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

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Abstract

This paper conducts conjoint analysis using a mixed logit model to estimate consumers' willingness to pay (WTP) for electric vehicles (EV) and plug-in hybrid electric vehicles (PHEV) on the basis of an online 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 the US consumers are more sensitive about fuel cost reduction and fuel station availability, whereas Japanese consumers are more sensitive about driving range and emissions reduction. As for the comparative analysis across the four US states, we find that WTP for fuel cost reduction varies significantly, and is the greatest in California. We use the estimates obtained in the conjoint analysis to consider EV/PHEV diffusion rates 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 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 conjoint 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 diffusion rates of alternative fuel vehicles.

Keywords: willingness to pay; conjoint analysis; discrete choice model; electric vehicles (EV); plug-in hybrid electric vehicles (PHEV)
JEL Classifications: D12, O33, Q42, R40

1. Introduction

President Barach 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 percent of new car sales be such vehicles by 2020, although sales at this time remain quite modest: for fiscal 2010, 4816 electric vehicles or just over 1 percent were provided to the domestic market.[3] Clearly 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 like hydrogen or natural-gas powered vehicles could become more significant in the future.[4] 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 percent 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

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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 2010 there were 4,212,267 new passenger vehicle registrations, and 3,524,788 in 2011.

[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 public charging station.

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

a policy change like this likely to have? The analysis presented in this article 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, 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.

Particularly, we use conjoint analysis and a discrete choice model to estimate consumers' willingness to pay for EV and PHEV. Moreover, based on the estimates we calculate the future diffusion of these alternative fuel vehicles under several states of the world or scenarios. As the full-scale deployment of alternative fuel vehicles has not yet been realized, empirical revealed preference data have not been sufficiently accumulated. Therefore, we adopt a stated preference (SP) data 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.

Several studies have conducted conjoint analysis of clean-fuel vehicles. Bunch (1993) conducted a conjoint analysis to determine how demand for clean-fuel vehicles and their fuels varied as a function of the attributes that distinguished these vehicles from conventional gasoline vehicles; clean-fuel vehicles encompassed both electric and unspecified liquid and gaseous fuel vehicles. Recently, Karplus (2010) found that vehicle cost could be a significant barrier to PHEV entry unless fairly aggressive goals for reducing battery costs were met. If a low-cost PHEV was available, its adoption had the potential to reduce greenhouse gas emissions and refined oil demand. Other past studies that studied clean-fuel or electric vehicles are summarized in Table 1 (cf. Hidrue et al. 2011). However, to the best of our knowledge, no comparative analysis between the US and Japan has been conducted.

<Table 1>

In this paper, the online survey was administered in February 2012 to 4202 and 4000 consumers in the US and Japan, respectively. Specifically, we focused on California (West), Texas (South), Michigan (Midwest), and New York (Northeast) as representative states for four regions in the US, and drew about 1000 samples from each state. We first estimate the SP data by using a mixed logit model allowing for individual heterogeneity, then investigate willingness to pay (WTP) for attributes of EV and PHEV.

This paper contributes to the existing literature in three ways. First, we conduct a comparative conjoint analysis on alternative fuel vehicles between the US and Japan using a large sample. Second, we also carry out a comparative conjoint analysis across the four US states, to see if there are important regional differences within the US. Third, our analysis is comprehensive and policy-relevant in the sense that we account for EV, PHEV, and conventional gasoline vehicles, to represent consumer choice from a variety of technologies and to simulate how these choices may be affected by public policies. The SP approach may be particularly useful for forward-looking policy analysis, and actual future revealed choices can be compared with SP estimates as a means to improve the methodology over time.

We summarize the main conclusions. Regarding the comparison between the US and Japan, we find that US consumers are more sensitive about fuel cost reduction and fuel station availability, whereas Japanese consumers are more sensitive about driving range on a full battery and emissions reduction. As for comparative analysis across the four US states, we find that WTP for fuel cost reduction significantly varies among these states. WTP for fuel cost reduction is the greatest in California, while the WTP values of the other three states are not significantly different from zero. We then conduct a numerical evaluation of EV/PHEV diffusion rates based on the estimates obtained in conjoint 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 significant purchase price reduction, we observe a high penetration of alternative fuel vehicles both in the US and Japan.

This paper is organized as follows. Section 2 explains the online survey method of conjoint analysis and the experimental design. Section 3 describes the mixed logit model used for estimation. Section 4 displays 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 conjoint analysis as a tool for forward-looking policy analysis, and Section 7 concludes.

2. Survey and design

This section explains the survey method of conjoint analysis 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 the sample size just over 1000 from each state. These states were chosen not only because they represent different regions, but they each have different electricity systems overseen by state regulators and differing clean vehicle policies.[6] While we present findings separately for each state, we also think it is of some interest to average responses across the four-state US sample to compare with the Japanese responses. It should be understood that this four-state average is not intended to be statistically representative of the full US.[7] For Japan which is under one regulatory system, we drew

[6] 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 percent 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.

[7] These four states contain approximately 30 percent of the US population. To the extent that higher electricity prices discourage interest in alternative fuel vehicles, our sample may

4000 consumers covering all prefectures to represent an average Japanese population.[8] 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.

Next, we explain conjoint analysis. Conjoint analysis considers the attributes of a service or product. 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 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). We thus obtained an appropriate number of questions for which the levels of the attributes varied stochastically and asked the respondents these questions.

There are pros and cons for the consumer considering an EV or PHEV. Driving an EV or PHEV can significantly reduce the expenses for gasoline or other fuels, and pollution is much lower compared with conventional gasoline vehicles. On the other hand, the purchase prices of these vehicles are relatively high 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 it would take time to find a charging station. Given these facts, we focus on the following six key attributes in this study: (1) purchase price premium, (2) fuel cost reduction (percentage) compared with gasoline vehicles, (3) driving range on full battery, (4) emissions reduction (percentage) compared with gasoline vehicles, (5) fuel station availability (expressed as a percentage of existing gas stations), and (6)

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understate slightly interest of the whole US population in these. 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 the whole US (858 kWh). These figures are from the US Energy Information Administration 2010 report on electricity sales and revenue. To the extent that higher electricity prices discourage interest in alternative fuel vehicles, our sample may understate interest of the whole US population in them.

