approach briefly in Appendix.

Table 3
Respondents' characteristics

	US respondents (%)	California (%)	Texas (%)	Michigan (%)	New York (%)	Japanese respondents (%)
Gender (Male)	38.2	44.6	37.4	32.8	38.2	56.0
Age from 30's to 50's	58.3	60.2	55.2	61.8	56.0	77.9
Married/couple	69.8	64.3	72.3	73.5	68.9	80.3
Detached house dwelling	72.0	62.0	78.1	78.8	68.4	54.7
Annual household income between $30,000 to $70,000	41.9	35.6	44.4	47.6	39.8	50.7
Ownership of conventional gasoline vehicles	96.0	96.0	97.0	96.4	94.4	78.5
Intent to purchase a car within next five years	56.7	58.8	56.2	54.9	52.5	41.3
Type of car respondents are planning to purchase						
Four-door sedan	43.5	50.6	37.3	35.5	51.0	20.9
Two-door sedan	5.0	8.0	5.2	3.7	3.1	0.6
Station wagon	1.4	1.0	1.3	1.7	1.6	11.7
Sports utility vehicle (US only)	27.8	18.6	32.8	31.4	28.3	–
Mini-vehicle (Keicar) (Japan only)	–	–	–	–	–	22.5
Compact car	6.1	6.3	6.4	7.5	4.2	21.1
Minivan	5.1	2.8	3.1	9.4	5.1	18.5
Sports car	3.8	5.3	3.9	2.8	3.0	1.6
Others	7.3	7.3	10.0	8.0	3.7	3.2
Price range for purchasing a next vehicle						
Under $20,000	32.2	28.5	31.0	39.0	30.4	54.7
Between $20,000 to $30,000	42.4	41.4	45.4	41.5	41.3	29.5
Between $30,000 to $40,000	18.1	20.0	16.5	16.4	19.6	9.7
Between $40,000 to $50,000	5.1	6.2	5.6	2.7	5.9	3.3
Over $50,000	2.2	4.0	1.5	0.5	2.8	2.7
Interest in alternative fuel vehicles (very/moderately interested)	59.5	67.2	55.6	56.6	58.8	52.8
Interest in charging alternative fuel vehicle at home	82.3	78.8	84.5	86.7	78.7	70.3

We now discuss the EV and PHEV estimation results for the US and Japan. We also present the results for the four US states separately. Table 4 shows the estimation results for the combined four-state US sample and for Japan. The McFadden R^2 values are 0.3378 for the former and 0.4223 for the latter, both of which are sufficiently high for a discrete choice model. We assume that alternative specific parameters (error components) are distributed normally, and the mean and standard deviation values are reported.

All the estimates (means) are statistically significant at the 1% level. For both the US and Japan, the signs of the estimates are positive for reduction in fuel costs, driving range, emissions reduction, and alternative fuel station availability, and neg-

Table 4
Estimation results for US and Japan.

	US respondents			Japanese respondents		
	Coeff.	Std. Err.	WTP (US$)	Coeff.	Std. Err.	WTP (US$)
<non random parameters>						
ASC for EV	5.77049	0.16766***	–	7.94481	0.19466***	–
ASC for PHEV	6.91993	0.16739***	–	9.25162	0.19855***	–
ASC for gasoline vehicles	6.57852	0.11927***	–	7.44048	0.13909***	–
Purchase price (US$)	−0.00030	0.00000***	–	−0.00036	0.00000***	–
Fuel cost (% off compared with gasoline vehicles)	0.01485	0.00099***	49.84	0.01315	0.00112***	36.74
Range (miles)	0.00064	0.00008***	2.15	0.00077	0.00005***	2.15
Emission reduction (% reduction compared with gasoline vehicles)	0.00864	0.00092***	29.00	0.00936	0.00101***	26.15
Alternative fuel station availability						
(% of existing gas stations)	0.01485	0.00050***	49.84	0.01202	0.00059***	33.59
Home plug-in construction fee (US$100)	−0.06359	0.00199***	−213.41	−0.06052	0.00232***	−169.10
<Standard deviation of error components>						
EV	1.58005	0.0354***	–	1.92815	0.0507***	–
PHEV	0.10192	0.0633	–	1.13103	0.0640***	–
Gasoline vehicles	3.85320	0.0792***	–	4.97706	0.1089***	–
Not buy	3.59628	0.0663***	–	5.03432	0.0979***	–
Number of obs.	33616			32000		
McFadden Pseudo R-squared	0.3378			0.4223		
Log likelihood function	−29328.94			−25626.60		

Note: ASC denotes *alternative specific constant*. The percentage variables (fuel cost, emission reduction, fuel station availability) are on a scale of 0–100.
*** Denotes significance at the 1% level.

