Willingness to pay for the infrastructure investments for alternative fuel vehicles

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Abstract

This study investigates potential demand for infrastructure investment for alternative fuel vehicles (AFVs) by using a stated preference survey of 1,531 Japanese citizens. The potential demand is estimated on the basis of how much people are willing to pay for AFVs under different refueling scenarios. By using the estimated parameters, the economic efficiency of establishing battery exchange stations for electric vehicles is examined. The result indicates that infrastructural development of battery exchange stations can be socially efficient when the percentage of electric vehicle purchasers out of the total number of new vehicle purchasers exceeds 5.63%. Furthermore, in contrast to intuitive prediction, we found a complement relationship between the cruising ranges of AFVs and the infrastructures established. The result suggests that people with AFVs might change their total trip distance depending on the sufficiency of infrastructure investment.

Keywords: Alternative fuel vehicle, infrastructure investment, stated preference method, choice experiment, discrete choice, nested logit model, cost-benefit analysis

1 Introduction

Alternative Fuel Vehicles (AFVs) are expected to play an important role in reviving the automobile industry as well as in mitigating carbon emissions in the transportation sector. Reduction of carbon emissions is becoming a matter of international importance. In the US, the American Recovery and Reinvestment Act of 2009 extended consumer tax incentives, providing tax credit ranges from 2,500 to 7,500 US dollars (hereafter dollars) for plug-in electric vehicles (EVs). In the UK, those who purchased EVs in 2011 could receive a rebate ranging from 2,000 to 5,000 pounds (Department for Transport, UK). Furthermore, they could also be exempt from annual vehicle taxes and showroom taxes, whereas the purchaser of an average new gasoline vehicle (GV) would be paying a one-off excise duty of 155 pounds from April 2010 onwards (after a one-time exemption from the duty). EVs are tax free. Similar incentives are being offered by other countries in Europe. In 2010, Japan also provided subsidies for EVs within a range of 660 thousand yen to 1,380 thousand yen (a range of 7,310 to 15,300 dollars).[1]

Nevertheless, the demand for AFVs is still at a premature stage. One of the reasons for this is the lack of investment in infrastructure for recharging/refueling these vehicles. The number of establishments for refueling EVs and fuel cell vehicles (FCVs) are insufficient. However, a few attempts have been made to resolve this problem. For example, in London it is planned to set up 1,300 charging points by 2013. The "Source London" project provides a network of 400 recharge points that enable recharge equipment individually owned to be shared as of March 2012 (London

[1] During the period our survey was conducted in February 2010, the average exchange rate was 90.28 Japanese yen per dollar.

Assembly Environment Committee, 2012). In the US, a California-based venture company known as Better Place proposed that establishing rental battery stations where drivers can replace their depleted batteries with fully charged ones within a minute, could serve as an effective solution. Shown evidence of consumer willingness to pay for these infrastructures, governments would be more inclined to approve investment in such infrastructure. A stated preference survey is useful for predicting such potential demand under hypothetical scenarios in which circumstances dramatically change.

Several studies have used the stated preference approach to investigate the potential demand and role of government support for AFVs. In the 1970s the studies of potential demand for EVs started in the US against a backdrop of the oil crisis (Beggs et al., 1981; Calfee, 1985). The concern of the early studies was how much the fuel efficiency of EVs characterized by a short cruising range can compete with conventional gasoline vehicles (GVs). After that, in response to California's zero-emission vehicle mandate, studies regarding AFVs that include a measure of emission level as one of the vehicle attributes were carried out (Bunch et al., 1993; Brownstone et al., 1996, 2000; Brownstone and Train, 1999; see also Hidrue et al., 2011). Ewing and Sarigöllü (1998) focused on the significance of economic incentives provided by governments and found that they had modest effects on the vehicle choices of residents in the metropolitan Montreal area. Potoglou and Kanaroglou (2007) examined the impact of non-economic incentives such as "free parking" and "permission to drive on high-occupancy vehicle lanes with one person in the car" and found that these incentives do not influence the preferences of the people in Hamilton, Canada with respect to "green" vehicles. In a survey conducted in Northern California, Cao et al. (2006) asked the respondents to characterize their neighborhoods using 34 attributes and analyzed the effects of these neighborhood characteristics on their choice of vehicle type. Responses showed a strong relationship between neighborhood characteristics and choice of vehicle type and suggested that land use policies, at least to a certain extent, can reduce the use of light-duty trucks, including minivans and pickup trucks. Although previous studies have investigated the attributes that consumers prefer in their vehicles of choice, questions regarding the type of infrastructure and the ideal minimum level of demand have not received much attention. Potoglou and Kanaroglou (2007) indicated disutility of vehicles owing to a lack of fuel availability. The availability of established alternative infrastructure also prompts consumers to switch to AFVs. Hence it is necessary to identify and compare all the benefits of establishing and improving different types of infrastructure.

This study aims to reveal the potential demand for infrastructure investment by using a stated preference survey conducted in Japan for three kinds of AFVs: hybrid electric vehicles (HEVs), EVs, and FCVs. We selected Japan as a case study because several competitive auto manufacturers in that country are attempting to establish mass production technology for AFVs.