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

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 preference for fuel efficiency.

After conducting several pretests, we determined the attribute levels of the EV/PHEV conjoint analysis as summarized in Table 2. Note that we here classify a hybrid electric vehicle (HEV), which does not have a plug-in function, as a conventional gasoline vehicle since its primary propulsion comes from an internal combustion engine.[9]

< Table 2>

Figure 1 displays an example of one of the questions used on the EV/PHEV conjoint questionnaire. There are three alternatives, where Alternative 1 denotes EV, Alternative 2 denotes PHEV, and Alternative 3 is gasoline vehicle purchases. There are sixteen questions in total that look like Figure 1 except that they vary the attributes, and they are divided into two versions of eight questions each. All respondents are asked one of the two versions at random.

<Figure 1>

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, independence from the irrelevant alternatives (IIA) property derived from the IID assumption of the CL model is too strict to allow flexible

[9] A HEV combines an internal combustion engine and relatively small electric motors with batteries that cannot be recharged via an external electric power source. A HEV has a longer driving range than a gasoline vehicle without any batteries. In this respect, we consider the HEV as an efficient, though slightly expensive, gasoline vehicle.

substitution patterns. A nested logit (NL) model partitions the choice set and allows alternatives to have common unobserved components compared with non-nested alternatives by partially relaxing the strong IID assumptions. 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 et al., 2001). Consequently, the best model for this study is a mixed logit (ML) model, which accommodates differences in the variance of random components (unobserved heterogeneity). This model is flexible enough to overcome 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).

Assuming that parameter β_n is distributed with density function $f(\beta_n)$ (Train 2003, Louviere et al., 2000), the ML 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

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

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 ML 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

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

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[10]. Furthermore, since each respondent completes eight questions in the

[10] Louviere et al. (2000, p. 201) suggest that 100 replications are normally sufficient for a typical problem involving five alternatives, 1,000 observations, and up to 10 attributes (also

conjoint analysis, the data form a panel, and we can apply a standard random effect estimation.

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

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

where x_{nit} and z_{nit} denote observable variables, γ 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.

Because ML choice probability is not expressed in closed form, simulations must be performed for the ML model estimation. Let $f(\beta_n)$ denote a density function. ML choice probability is approximated through the simulation method (see Train, 2003 p. 148 for details). We can also calculate the estimator of the conditional mean of random parameters conditional on individual specific choice profile y_n (see Revelt and Train, 1998 for details), given as

$$h(\beta_n \mid y_n) = [P(y_n \mid \beta_n) f(\beta_n)] / \int P(y_n \mid \beta_n) f(\beta_n) d\beta_n . \quad (4)$$

From Eq. (4) $h(\beta_n \mid y_n)$, the conditional choice probabilities $\hat{P}_{nit}(\beta_n)$ can be calculated individually:

$$\hat{P}_{nit}(\beta_n) = \exp(V_{nit}(h(\beta_n \mid y_n)) / \sum_{j=1}^{J} \exp(V_{njt}(h(\beta_n \mid y_n))) . \quad (5)$$

4. Data description and estimation results

After briefly describing the data used in this study, we show the estimation results of EV and PHEV in this section. First, Table 3 summarizes the basic demographic

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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 1,000 random draws for simulating an ML model.

characteristics of the respondents in the four-state US and Japan samples.[11] Table 4 shows the preferences for EV/PHEV utilization. 57% and 41% of the respondents in the US and Japan samples, respectively, indicate intention to purchase a car within next five years. Moreover, 60% and 53% of the respondents in the US and Japan, respectively, show interest in alternative fuel vehicles.

<Table 3>

<Table 4>

We now discuss the estimation results of EV and PHEV for both the US and Japan, and for the four US states separately. Table 5 shows the estimation results for the combined four-state US sample and for Japan. The McFadden R^2 values are 0.3302 for the former and 0.3850 for the latter, both of which are sufficiently high for a discrete choice model. We assume that, except for purchase price, which is set as a numeraire, the parameters are distributed normally, and the mean and standard deviation values are reported. We allow different constant terms for the no choice option across the four states respectively for the US data. (Note that *** denotes 1% significance; **, 5% significance; and *, 10% significance.)

<Table 5>

All the estimates (mean) are statistically significant at the 1% level, except for fuel costs for the Japanese respondents, which is statistically significant at the 10% level. For both the US and Japan, the signs of the estimates are positive for reduction in fuel costs, driving range, emissions reduction, and fuel station availability, and negative for purchase price and home plug-in construction fee, which all have natural interpretation. The statistically significant estimates (standard deviation) include all parameters for both

[11] 81% and 72% of the respondents replied that they are the primary handlers of household bills in the US and Japan, respectively. A bit asymmetric gender distribution between US and Japan in this survey might be attributed to some extent to who primarily handles household bills.

countries and the differential constant terms for the US states.

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 Figure 2. It is worth noting the difference in WTP between the US and Japan. WTP for fuel cost reduction ($14.2) and fuel station availability ($27.5) in the US almost doubles those ($7.5 and $13.3, respectively) in Japan. In contrast, WTP for driving range on full battery ($11.7) in Japan almost doubles that ($5.8) in the US. Moreover, WTP for emissions reduction ($86.4) in Japan is $23.7 greater than that ($62.7) in the US. These results show that the US consumers are, on average, more sensitive about fuel cost reduction and fuel station availability, whereas Japanese consumers are more sensitive about driving range on full battery and emissions reduction.

<Figure 2>

A rough illustrative calculation provides an interesting plausibility check on the fuel cost parameter. The WTP parameter is for a 1 percent reduction in annual fuel costs, and of course individuals vary in their annual fuel expenses. In the US as a whole, the number of vehicles per adult is .787, and the average vehicle is driven about 12,000 miles per year and gets 20 mpg. Thus the average gallons per adult per year is about 472, and at the average price of $3.7 per gallon (February 27, 2012), that implies average fuel costs of $1748 per year or $17.48 as 1 percent. While an individual's WTP for a quantity can of course be higher than that quantity's market cost, it would be surprising if the average WTP of individuals for this marginal amount was very different than the market cost. Thus our estimated $14.2 average WTP for fuel cost reduction in the four-state sample seems reasonably consistent with this.