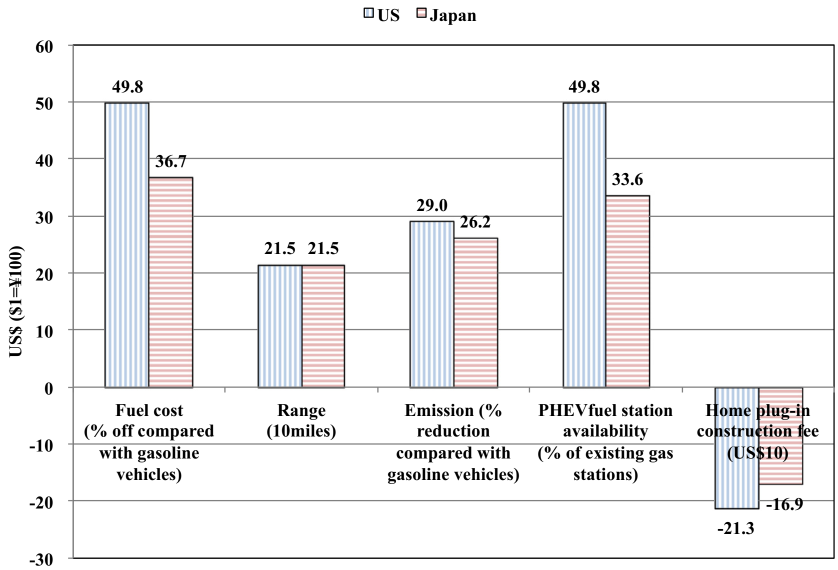

Fig. 2. WTP values for US and Japan. *Note:* The *t* values for testing the difference in WTP values between US and Japan: Fuel cost, 2.82***; Range, 0.01; Emission, 0.67; Alternative fuel station availability, 6.54***; Home plug-in construction fee, 4.44***; (**$p < 0.05$, ***$p < 0.01$). We use here the approximate solution for the variance of the WTP values as follows: $\mathrm{var}\left(\frac{\beta_i}{\beta_j}\right) = \left(\frac{\beta_j}{\beta_i}\right)^2 \left(\frac{\mathrm{var}(\beta_i)}{\beta_i^2} + \frac{\mathrm{var}(\beta_j)}{\beta_j^2} - \frac{2\mathrm{cov}(\beta_i,\beta_j)}{\beta_i\beta_j}\right)$.

ative for purchase price and home plug-in construction fee, which all have a natural interpretation. The statistically significant estimates include all error component parameters for both countries.

The WTP values are the negative of the resultant derived by dividing the parameter of the attribute by the parameter of the numeraire. The WTP values for the US and Japan are summarized in Fig. 2. It is worth noting the difference in the WTP between the US and Japan. The WTP values for fuel cost reduction ($49.8) and alternative fuel station availability ($49.8) in the US are almost one and a half times higher than those ($36.7 and $33.6, respectively) in Japan. In contrast, the WTP values for the driving range on a full battery ($21.5) and emissions reduction ($29.0) in the US are almost the same as those ($21.5 and $26.2, respectively) in Japan. These results show that US consumers in our four-state sample are, on average, more sensitive to fuel cost reductions and to alternative fuel station availability, whereas the US and Japanese consumers are equally sensitive to the driving range on a full battery and to emissions reduction.[13] Keeping in mind that the four states were chosen to represent differing circumstances and attitudes within the US (Table 5 and Fig. 3), the country differences observed here are notable because they hold not just as an average but in comparison of Japan with each state separately (with one exception of lower Michigan WTP than Japan for alternative fuel station availability).

Table 5 shows the estimation results across the four US states. We here treat Michigan as the base line and interact other state indicator variables (California, Texas, and New York) with each of the six choice attribute variables. All the base estimates (Michigan) are statistically significant at the 1% level. Using California as an example, the purchase price parameter is not significant, meaning that the preferences are not different between Michigan and California. The parameters for fuel cost and alternative fuel station availability are considerably higher in California than those in Michigan, while the parameters for range and emission reduction are lower. The same tendencies apply to Texas and New York with some differentiated statistical significances.

Fig. 3 summarizes the WTP values across the four US states. It is notable that the WTP for fuel cost reduction is greater in each state than that in Japan ($36.7) except for Michigan ($36.2). In addition, the WTP in California ($60.9) is considerably greater than those in the other states, which are all around $40. The difference in the WTP for fuel cost reduction may be partially because gasoline prices differ among these states. Specifically, California adopts the strictest emissions control regulations in the US, and uses a different and more expensive formulation to produce gasoline. For example, the regular gasoline prices were $4.3, $3.6, $3.7, and $3.9, per gallon on February 27, 2012, in California, Texas, Michigan, and New York, respectively, while the average price across all states was $3.7 per gallon. Other conditions such as the average annual driving mileage may also vary significantly across these states, and further explain the WTP variation.

With regard to attributes other than fuel cost reduction, the WTP values are very similar across those states except for Michigan. The WTP values for range and emissions are much higher in Michigan ($26.4 and $44.6) than those in other states ($16.8–18.8 and $26.5–34.1), while the alternative fuel station availability is lower ($25.9) than in Japan ($33.6), and much

[13] The result further demonstrates that the home plug-in construction fee ($10) is compensated for by the reduction in auto purchase costs ($21.3 in the US and $16.9 in Japan).

Table 5
Estimation results across four US states.

	US respondents		
	Coeff.	Std. Err.	WTP (US$)
<non random parameters: Base = Michigan>			
ASC for EV	5.62129	0.16858***	–
ASC for PHEV	6.80828	0.16816***	–
ASC for gasoline vehicles	5.84320	0.13605***	–
Purchase price (US$)	−0.00030	0.00623***	–
Fuel cost (% off compared with gasoline vehicles)	0.01074	0.00175***	36.22
Range (miles)	0.00078	0.00011***	2.64
Emission reduction (% reduction compared with gasoline vehicles)	0.01322	0.00158***	44.59
Alternative fuel station availability			
(% of existing gas stations)	0.00768	0.00068***	25.90
Home plug-in construction fee (US$100)	−0.07092	0.00406***	−239.19
<Interaction term: California>			
Purchase price (US$)	0.00000	0.00001	–
Fuel cost (% off compared with gasoline vehicles)	0.00727	0.00240***	24.67
Range (miles)	−0.00026	0.00012**	−0.87
Emission reduction (% reduction compared with gasoline vehicles)	−0.00376	0.00207*	−12.76
Alternative fuel station availability			
(% of existing gas stations)	0.00793	0.00119***	26.91
Home plug-in construction fee (US$100)	0.01820	0.00556***	61.76
<Interaction term: Texas>			
Purchase price (US$)	0.00000	0.00001	–
Fuel cost (% off compared with gasoline vehicles)	0.00264	0.00234	8.82
Range (miles)	−0.00029	0.00013**	−0.96
Emission reduction (% reduction compared with gasoline vehicles)	−0.00313	0.00210	−10.46
Alternative fuel station availability			
(% of existing gas stations)	0.00743	0.00120***	24.83
Home plug-in construction fee (US$100)	0.01080	0.00566*	36.09
<Interaction term: New York>			
Purchase price (US$)	0.00000	0.00001	–
Fuel cost (% off compared with gasoline vehicles)	0.00309	0.00234	10.57
Range (miles)	−0.00022	0.00013*	−0.77
Emission reduction (% reduction compared with gasoline vehicles)	−0.00528	0.00207**	−18.07
Alternative fuel station availability			
(% of existing gas stations)	0.00732	0.00117***	25.05
Home plug-in construction fee (US$100)	0.00723	0.00568	24.74
<Standard deviation of error component>			
EV	1.60359	0.0363***	–
PHEV	0.09710	0.0641	–
Gasoline vehicles	3.90483	0.0827***	–
Not buy	3.61312	0.0670***	–
Number of obs.	33616		
McFadden Pseudo R-squared	0.3704		
Log likelihood function	−29340.92		