The contribution of this paper is that it reveals the potential demand for infrastructure investment for different AFVs. This potential demand is estimated on the basis of how much people are willing to pay for AFVs under different refueling scenarios. By using estimated parameters, the economic efficiency of establishing battery exchange stations for EVs and hydrogen stations for FCVs can be examined. Subsequently, we investigate the substitutability between the cruising ranges of AFVs and the infrastructures established.

The rest of the paper is organized as follows: Section 2 addresses the survey strategy and the manner in which our data is collected. Section 3 explains the theoretical background of the nested multinomial logit model (NMNL). Section 4 presents the estimation results. Section 5 discusses two scenario forecasts of market shares and the effect of subsidization of EVs. Section 6 presents concluding remarks.

2 Survey design

AFVs differ from conventional GVs in fuel availability, level of CO_2 emissions, cruising range, and fuel cost. Assessing consumers' willingness to pay for fuel availability and for longer cruising ranges is required for policy makers to evaluate options for infrastructural development and investment in technical development. However, because no market data is available until some infrastructural and technical development takes place, the potential demand for such development is hard to judge. The advantage of a questionnaire survey is that it enables surveyors to present situations that are yet to be realized, or to present new products that cannot yet be produced by existing technology, in order to enable potential customers to describe their reactions to them (Beggs et al., 1981). We conducted a questionnaire survey of choice experiments in order to reveal such a potential demand for infrastructures and a longer cruising range for AFVs.

2.1 Vehicle attributes and their levels

Thus far the construction of infrastructure for AFVs has been inadequate. Hence in the real world, where we do not have much infrastructure for AFVs, market data does not provide enough information on the demand for various types of infrastructure.

Moreover, a decision to purchase a car depends on numerous attributes. In this study, therefore, we have selected nine attributes on the basis of the focus of our study and the findings of previous studies. Attributes connected with refueling, refueling rate, and fuel availability are important factors that influence vehicle choice (see Ewing and Sarigöllü, 1998; Potoglou and Kanaroglou, 2007). Table 2.1 indicates these attributes and levels in detail. Characteristics of the attributes are as follows:

Fuel type: In order to compare the benefits of establishing infrastructures for EVs and FCVs, we considered the following four fuel types: conventional GVs, HEVs, EVs, and FCVs. The conventional GVs are treated as the base alternative that the respondents were willing to purchase.

Table 2.1: The attributes and levels of choice experiments

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Body type: We asked respondents to choose two vehicle body types out of a total of nine alternatives that they would consider in their next purchase decisions; we used these two body type preferences to create respondent profiles. The following nine categories of vehicle body types were included in our survey: subcompact, compact/hatchback (hereafter compact), coupe, sedan, convertible, wagon, minivan, SUV/pickup truck, and truck/bus. The body types are unrelated to fuel types.

Manufacturer: We asked respondents to choose one automobile manufacturer from among a list of manufacturers that they would definitely consider in their next purchase decision; we used their preferences to create profiles for GVs. The list comprised thirty manufacturers, including foreign companies. It was assumed that only the following four representative automobile manufacturers in Japan produce HEVs, EVs, and FCVs:

Toyota Motor Corporation, Honda Motor Company, Nissan Motor Company, and Mitsubishi Motors Corporation.

Cruising range: The cruising range is also a critical consideration when choosing AFVs. The cruising ranges are set as 800 kilometers for GVs; 1,000 kilometers for HEVs; between 50 kilometers and 200 kilometers for EVs;[2] and between 300 kilometers and 600 kilometers for FCVs.

Refueling rate: The total time taken to refuel all AFVs except EVs is 5 minutes. As compared to other AFVs, EVs usually take a longer time to recharge; however, where battery-exchange stations are available, the time taken to recharge is comparable to other AFVs. A California-based venture company known as Better Place has established a battery-exchange station that permits drivers to exchange their depleted battery packs for fully recharged ones in under 80 seconds (Source: Better Place's website).

Carbon dioxide: By choosing an AFV, drivers can reduce the emissions of CO_2. The fuel type being used determines the CO_2 levels for all vehicles except HEVs. Only HEVs have two different levels of CO_2 emissions; their emission levels have been reduced by 40% and 60% from the current levels.

Fuel availability: Fuel availability is described in terms of the percentage of refueling stations that offer the new fuel. Depending on the type of FCV, either 10% or 50% of currently existing service stations offer the new fuel. When the battery-switching scenario is assumed, depending on the type of EV, either 10% or 50% of currently existing service stations provide the facility. When a battery-recharging scenario is assumed, drivers of EVs can recharge the batteries at their homes and/or at

[2] The cruising range of Nissan's EV model Leaf is between 100 kilometers and 220 kilometers depending on the conditions of speed, climate, road, etc. (Source: Nissan Leaf's website)

supermarkets.

Purchase price: The purchase price for GVs is based on respondents' answers regarding the amount they are willing to spend on their next purchase opportunity. The purchase prices for AFVs are indicated by the increase in the price that the customers are willing to pay for their next purchase of a GV.