A similar illustrative calculation of the fuel cost parameter for Japan further confirms the plausibility of our estimates. In Japan as a whole, the number of vehicles per adult is .552, and the average vehicle is driven about 5,000 miles per year and gets 23 mpg. Thus the average gallons per adult per year is about 120, and at the average price of $6.9 per gallon (February 27, 2012). This implies average fuel costs of $825 per year or $8.25 as

1 percent. Thus our estimated $7.5 average WTP in Japan seems reasonably consistent with this.

Next, Table 6 shows the estimation results across the four US states.[12] All the estimates (mean) are statistically significant at 1% level, except for fuel costs for the Texas, Michigan, and New York respondents, which are not statistically different from zero. For all four states, the signs of the estimates are positive for reduction in fuel costs, driving range, emissions reduction, and fuel station availability, and negative for purchase price and home plug-in construction fee, except for the insignificant Michigan estimate for reduction in fuel costs. The statistically significant estimates (standard deviation) include all parameters for four states.

<Table 6>

Figure 3 summarizes the WTP values across the four US states. It is notable that WTP for fuel cost reduction in California ($39.4) is significantly greater than the other states: the WTP values of the other three states are not significantly different from zero. The difference in WTP for fuel cost reduction may be partially because gasoline prices differ among these states. Specifically, California adopts the strictest emission control regulations in US, and it uses 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 of all states was $3.7 per gallon. Other conditions like average annual driving mileage may also vary significantly across these states, and further explain the WTP variation.

Regarding attributes other than fuel cost reduction, WTP is very similar across the four US states. It is interesting that WTP for emissions reduction in California is very

[12] When comparing the combined four-state US sample with the Japanese sample, we take account of the possible heterogeneity of the US states by assuming different constant terms across the four states. This treatment facilitates the two-country comparison. In addition and in order to further explore a comparative analysis across the four US states, we conduct the estimation separately for each state, thereby effectively taking account of the possible heterogeneity of not only constant terms but also coefficients.

similar to the other states, despite the fact that consumers in California are reputed to have higher awareness for environmental protection than those in other states.

<Figure 3>

5. Implications for future diffusion

This section discusses the numerical implications for EV/PHEV diffusion based on the estimates obtained in Section 4. We consider three different states of the world or scenarios:

- A base case Scenario 1 with relatively realistic attribute levels, which are within the attainable ranges with the current technologies
- Scenario 2 with purchase price reduction for an EV/PHEV, while other attribute levels are the same as in Scenario 1
- Scenario 3 with more favorable attribute levels, which could be achieved by further innovations in advanced EV/PHEV technologies.

Purchase price reduction in Scenario 2 might be achieved by government subsidies as we will discuss further in Section 6. These are not forecasts of the exact future diffusion of EV/PHEV, which would depend on many other factors like the general state of the economy. Rather, we illustrate that by using the estimates obtained in Section 4, one can calculate the EV/PHEV diffusion rates implied by many possible scenarios.

The scenarios used are summarized in Table 7. The base case Scenario 1 considers relatively realistic attribute levels, which are within the achievable ranges with the existing technologies. In this scenario, the purchase price premium of an EV/PHEV is $10000. 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. Driving ranges on full battery are set at 100 and 700 miles for an EV and a PHEV, respectively. In Scenario 2, purchase price premiums of an EV and a PHEV are assumed to be significantly reduced to $5000, while other attribute levels remain the same as in Scenario 1. Moreover, we assume that in Scenario 3, other attributes are also further improved in addition to purchase price reduction of $5000, as shown in Table 7.

<Table 7>

Figures 4 to 6 show the diffusion rates obtained by applying the scenario attribute levels to our earlier estimated equation: the percent of new car purchases that are expected to be EV, PHEV and conventional gasoline at the specified attribute levels. In the base case Scenario 1, conventional gasoline vehicles still dominate, i.e., 70.6% and 69.7% in the US and Japan, respectively.[13] Specifically, the very high purchase price premium of EV/PHEV prevents alternative vehicles from diffusing more broadly. However, we find that PHEVs do begin to penetrate into the Japanese market with a diffusion rate of 20.1%. In contrast, the PHEV diffusion rate is still only 5.9% in the US. As discussed in Section 4, Japanese consumers have higher WTP for driving range on full battery than US consumers. The driving range of 700 miles would make PHEVs more attractive to Japanese consumers than to US consumers. EVs appear not very popular in both countries with diffusion rates of only 3.5% and 5.7% in the US and Japan, respectively.

<Figure 4>

In Scenario 2, the purchase price premium of EV/PHEV is significantly reduced to $5000. As illustrated in Figure 5, the EV/PHEV diffusion rates reach 27.7% and 54.2% in the US and Japan, respectively. The PHEV diffusion rate is 42.2% in Japan, while the rate is 17.3% in the US. As in the base case Scenario 1, PHEVs would be more attractive to Japanese consumers. In contrast, the EV diffusion rate is 10.4% in the US, which is close to the rate of 12.0% in Japan. As discussed in Section 4, US consumers have higher WTP for

[13] 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 those respondents will not own any vehicle. For example, the respondents who indicated "Not Buy" might still purchase less expensive gasoline vehicles in used-car markets, particularly in the US that has a large share of those markets.

fuel cost reduction than Japanese consumers. Thus EVs with less fuel costs could be attractive to US consumers in relative terms. In Scenario 3 with further innovations, the EV/PHEV diffusion rates reach 44.8% and 81.0% in the US and Japan, respectively, as shown in Figure 6. In this scenario of technological advances with purchase price reduction, a high penetration of alternative fuel vehicles might be achieved in both countries.