Note: ASC denotes *alternative specific constant*. The percentage variables (fuel cost, emission reduction, fuel station availability) are on a scale of 0-100. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively

lower than each of the other three states ($50.7–52.9). It is interesting that the WTP for emissions reduction in California is similar to the other states, despite consumers in California reputedly being more aware of environmental protection than those in other states.

5. Implications for future diffusion

This section discusses the numerical implications for EV/PHEV market shares (percent of car purchases) based on the estimates obtained in Section 4. For this purpose, we insert the estimates obtained in Tables 5 and 6 into the ECML choice probabilities represented in Eq. (2). We consider three different states of the world, or scenarios:

- A base case Scenario 1 with relatively realistic attribute levels attainable with current technologies.
- Scenario 2 with a purchase price reduction for an EV/PHEV, while the other attribute levels are the same as in Scenario 1.

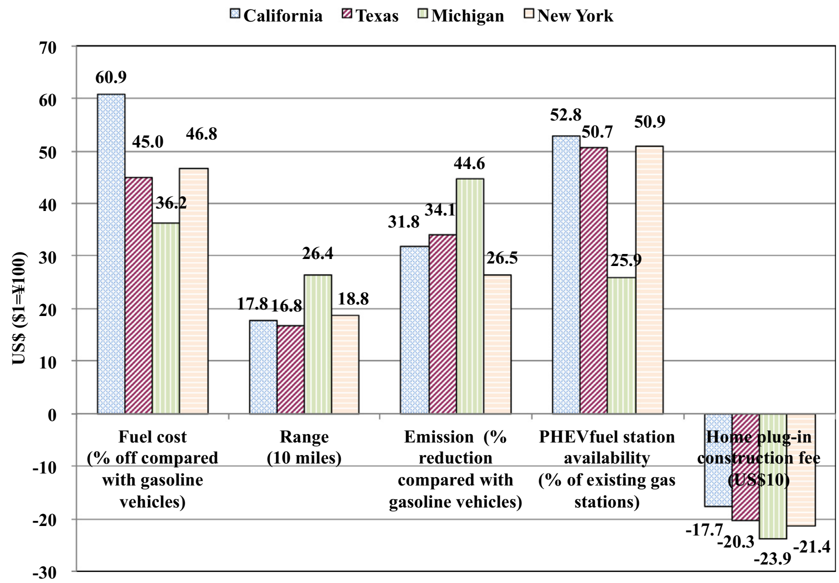

Fig. 3. WTP values across four US states. *Note:* The *t* values for testing the difference in WTP values across four states: Fuel cost, 2.44**; Range, 1.68*; Emission, 2.03**; Alternative fuel station availability, 5.65***; Home plug-in construction fee, 2.58**. (*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.).

Table 6
Scenarios used in the simulation.

	Scenario 1 (Realistic case)				Scenario 2 (Purchase price reduction)				Scenario 3 (Purchase price reduction and further innovation)			
	EV	PHEV	Gas Car	Not Buy	EV	PHEV	Gas Car	Not Buy	EV	PHEV	Gas Car	Not Buy
Purchase price (US$)	28,000	28,000	18,000	–	23,000	23,000	18,000	–	23,000	23,000	18,000	–
Fuel cost (% off compared with conventional gasoline vehicles)	60	40	–	–	60	40	–	–	70	50	–	–
Driving range (miles)	100	700	400	–	100	700	400	–	200	800	400	–
Emission reduction (% reduction compared with conventional gasoline vehicles)	70	50	–	–	70	50	–	–	80	60	–	–
Alternative fuel station availability (% of existing gas stations)	10	10	–	–	10	10	–	–	20	20	–	–
Home plug-in construction fee (US$)	1,000	1,000	–	–	1,000	1,000	–	–	500	500	–	–

- Scenario 3 with more favorable attribute levels, which could be achieved by further innovations in advanced EV/PHEV technologies.

The purchase price reduction in Scenario 2 might be achieved by government subsidies as we will discuss further in Section 6. It should be noted that these are not forecasts of the exact future diffusion of EVs/PHEVs, which would depend on many other factors including the general state of the economy. Rather, we illustrate that by using the estimates obtained in Section 4, one can calculate the EV/PHEV market shares implied by many possible scenarios. As mentioned earlier, this is in line with other studies that use discrete choice analysis for forward-looking policy discussion.

The scenarios are summarized in Table 6. In Scenario 1, the purchase price premium of an EV/PHEV is $10,000. Compared to conventional gasoline vehicles, the fuel cost reduction and the emissions reductions are set at 60% and 70%, respectively, for an EV, and at 40% and 50%, respectively, for a PHEV. The driving ranges on a full battery are set at 100 and 700 miles for an EV and PHEV, respectively. In Scenario 2, purchase price premiums of an EV and PHEV are reduced significantly to $5000, while the other attribute levels remain the same as in Scenario 1. Moreover, we assume that in Scenario 3, the other attributes improve further in addition to the purchase price reduction of $5000 (see, Table 6).

The market share can be obtained by substituting the levels of the exogenous variables in the following equation:

$$\text{Market share}_i = \exp(V_i(\beta)) \Big/ \sum_{j=1}^{J} \exp(V_j(\beta)), \tag{4}$$

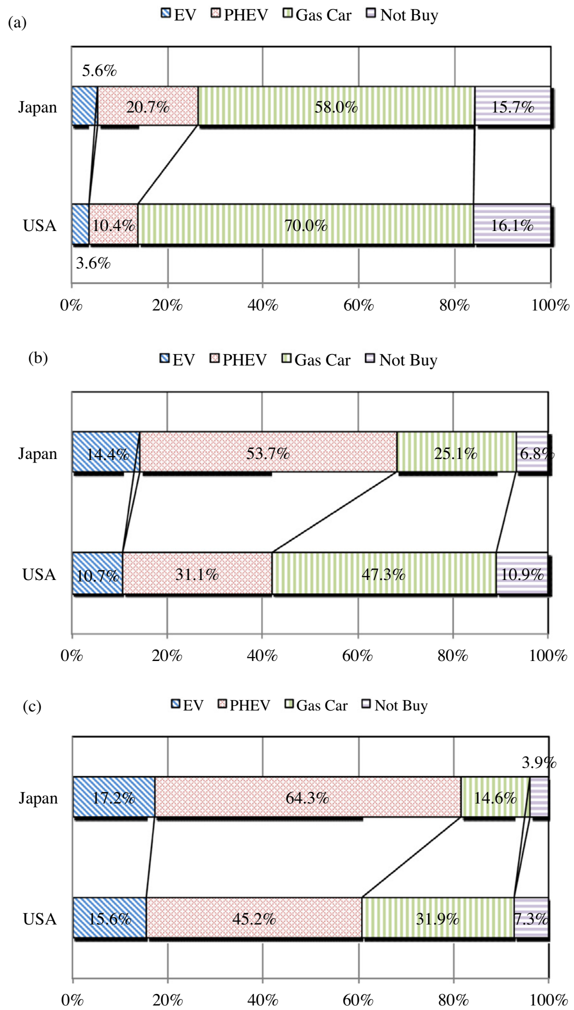

Fig. 4. Market shares in US and Japan. (a) Base case scenario 1 (realistic case), (b) Scenario 2 (Purchase price reduction) and (c) Scenario 3 (Further innovation with purchase price reduction).

which is the normal logit formula, as shown in earlier estimations. We calculate the percentage of those who would purchase an EV, PHEV, or conventional gasoline vehicle as the expected market share in each case. We here use the estimated coefficients for the alternative constants, and we emphasize the market share changes caused by simulating the alternative scenarios within each of our studied jurisdictions (rather than across them).[14]

Fig. 4(a)–(c) show the market shares obtained by applying the scenario attribute levels to our earlier estimated equation: the expected percentages of new car purchases for EVs, PHEVs and conventional gasoline vehicles at the specified attribute levels. In the base case Scenario 1, conventional gasoline vehicles still dominate at 70.0% and 58.0% in the US and Japan, respectively. More specifically, the very high purchase price premium of EVs/PHEVs prevents alternative vehicles from diffusing more broadly. However, we find that PHEVs do begin to penetrate the US and Japanese markets with shares of 10.4% and 20.7%, respectively. On the other hand, EVs appear not very popular in both countries with market shares of only 3.6% and 5.6% in the US and Japan, respectively.[15]

In Scenario 2, the purchase price premium of EVs/PHEVs is reduced significantly to $5000. As illustrated in Fig. 4(b), the EV/PHEV market shares reach 41.8% and 68.1% in the US and Japan, respectively. The PHEV share is 53.7% in Japan, while the share is 31.1% in the US. As in the base case Scenario 1, PHEVs would be more attractive to Japanese consumers. The EV shares are 10.7% and 14.4% in the US and Japan, respectively. In Scenario 3 with further innovations, the EV/PHEV shares

[14] Although the number of respondents is almost the same (4202 for US and 4000 for Japan) and they responded to the same eight questions, the values of McFadden Pseudo R2 are slightly different (0.3378 for US and 0.4223 for Japan).

[15] Note that "Not Buy" means the respondents will not buy any of those vehicles with the "specified attribute levels." This does not necessarily imply that they will not own any vehicle. For example, the respondents who indicated "Not Buy" might still purchase less expensive gasoline vehicles in the used-car market.