<Figure 5>

<Figure 6>

Figures 7 to 9 show the details of the four states in the US. Notably, California is the top runner in deploying alternative fuel vehicles. Specifically, the EV diffusion rate is the greatest in California for both scenarios because of high WTP for fuel cost reduction.

<Figure 7>

<Figure 8>

<Figure 9>

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 percent 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.[14] 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

[14] For a review of these as they affect energy-efficiency decisions, see Gillingham, Newell and Palmer (2009).

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.[15] 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" 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 underinvest 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 offpeak charging.[16] 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 5.9 % 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 17.3 % 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 conjoint analysis using a mixed logit model to estimate

[15] 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.

[16] See for example Friedman (2011).

consumers' willingness to pay for EV and PHEV on the basis of an online survey carried out in both the US and Japan in 2012. We also carried out comparative analysis across the four US states that comprised the US sample. We obtained the following findings regarding comparison between the US and Japan. WTP for fuel cost reduction and fuel station availability in the US almost doubles those in Japan. In contrast, WTP for driving range on full battery in Japan almost doubles that in the US. Moreover, WTP for emissions reduction in Japan is greater than that in the US. These results show that US consumers are, on average, more sensitive about fuel cost reduction and fuel station availability, whereas Japanese consumers are more sensitive about driving range on full battery and emissions reduction. As for comparative analysis across the four US states, we found that WTP for fuel cost reduction in California is significantly greater than the other states: the WTP values of the other three states are not significantly different from zero. Furthermore, we conducted numerical simulation of EV/PHEV diffusion based on the estimates obtained in the conjoint 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 innovation scenario with significant purchase price reduction, we observe a high penetration of alternative fuel vehicles both in the US and Japan. Our estimates imply that government purchase price subsidies can have a significant effect on diffusion of these vehicles: we estimated that an increase of $5000 in such a subsidy would increase the diffusion rate of PHEVs from 5.9 percent in the US under Scenario 1 to 17.3 percent. As a final remark, we acknowledge that all of these results are based on a data analysis of stated preference, which should be compared with results using a revealed preference data analysis in the future. The results of such an analysis remain an important source for improving stated preference methodology in the future.

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Table 1: Summary of past clean fuel or electric vehicle conjoint studies (cf. Hidrue et al. 2011)

Study	Econometric model	Number of choice sets, attributes, and levels	List of attributes used
Beggs et al. (1981)	Ranked logit	16, 8, NA	price, fuel cost, range, top speed, number of seats, warranty, acceleration, air consitioning
Calfee (1985)	Disaggregate MNL	30, 5, NA	price, opeating cost, range, top speed, number of seats
Bunch et al. (1993)	MNL and Nested logit	5, 7, 4	price, fuel cost, range, acceleration, fuel availability, emission reduction, dedicated versus multi-fuel
Segal (1995)	First choice model	NA, 7, 2-3	price, fuel cost, range, fuel type, refueling duration, refueling location, refueling time of day
Brownstone and Train (1999); Brownstone et al. (2000)	MNL and Mixed logit; Joint SP/RP Mixed logit	2, 13, 4	(*) price, range, home refueling time, home refueling cost, service station refueling cost, fuel availability, acceleration, top speed, emission reduction, vehicle size,
Ewing and Sarigollu (2000)	MNL	9,7,3	price, fuel cost, repair and maintenance cost, commuting time, acceleration, range, charging time
Dagsvike et al. (2002)	Ranked logit	15, 4, NA	price, fuel cost, range, top speed
Potoglou and Kanaroglou (2007)	Nested logit	8, 7, 4	price, fuel cost, maintenance cost, fuel availability, acceleration, incentives, emission reduction
Ahn et al. (2008)	multiple discrete-continuous extreme value (MDCEV model)	4, 6, 2-5	fuel type, body type, maintenance cost, engine displacement, fuel efficiency, fuel price
Mau et al. (2008)	MNL	18, 6, 3	price, fuel cost, subsidy, range, fuel availability,
Axsen et al. (2009)	MNL; Joint SP/RP MNL	18, 5, 3	price, subsidy, horsepower, fuel efficiency, fuel price
Hidrue et al. (2011)	Latent class	2, 6, 4	price, range, charge time, acceleration, emission reduction, fuel cost
Ito et al. (2013)	Nested logit	3, 9, 4	price, fuel cost, fuel type, body type, manufacturer, range, refueling rate, acceleration, emission reduction,

NA: not available.

(*) The two papers used the same data/study. Hence the list in the attribute column and the number of choice sets, atributes and levels columun are the same for both.

Table 2: Attribute levels of conjoint analysis

	EV (Electric vehicle)				PHEV （Hybrid electric vehicle with a plug-in function）				Gasoline Vehicles (including conventional hybrid vehicle without a plug-in function）			
	Level 1	Level 2	Level 3	Level 4	Level 1	Level 2	Level 3	Level 4	Level 1	Level 2	Level 3	Level 4
Purchace 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 $20,000 (fixed)			
Fuel cost (compared with conventional gasoline vehicles)	60% off	80% off			40% off	60% off			0% off（as conventional）	10% off	20% off	30% off
Driving range	100miles	200miles	300miles	400miles	700miles	800miles	900miles	1000miles	400miles	500miles	600miles	700miles
Emission reduction (compared with conventional gasoline vehicles)	70% reduction	80% reduction	90% reduction	100% reduction	50% reduction	60% reduction	70% reduction	80% reduction	No reduction	10% reduction	20% reduction	30% reduction
Fuel availability (% of existing gas stations)	10%	30%	50%	70%	10%	30%	50%	70%	100%			
Home plug-in construction fee	No fee	1,000 US$			No fee	1,000 US$			—			

Figure 1: Example of conjoint questionnaire

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 $20,000	**Do not buy any of them**
Fuel cost (compared with conventional gasoline vehicles)	60% off	40% off	10% off	
Driving range	200 miles	700 miles	400 miles	
Emission reduction (compared with conventional gasoline vehicles)	80% reduction	60% reduction	20% reduction	
Fuel availability (% of existing gas stations)	50%	30%	100%	
Home plug-in construction fee	No fee	1,000 US$	-	
	↓	↓	↓	↓
Please circle one choice→				

Table 3: Demographic characteristics

	US respondents	Japanese respondents
Gender (Male)	38.2%	56.0%
Age from 30's to 50's	58.3%	78.0%
Married/couple	69.8%	80.3%
Detached house dwelling	72.0%	54.7%
Annual household income between $30,000 to $70,000	42.0%	50.7%

Table 4: Preferences for EV/PHEV utilization

	US respondents	Japanese respondents
Ownership of one or two conventional gasoline cars	80.9%	72.7%
Intent to purchase a car within next five years	56.7%	41.3%
Interest in alternative fuel vehicles (very/moderately interested)	59.5%	52.8%
Interest in charging alternative fuel vehicles at home	82.3%	70.3%

Table 5: Estimation results for US and Japan

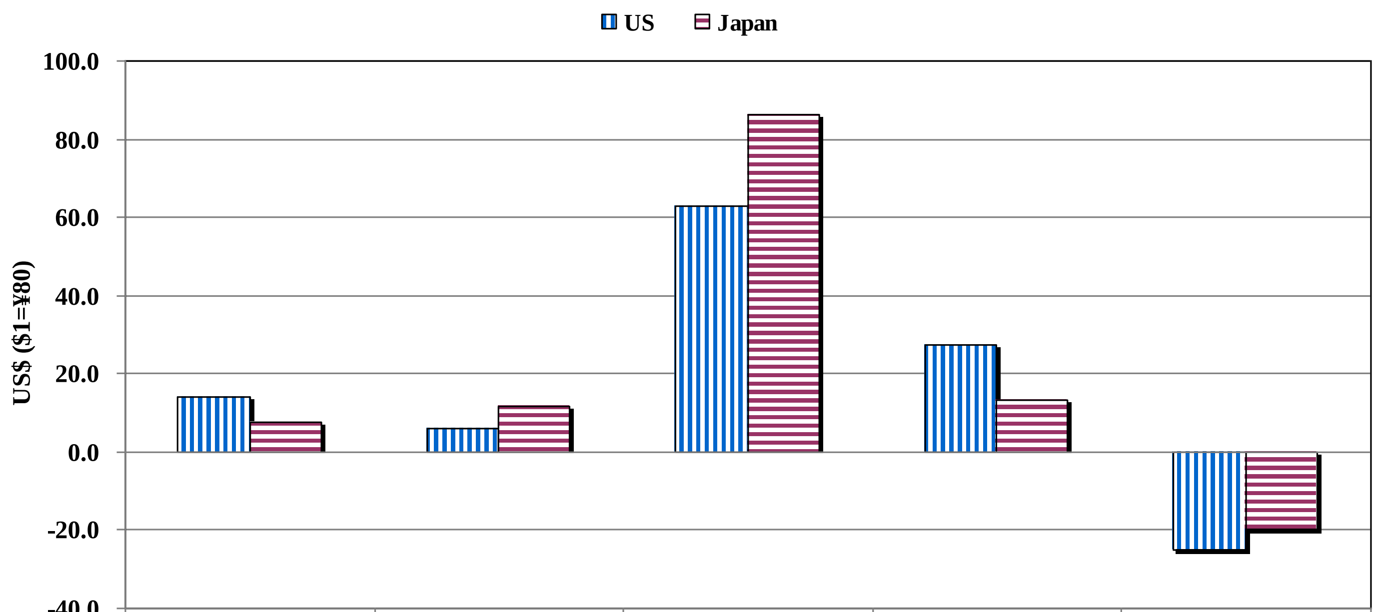
	US respondents (all)			
	Coeff.	Std.Err.		WTP($)
＜fixed parameter＞				
Purchace Price (US$)	-0.0003	0.0000	***	
Constant_No_car (CAL)	-5.1411	0.1485	***	
Constant_No_car (TEX)	-5.1269	0.1430	***	
Constant_No_car (MIC)	-5.3270	0.1445	***	
Constant_No_car (NY)	-4.9662	0.1443	***	
＜mean of random parameter＞				
Fuel cost (% off compared with gasoline vehicles)	0.0037	0.0009	***	14.15
Range (miles)	0.0015	0.0000	***	5.85
Emission reduction (% reduction compared with gasoline vehicles)	0.0163	0.0009	***	62.73
Fuel station availability (% of existing gas stations)	0.0072	0.0006	***	27.50
Home plug-in construction fee (US$1000)	-0.0654	0.0030	***	-251.50
＜s.d. of random parameter＞				
Fuel cost	0.0328	0.0011	***	
Range	0.0016	0.0000	***	
Emission reduction	0.0320	0.0009	***	
Fuel station availability	0.0266	0.0005	***	
Home plug-in construction fee	0.0829	0.0042	***	

Number of obs.	33616
McFadden Pseudo R-squared	0.3302
Log likelihood function	-31215.014

	Japanese respondents			
	Coeff.	Std.Err.		WTP(US$)
＜fixed parameter＞				
Purchase Price (US$)	-0.0002	0.0000	***	
Constant_No_car	-6.1664	0.13581	***	
＜mean of random parameter＞				
Fuel cost (% off compared with gasoline vehicles)	0.0018	0.0011	*	7.51
Range (miles)	0.0029	0.0001	***	11.70
Emission reduction (% reduction compared with gasoline vehicles)	0.0212	0.0010	***	86.37
Fuel station availability (% of existing gas stations)	0.0033	0.0007	***	13.31
Home plug-in construction fee (US$1000)	-0.0490	0.0029	***	-200.18
＜s.d. of random parameter＞				
Fuel cost	0.0399	0.0012	***	
Range	0.0042	0.0001	***	
Emission reduction	0.0306	0.0010	***	
Fuel station availability	0.0288	0.0006	***	
Home plug-in construction fee	0.0468	0.0061	***	

Number of obs.	32000
McFadden Pseudo R-squared	0.3849643
Log likelihood function	-27283.86