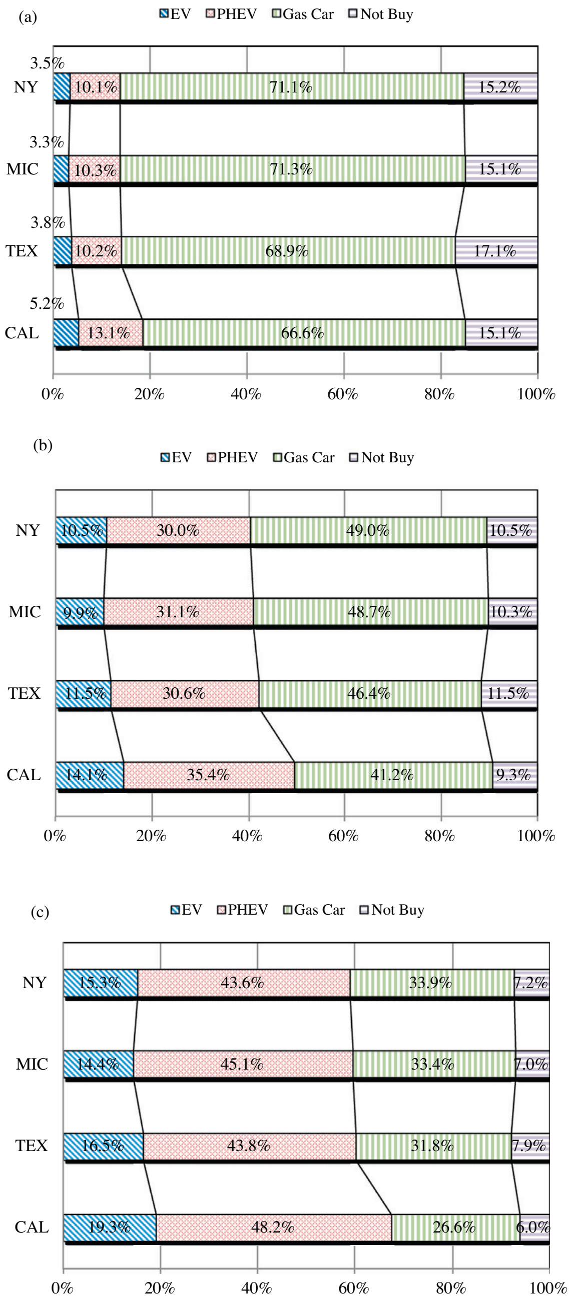

Fig. 5. Market shares across four US states. (a) Base case scenario 1 (realistic case), (b) Scenario 2 (Purchase price reduction) and (c) Scenario 3 (Further innovation with purchase price reduction).

reach 60.8% and 81.5% in the US and Japan, respectively, as shown in Fig. 4(c). In this scenario of technological advances with purchase price reduction, a high penetration of alternative fuel vehicles might be achieved in both countries.

Fig. 5(a)–(c) show the details of the four states in the US. Notably, California leads the way in deploying alternative fuel vehicles. Specifically, the EV share is the greatest in California for all scenarios because of the high WTP for fuel cost reductions.

6. Further policy discussion

We mentioned in our introduction that it is the explicit goal of the US and Japanese governments, as well as many other governments, to increase the number of greener, alternative fuel vehicles on the roads. Policies that may serve this purpose

can work from the supply side, as with new emission standards that manufacturers must meet, and from the demand side to influence the buying choices of consumers. The investigation of this article has been on the demand side, to understand better the concerns, considerations and likely tradeoffs among vehicle attributes of consumers. Thus our results apply most directly to the demand side policies that governments may be using or considering.

There are actually quite a broad range of demand-side policies that either are or could be in use. We have already mentioned rebates for the purchase of these vehicles, in effect in Japan through tax exemptions equal to about 5.7% of the purchase price and in the US for up to $7500 per vehicle and an additional $2500 in the state of California. In addition, there may be rebates or subsidies for the purchase or installation of home charging equipment. In the San Francisco area, the local Bay Area Air Quality Management District is offering a free charger and up to a $1200 installation credit for as many as 2750 residents. There are policies to make trip-making in these vehicles easier, notably to facilitate convenient access to rapid-charging stations in various locations like those along highways. California allows alternative vehicles unlimited free access to the High Occupancy Vehicle lanes of its highways. Acting through the electric utilities, governments may act to provide special low-cost electric vehicle charging rates. Government could also offer parking incentives for these vehicles.

A full discussion of these policies is of course beyond the scope of this article. However, we wish to highlight here the general potential of the methods used in this research to strengthen policy analysis. Economics is used in policy analysis at both the theoretical and empirical levels. Because actual policy choices are intended to affect the future, it is often the case that some policy alternatives have not yet been tried and there is therefore no direct empirical evidence on its effects from actual behavioral responses. As the survey-based methodology of conjoint analysis continues to improve, it does have the potential to provide useful empirical evidence in these forward-looking situations. Furthermore, when policies do go into effect, there is the opportunity to compare the results from the earlier conjoint analysis with the actual behavioral responses—thus providing important evidence that over time can be used to improve the methodology.

At the theoretical level for policy with respect to increasing the diffusion of alternative fuel vehicles, the arguments for policy interventions are generally strongest when they successfully address specific market failures.[16] The private sector can itself be expected to provide many of these services mentioned above as potential policy levers, such as convenient charging stations. Tesla, for example, has already set up 6 free charging stations along California freeways for its Model S vehicles, and plans to put up dozens more in California and eventually to cover most of the U.S.[17] As there may be a "chicken and egg" problem as to which comes first (the vehicles or the charging stations), it may be appropriate in some circumstances for policy to help initiate these services. The case for vehicle purchase incentives comes primarily from the behavioral economics literature. That literature suggests many consumers may suffer from "sticker shock" or the "energy paradox" (Jaffe and Stavins, 1994) where they perceive immediately the higher upfront cost of an EV or PHEV vehicle (or other energy-efficient durable goods like refrigerators), but have difficulty recognizing, knowing or understanding the expected present value of fuel savings over time—leading them to under invest in clean energy investments. The electricity rate policy is more complex. Few electricity rates are actually set close to their marginal costs, and there are very strong arguments that these rates should be time-differentiated which would encourage off-peak charging.[18] However, the social cost of electricity is the same regardless of the device that it runs, so it would be inefficient to have a special rate that applies to only one type of device.

It is worthwhile noting that a $5000 policy increase in vehicle purchase incentives would have the same effect as a $5000 purchase price reduction resulting from market forces (if the incentive is applied at the time of purchase). To get a sense of the effect of such a policy increase, consider the Scenario 1 finding that only 10.4% of households in the four-state US sample would purchase a PHEV. If the purchase incentive were increased by $5000 holding all other factors constant at the Scenario 1 level, our estimates imply this would cause PHEV purchases to rise to 31.1% of households. This estimate of a substantial effect can in the future be compared with other econometric estimates resulting from studies of actual purchase decisions.

7. Concluding remarks

This paper conducted a comparative discrete choice analysis to estimate consumers' willingness to pay for EVs and PHEVs based on the same online stated preference survey carried out in both the US and Japan in 2012. We also carried out a comparative analysis across the four US states that comprised the US sample. Our findings showed that the WTP values for fuel cost reduction ($49.8) and alternative fuel station availability ($49.8) in the US are almost one and a half times higher than those in Japan ($36.7 and $33.6, respectively). In contrast, the WTP values for the driving range on a full battery ($21.5) and emissions reduction ($29.0) in the US are almost the same as those in Japan ($21.5 and $26.2, respectively). These results imply that US consumers are, on average, more sensitive to fuel cost reductions and to alternative fuel station availability, while the US and Japanese consumers are equally sensitive to the driving range on a full battery and to emissions reduction. With regard to the comparative analysis across the four US states, we found that the WTP for a fuel cost reduction in California ($60.9) is 30–70% higher than those in the other three states ($36–47). Furthermore, we conducted a numerical simulation of EV/PHEV diffusion based on the estimates obtained in the discrete choice analysis. In the base case scenario with relatively realistic attribute levels, conventional gasoline vehicles still dominate both in the US and Japan. However, in an

[16] For a review of these as they affect energy-efficiency decisions, see Gillingham et al. (2009).

[17] See the Business Week report of the Tesla announcement posted by Ashlee Vance on September 24, 2012 at http://www.businessweek.com/articles/2012-09-25/tesla-fires-up-solar-powered-charging-stations.

[18] See for example Friedman (2011).

innovation scenario with a significant purchase price reduction, we observed a high penetration of alternative fuel vehicles in both countries. Our estimates imply that government purchase price subsidies can have a significant effect on the diffusion of these vehicles: we estimated that an increase of $5000 in such a subsidy would increase the market share of PHEVs from 10.4% in the US under Scenario 1 to 31.1%. As a final remark, we acknowledge that our results are all based on a data analysis of stated preferences, which should be compared with the results of a revealed preference data analysis in the future. The results of such an analysis remain an important source of improvements for the stated preference methodology.

Acknowledgement

We are grateful to Aleka Seville for her valuable support. We also wish to thank two anonymous referees for their helpful comments. The usual disclaimers apply.

Appendix A. Individual/household heterogeneity analysis

The analysis presented in this study can be developed to address individual and household heterogeneity. While our primary interest has been in cross-country and state comparisons, we present a simple model based on the idea that individual

Table A1
Estimation results of household heterogeneity.

	US respondents			Japanese respondents		
	Coeff.	Std. Err.	WTP (US$)	Coeff.	Std. Err.	WTP (US$)
ASC for EV	12.14100	0.37340***	–	12.86400	0.47391***	–
ASC for PHEV	12.26740	0.34099***	–	13.98590	0.41320***	–
ASC for gasoline vehicles	5.97089	0.32135***	–	12.02930	0.46019***	–
Purchase Price (US$)	−0.00030	0.00000***	–	−0.00036	0.00000***	–
Fuel cost (% off compared with gasoline vehicles)	0.01511	0.00099***	50.52	0.01274	0.00113***	35.58
Range (miles)	0.00064	0.00008***	2.14	0.00077	0.00009***	2.15
Emission reduction (% reduction compared with gasoline vehicles)	0.00865	0.00092***	28.92	0.00922	0.00101***	25.75
Alternative fuel station availability (% of existing gas stations)	0.01493	0.00050***	49.92	0.01203	0.00059***	33.60
Home plug-in construction fee (US$100)	−0.06410	0.00200***	−214.34	−0.06084	0.00234***	−169.93
Household income for EV (US$100)	−0.02080	0.01410	−69.55	0.11400	0.01760***	318.42
Household income for PHEV (US$100)	0.01510	0.01200	50.49	0.14060	0.01490***	392.72
Household income for gasoline vehicles (US$100)	0.05770	0.01410***	192.94	0.06230	0.01820***	174.01
Age for EV	−0.03793	0.00340***	−126.83	−0.00031	0.00573	−0.87
Age for PHEV	−0.02444	0.00299***	−81.72	−0.01067	0.00487**	−29.80
Age for gasoline vehicles	0.00041	0.00343	1.37	−0.06181	0.00620***	−172.64
University graduate dummy for EV	0.09497	0.05368*	317.56	0.03403	0.13630	95.05
University graduate dummy for PHEV	0.08101	0.04551*	270.88	−0.12736	0.11721	−355.73
University graduate dummy for gasoline vehicles	0.22630	0.05716***	756.70	0.14002	0.13054	391.10
Female dummy for EV	−0.32339	0.11140***	−1081.35	−0.08230	0.13912	−229.88
Female dummy for PHEV	−0.42967	0.09726***	−1436.74	−0.37840	0.11932***	−1056.92
Female dummy for gasoline vehicles	−0.35872	0.11122***	−1199.49	−0.98171	0.13897***	−2742.05
Married/coupled dummy for EV	0.24945	0.11931**	834.11	0.30406	0.14740**	849.28
Married/coupled dummy for PHEV	0.30043	0.10310***	1004.58	0.58939	0.12702***	1646.25
Married/coupled dummy for gasoline vehicles	0.36028	0.11686***	1204.71	1.78572	0.15389***	4987.77
Intent to purchase a car for EV (3levels)	−0.27140	0.09378***	−907.51	0.10163	0.10066	283.87
Intent to purchase a car for PHEV (3levels)	−0.39825	0.08061***	−1331.67	0.11711	0.08338	327.10
Intent to purchase a car for gasoline vehicles (3levels)	−0.69210	0.08915***	−2314.25	−0.84585	0.10242***	−2362.58
Price range for EV (US$10,000)	0.03277	0.07726	109.58	0.34399	0.09989***	960.81
Price range for PHEV (US$10,000)	0.02164	0.06727	72.36	0.57241	0.08171***	1598.82
Price range for gasoline vehicles (US$10,000)	−0.14328	0.07217**	−479.10	0.34846	0.10198***	973.30
Interest in alternative fuel vehicles for EV (5 levels)	1.71414	0.04677***	5731.76	2.42588	0.07028***	6775.82
Interest in alternative fuel vehicles for PHEV (5 levels)	1.49525	0.04368***	4999.83	2.25352	0.06311***	6294.40
Interest in alternative fuel vehicles for gasoline vehicles (5 levels)	−0.53662	0.04361***	−1794.36	0.49321	0.05428***	1377.60
<Standard deviation of error component>						
EV	1.57270	0.0356***	–	2.28244	0.0458***	–
PHEV	0.11220	0.0629*	–	0.08101	0.0591	–
Gasoline vehicles	3.51505	0.0732***	–	4.42156	0.0990***	–
Not buy	−2.80823	0.0562***	–	4.37028	0.0848***	–
Number of obs.	32,000			32,000		
McFadden Pseudo R-squared	0.3917			0.4396		
Log likelihood function	−28348.62			−24859.26		