Figure 2: WTP values for US and Japan

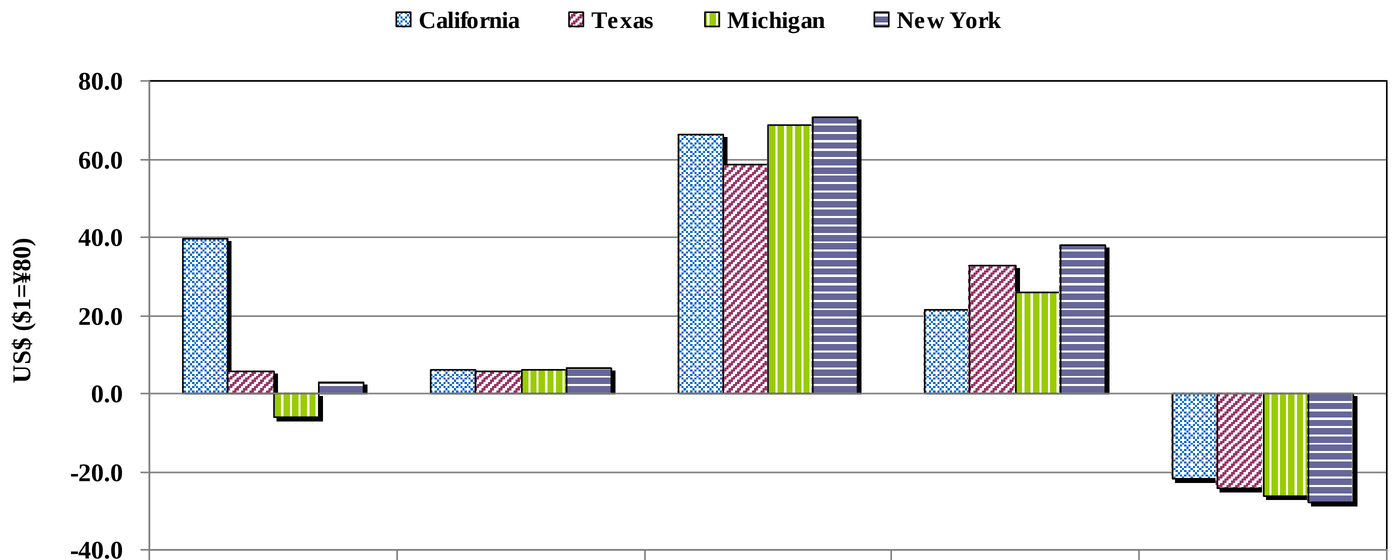


	Fuel cost (% off compared with gasoline vehicles)	Range (miles)	Emission (% reduction compared with gasoline vehicles)	Fuel station availability (% of existing gas stations)	Home plug-in construction fee (US$100)
US	14.2	5.8	62.7	27.5	-25.2
Japan	7.5	11.7	86.4	13.3	-20.0

Table 6: Estimation results across four US states

	California				Texas				Michigan				New York			
	Coeff.	Std.Err.		WTP($)	Coeff.	Std.Err.		WTP($)	Coeff.	Std.Err.		WTP($)	Coeff.	Std.Err.		WTP($)
＜fixed parameter＞																
Purchace Price (US$)	-0.0003	0.0000	***		-0.0003	0.0001	***		-0.0003	0.0000	***		-0.0003	0.0000	***	
Constant_No_car	-4.7112	0.2295	***		-5.2604	0.2448	***		-5.6556	0.2455	***		-4.4028	0.2360	***	
＜mean of random parameter＞																
Fuel cost (% off compared with gasoline vehicles)	0.0099	0.0018	***	39.40	0.0015	0.0020		5.52	-0.0017	0.0019		-5.97	0.0007	0.0020		2.73
Range (miles)	0.0015	0.0001	***	6.16	0.0016	0.0008	***	5.78	0.0017	0.0001	***	5.90	0.0016	0.0001	***	6.38
Emission reduction (% reduction compared with gasoline vehicles)	0.0166	0.0017	***	66.40	0.0158	0.0018	***	58.59	0.0199	0.0017	***	68.59	0.0177	0.0016	***	70.77
Fuel station availability (% of existing gas stations)	0.0054	0.0012	***	21.48	0.0088	0.0013	***	32.74	0.0075	0.0013	***	25.76	0.0095	0.0013	***	37.89
Home plug-in construction fee (US$1000)	-0.0547	0.0056	***	-218.76	-0.0658	0.0062	***	-243.59	-0.0765	0.0063	***	-263.86	-0.0696	0.0063	***	-278.30
＜s.d. of random parameter＞																
Fuel cost	0.0277	0.0018	***		0.0358	0.0023	***		0.0390	0.0020	***		0.0409	0.0020	***	
Range	0.0017	0.0001	***		0.0018	0.0001	***		0.0016	0.0001	***		0.0015	0.0001	***	
Emission reduction	0.0315	0.0014	***		0.0329	0.0021	***		0.0270	0.0016	***		0.0222	0.0017	***	
Fuel station availability	0.0235	0.0010	***		0.0276	0.0011	***		0.0290	0.0011	***		0.0274	0.0011	***	
Home plug-in construction fee	0.0735	0.0087	***		0.0799	0.0087	***		0.0839	0.0098	***		0.0889	0.0089	***	
Number of obs.	8176				8712				8560				8168			
McFadden Pseudo R-squared	0.3066				0.3463				0.3487				0.3178			
Log likelihood function	-7858.7951				-7895.5734				-7728.6037				-7724.9435			