Note: ASC denotes *alternative specific constant*. The percentage variables (fuel cost, emission reduction, fuel station availability) are on a scale of 0–100. The percentage variables (fuel cost, emission reduction, fuel station availability) are on a scale of 0-100. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

decisions can also be understood as a function of demographic characteristics and consumer consciousness. The following variables are included in the model:

- Household income (unit: $100 increase)
- Age
- University graduate dummy
- Female dummy
- Married/cohabiting dummy
- Intent to purchase a car within the next five years (1 = buy, 2 = lease, 3 = not to buy)
- Price range for purchasing a next vehicle (unit: $10,000 increase)
- Interest in alternative fuel vehicles (1 = not interested ... 5 = very interested)

The estimation results are presented in Table A1.[19] The WTP values are measured for each alternative based on the baseline (not buy) alternatives. Some observations can be summarized as follows:

- Household income considerably influences the WTP values for the purchase of EVs, PHEVs, and gasoline vehicles in Japan. For example, a household with $100 higher income indicates that they would pay more to purchase an EV or PHEV ($318 and $393 for Japan, respectively). Unexpectedly, however, the EV and PHEV premiums are not necessarily high because the WTP values are also high for purchasing gasoline vehicles ($193 for the US and $174 for Japan). This simply means that a rich family can afford to buy a more expensive vehicle.
- Age has a negative effect on the WTP values for purchasing an EV, PHEV, and gasoline vehicle. However, it is interesting to note that the impact is asymmetric between the US and Japan: the values for EV are −$127 for the US and −$1 for Japan, while the values for gasoline vehicles are $1 for the US and −$173 for Japan.
- University graduates have a higher WTP for the purchase of EVs, PHEVs, and gasoline vehicles in the US ($318, $271, and $757, respectively). On the other hand, such graduates have no statistically significant preferences in Japan ($95, −$356, and $391, respectively).
- Females have negative WTP values for the purchase of EVs, PHEVs, and gasoline vehicles in the US (−$1081, −$1437, and −$1199, respectively). This implies that females are generally negative about purchasing vehicles but are much less negative about EVs and PHEVs. The same tendencies are observed in Japan (−$230, −$1057, and −$2742, respectively).
- Married/cohabiting couples have positive WTP values for the purchase of EVs, PHEVs, and gasoline vehicles in the US ($834, $1005, and $1205, respectively). This implies that married/cohabiting couples are generally positive about the purchase of PHEVs and gasoline vehicles but are much less positive about EVs. The same tendencies are obvious in Japan ($849, $1646, and $4988, respectively).
- Households that intend to purchase a car within the next five years have large WTP values for the purchase of a gasoline vehicle in the US ($2314), but relatively smaller values for an EV and PHEV ($908 and $1332, respectively). Again, the same tendencies are obvious in Japan (−$284, −$327, and $2363, respectively).
- Households considering purchasing an expensive vehicle have positive but not statistically significant WTP values for an EV and PHEV ($110 and $72, respectively) and a significantly negative WTP value for gasoline vehicles in the US (−$479). It is remarkable that households considering purchasing an expensive vehicle have a large WTP value for EVs, PHEVs and gasoline vehicles in Japan ($961, $1599, and $973, respectively).
- Finally, households that are interested in an alternative fuel vehicle have very large WTP values for the purchase of an EV and PHEV ($5732 and $5000, respectively) but a negative WTP value for gasoline vehicles in the US (−$1794). Similar tendencies are observed in Japan ($6776, $6294, and $1378, respectively).

References

Achtnicht, M., Buhler, G., Hermeling, C., 2012. The impact of fuel availability on demand for alternative-fuel vehicles. Transp. Res. Part D 17, 262–269.

Ahn, J., Jeong, G., Kim, Y., 2008. A forecast of household ownership and use of alternative fuel vehicles: a multiple discrete-continuous choice approach. Energy Econ. 30, 2091–2104.

Axsen, J., Mountain, D.C., Jaccard, M., 2009. Combining stated and revealed choice research to simulate the neighbor effect: the case of hybrid-electric vehicles. Resour. Energy Econ. 31, 221–238.

Beggs, S., Cardell, S., Hausman, J., 1981. Assessing the potential demand for electric cars. J. Economet. 16, 1–19.

Ben-Akiva, M., Bolduc D., Walker J., 2001. Specification, estimation and identification of the logit kernel (or continuous mixed logit) model. Department of Civil Engineering, MIT, Working Paper.

Bhat, C., 2001. Quasi-random maximum simulated likelihood estimation of the mixed multinomial logit model. Transp. Res. Part B 35, 677–693.

Brownstone, D., Train, K.E., 1999. Forecasting new product penetration with flexible substitution patterns. J. Economet. 89, 109–129.