Figure 3: WTP values across four US states

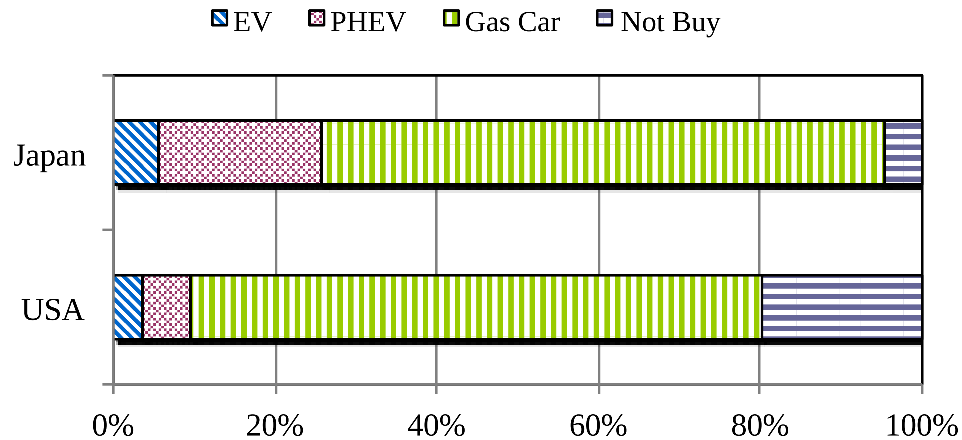


	Fuel cost (% off compared with gasoline vehicles)	Range (miles)	Emission (% reduction compared with gasoline vehicles)	Fuel station availability (% of existing gas stations)	Home plug-in construction fee (US$100)
California	39.4	6.2	66.4	21.5	-21.9
Texas	5.5	5.8	58.6	32.7	-24.4
Michigan	-6.0	5.9	68.6	25.8	-26.4
New York	2.7	6.4	70.8	37.9	-27.8

Table 7: Scenarios used in the simulation

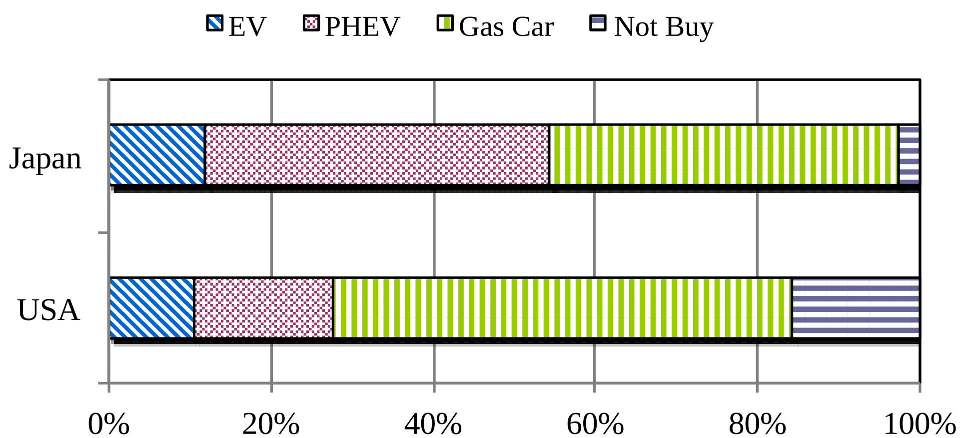
	Scenario 1 (Realistic case)				Scenario 2 (Purchase price reduction)				Scenario 3 (Purchase price reduction & further innovation)			
	EV	PHEV	Gas Car	Not Buy	EV	PHEV	Gas Car	Not Buy	EV	PHEV	Gas Car	Not Buy
Purchase price (US$)	30000	30000	20000	0	25000	25000	20000	0	25000	25000	20000	0
Constant_No_car	0	0	0	1	0	0	0	1	0	0	0	1
Fuel cost (% off compared with conventional gasoline vehicles)	60	40	0	0	60	40	0	0	70	50	0	0
Driving range (miles)	100	700	400	0	100	700	400	0	200	800	400	0
Emission reduction (% reduction compared with conventional gasoline vehicles)	70	50	0	0	70	50	0	0	80	60	0	0
Fuel station availability (% of existing gas stations)	10	10	100	0	10	10	100	0	20	20	100	0
Home plug-in construction fee (US$100)	10	10	0	0	10	10	0	0	5	5	0	0

Figure 4: Diffusion rates in US and Japan: Base case scenario 1 (realistic case)



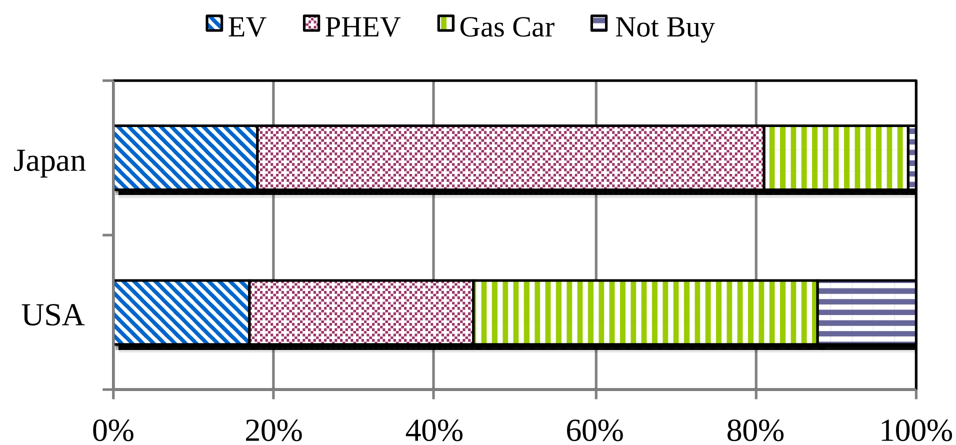
	USA	Japan
EV	3.5%	5.7%
PHEV	5.9%	20.1%
Gas Car	70.6%	69.7%
Not Buy	20.0%	4.5%

Figure 5: Diffusion rates in US and Japan: Scenario 2 (Purchase price reduction)



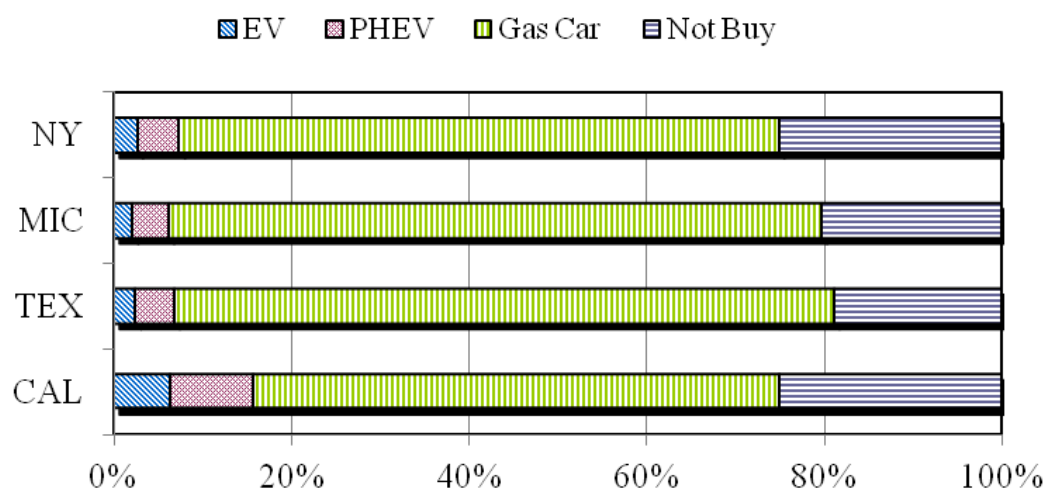
	USA	Japan
EV	10.4%	12.0%
PHEV	17.3%	42.2%
Gas Car	56.3%	43.0%
Not Buy	15.9%	2.8%

Figure 6: Diffusion rates in US and Japan: Scenario 3 (Further innovation with purchase price reduction)



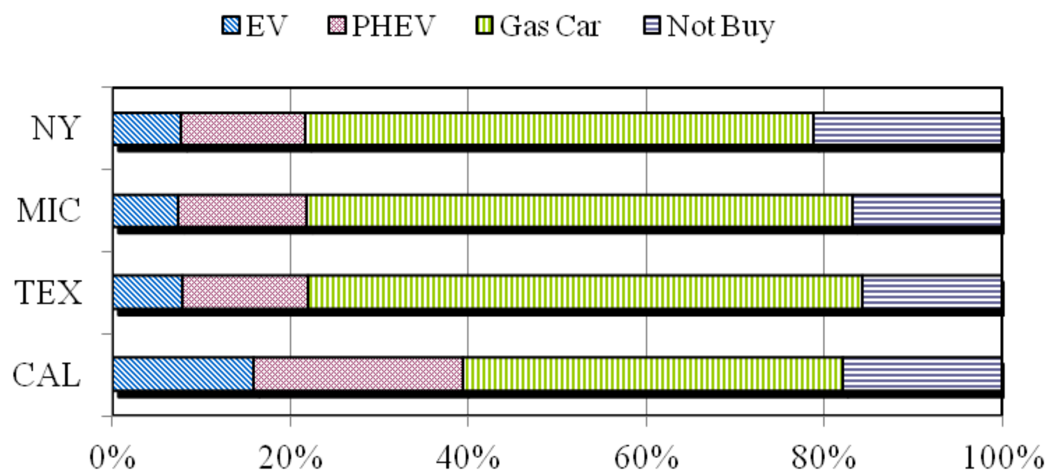
	USA	Japan
EV	16.8%	17.9%
PHEV	28.0%	63.1%
Gas Car	43.0%	17.8%
Not Buy	12.2%	1.1%

Figure 7: Diffusion rates across four US states: Base case scenario 1 (realistic case)



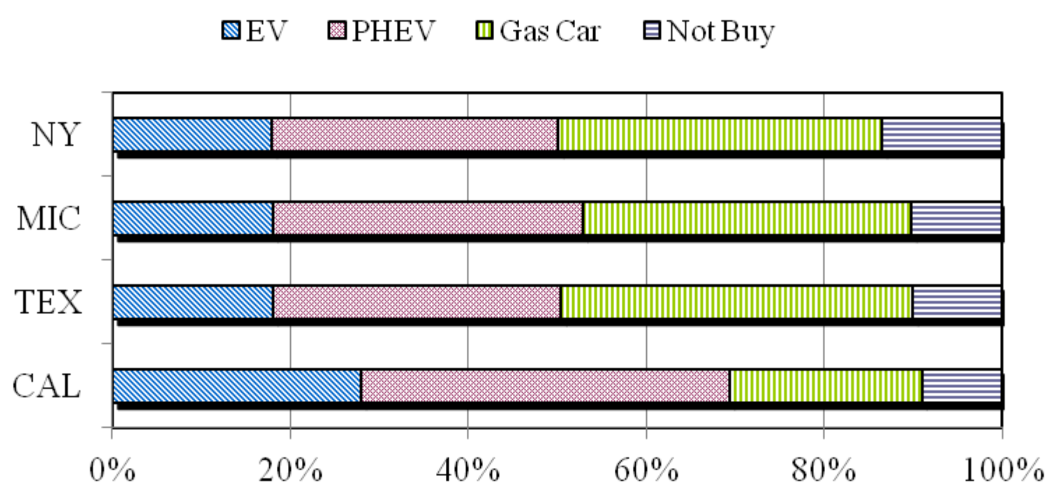
	CAL	TEX	MIC	NY
EV	6.3%	2.4%	2.1%	2.6%
PHEV	9.4%	4.4%	4.1%	4.7%
Gas Car	59.3%	74.3%	73.5%	67.5%
Not Buy	25.0%	18.9%	20.3%	25.1%

Figure 8: Diffusion rates across four US states: Scenario 2 (Purchase price reduction)



	CAL	TEX	MIC	NY
EV	15.9%	7.8%	7.4%	7.7%
PHEV	23.5%	14.1%	14.4%	14.0%
Gas Car	42.6%	62.2%	61.3%	57.1%
Not Buy	18.0%	15.8%	16.9%	21.2%

Figure 9: Diffusion rates across four US states: Scenario 3 (Further innovation with purchase price reduction)



	CAL	TEX	MIC	NY
EV	27.9%	18.0%	18.0%	17.9%
PHEV	41.4%	32.4%	34.8%	32.2%
Gas Car	21.6%	39.5%	37.0%	36.4%
Not Buy	9.1%	10.1%	10.2%	13.5%