Brownstone, D., Bunch, D.S., Train, K.E., 2000. Joint mixed logit models of stated and revealed preferences for alternative-fuel vehicles. Transp. Res. Part B 34, 315–338.

Bunch, D.S., Bradley, M., Golob, T.F., Kitamura, R., Occhiuzzo, G.P., 1993. Demand for clean-fuel vehicles in California: a discrete-choice stated preference pilot project. Transp. Res. Part A 27 (3), 237–253.

Calfee, J.E., 1985. Estimating the demand for electric automobiles using disaggregated probabilistic choice analysis. Transp. Res. Part B 19 (4), 287–301.

[19] See, for example, Daziano and Chiew (2012) for a detailed review of past studies.

Center for Sustainable Energy, 2013. 2012 Annual Report.
Dagsvik, J.K., Wetterwald, D.G., Wennemo, T., Aaberge, R., 2002. Potential demand for alternative fuel vehicles. Transp. Res. Part B 36, 361–384.
Daziano, R.A., Bolduc, D., 2013. Incorporating pro-environmental preferences toward green automobile technologies through a Bayesian Hybrid Choice Model. Transport. A: Transp. Sci. 9 (1), 74–106.
Daziano, R.A., Chiew, E., 2012. Electric vehicles rising from the dead: data needs for forecasting consumer response toward sustainable energy sources in personal transportation. Energy Policy 51, 876–894.
Ewing, G.O., Sarigöllü, E., 1998. Car fuel-type choice under travel demand management and economic incentives. Transp. Res. Part D 3 (6), 429–444.
Ewing, G., Sarigöllü, E., 2000. Assessing consumer preferences for clean-fuel vehicles: a discrete choice experiment. J. Public Policy Mark. 19 (1), 106–118.
Friedman, L.S., 2011. The Importance of marginal cost electricity pricing to the success of greenhouse gas reduction programs. Energy Policy 39 (11), 7347–7360.
Gillingham, G., Newell, R.G., Palmer, K., 2009. Energy efficiency economics and policy. Ann. Rev. Resour. Econ. Ann. Rev. 1 (1), 597–620.
Graham-Rowe, E., Gardner, B., Abraham, C., Skippon, S., Dittmar, H., Hutchins, R., Stannard, J., 2012. Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: a qualitative analysis of responses and evaluations. Transp. Res. Part A 46 (1), 140–153.
Hackbarth, A., Madlener, R., 2013. Consumer preferences for alternative fuel vehicles: a discrete choice analysis. Transp. Res. Part D 25, 5–17.
Halton, J.E., 1960. On the efficiency of certain quasi-random sequences of points in evaluating multi-dimensional integrals. Numer. Math. 2, 84–90.
Hidrue, M.K., Parsons, G.R., Kempton, W., Gardner, M.P., 2011. Willingness to pay for electric vehicles and their attributes. Resour. Energy Econ. 33, 686–705.
Hess, S., Fowler, M., Adler, T., Bahreinian, A., 2012. A joint model for vehicle type and fuel type choice: evidence from a cross-nested logit study. Transportation 39 (3), 593–625.
Horne, M., Jaccard, M., Tiedemann, K., 2005. Improving behavioral realism in hybrid energy–economy models using discrete choice studies of personal transportation decisions. Energy Econ. 27, 59–77.
Ito, N., Takeuchi, K., Managi, S., 2013. Willingness to pay for the infrastructure investments for alternative fuel vehicles. Transp. Res. Part D 18, 1–8.
Jaffe, A., Stavins, R., 1994. The energy paradox and the diffusion of conservation technology. Resour. Energy Econ. 16, 91–122.
Japan Automobile Manufacturers Association Inc., 2012. The motor industry of Japan 2012.
Karplus, V.J., Paltsev, S., Reilly, J.M., 2010. Prospects for plug-in hybrid electric vehicles in the United States and Japan: a general equilibrium analysis. Transp. Res. Part A 44, 620–641.
Krupa, J.S., Rizzo, D.M., Eppstein, M.J., Brad Lanute, D., Gaalema, D.E., Lakkaraju, K., Warrender, C.E., 2014. Analysis of a consumer survey on plug-in hybrid electric vehicles. Transp. Res. Part A 64, 14–31.
Louviere, J.J., Hensher, D.A., Swait, J.D., 2000. Stated Choice Methods: Analysis and Applications. Cambridge University Press.
McFadden, D., Train, K.E., 2000. Mixed MNL models of discrete choice models of discrete response. J. Appl. Economet. 15, 447–470.
Mau, P., Eyzaguirre, J., Jaccard, M., Collins-Dodd, C., Tiedemann, K., 2008. The 'neighbor effect': simulating dynamics in consumer preferences for new vehicle technologies. Ecol. Econ. 68, 504–516.
Musti, S., Kockelman, K.M., 2011. Evolution of the household vehicle fleet: anticipating fleet composition, PHEV adoption and GHG emissions in Austin, Texas. Transp. Res. Part A 45 (8), 707–720.
Potoglou, D., Kanaroglou, P.S., 2007. Household demand and willingness to pay for clean vehicles. Transp. Res. Part D 12, 264–274.
Qian, L., Soopramanien, D., 2011. Heterogeneous consumer preferences for alternative fuel cars in China. Transp. Res. Part D 16, 607–613.
Revelt, D., Train, K.E., 1998. Mixed logit with repeated choices: households' choices of appliance efficiency level. Rev. Econ. Stat. 80, 647–657.
Segal, R., 1995. Forecasting the market for electric vehicles in California using conjoint analysis. Energy J. 16 (3), 89–111.
Train, K.E., 2003. Discrete Choice Methods with Simulation. Cambridge University Press.
Ziegler, A., 2012. Individual characteristics and stated preferences for alternative energy sources and propulsion technologies in vehicles: a discrete choice analysis for Germany. Transp. Res. Part A 46, 1372–1385.