Annual fuel cost: The annual fuel costs for GVs are calculated by multiplying the respondents' current number of refuels per month by the amount spent by them per refuel and by twelve months. The annual fuel costs for AFVs are indicated by comparing the decrease in the annual fuel costs of AFVs by the annual fuel costs of GVs. In the choice experiments, the respondents were instructed to assume that the annual fuel costs include the cost of replacing the batteries of the recharge type of AFVs. It must be noted that the attributes of different fuel types, refueling frequencies, and refuel stations are correlated owing to the common technological aspects among vehicles.

Furthermore, respondents were asked to consider all the non-listed attributes as identical for all the vehicles in the alternatives. If respondents required information regarding vehicle attributes while answering the choice experiment questions, they were permitted to obtain that information.

2.2 Design of choice sets

Figure 2.1 provides an example of a choice set. The profile for vehicle 1 (GV) is created on the basis of the respondent answers regarding their next purchase opportunity. Thus, vehicle 1 remains fixed throughout the choice sets for each of the respondents.

We made profiles for all types of AFVs using orthogonal arrays for 10 attributes and

4 levels. Maintaining the orthogonality, the EV profiles that contradicted the scenarios regarding the refueling rate and fuel availability were modified. Under the battery-switching scenario, the refueling rate becomes 5 minutes and fuel availability is indicated by the percentage of current service stations offering the new fuel. Under the battery-recharging scenario, drivers can recharge the batteries at homes and/or supermarkets.

We constructed 64 profiles for each AFV; therefore, there were a total of 192 (64 × 3) profiles. We randomly selected two profiles from three AFVs and matched it with the GV profile, thereby creating 128 choice sets. Thus, the profiles of GVs are the same in any choice sets. There were 16 versions of the questionnaire and each respondent answered eight choice sets.

Figure 2.1: Example of choice set

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2.3 Data

We conducted a web-based survey in February 2010. The articulation and clarity of the questions were examined by a pretest that was conducted in December 2009. We sent e-mails in order to invite registered monitors to participate in the online survey and 1,531 people aged between 19 and 69 responded to this questionnaire. The response rate was 23.6%.

Table 2.2 presents the summary statistics. Although the distribution of the genders and ages of our sample is similar to those of the census population in each prefecture, there were relatively fewer households with low incomes and more households with high incomes as compared to the census.

Table 2.2: Summary statistics of respondents' characteristics

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3 Discrete choice models

Vehicle choice behavior was analyzed using discrete choice models, which assume that consumers' choice behaviors are based on the random utility theory. We applied the nested multinomial logit model (NMNL) in order to avoid the restriction of independence from irrelevant alternatives, usually known as the IIA property, which is assumed to exist in a multinomial logit model (MNL). For example, let us consider three choice alternatives: a GV, an HEV, and an EV. Let each of the choice probabilities be 40% and 20%. IIA implies that the ratios of probabilities choosing these alternatives remain unaffected by the addition or deletion of other fuel type alternatives from the choice set. However, if decision makers have the same utility for a GV and an HEV, the ratio of choice probabilities between the GV and EV changes to four from two by omitting the HEV alternative. In this case, the MNL would be an unacceptable model, and parameter estimates would be biased. Use of NMNL is appropriate when the set of alternatives faced by a decision maker can be portioned into subsets, known as nests, in such a manner that the following properties hold: for any two alternatives that are in the same nest, IIA holds, and for any two alternatives in different nests, IIA does not hold (see Ben-Akiva and Lerman, 1985; Train, 2003).

In the NMNL, the utility of decision maker n who is required to choose among J alternatives is denoted by

(3.1) $U_{nj} = V_{nj|k} + V_{nk} + \varepsilon_{nj|k} + \varepsilon_{nk}$ for $\forall j \in B_k$ and $\forall k \in K$,

where $V_{nj|k}$ and $\varepsilon_{nj|k}$ are observable and unobservable terms respectively, which are given by choosing the subsets of alternatives known as nests; V_{nk} and ε_{nk} are observable and unobservable terms, respectively, within the same nest. The set of alternatives included in each nest k is denoted as B_k. We now describe the probability choice system as a two-level tree structure; therefore, the choice probability that chooses alternative j in the nest k is given by

$$\begin{aligned} \Pr(j,k) &= \Pr(j \mid k) \cdot \Pr(k) \\ &= \frac{\exp(\beta' x_{j|k})}{\sum_{j|k}^{B_k} \exp(\beta' x_{j|k})} \frac{\exp\{\mu_k(\gamma' z_k + \mathrm{IV}_k)\}}{\sum_{k \in K} \exp\{\mu_k(\gamma' z_k + \mathrm{IV}_k)\}}, \end{aligned} \tag{3.2}$$

where $\mathrm{IV}_k = \ln \sum_{j|k}^{B_k} \exp(V_{nj|k})$; $x_{j|k}$ is a vector of observable variables related to alternative j; z_k is a vector of observable variables that are related to nest k; μ_k is the scale parameter of nest k (IV parameter below); and all the scale parameters of alternative levels are standardized as one (Ben-Akiva and Lerman, 1985; Louviere et al., 2000; Hensher and Greene, 2002; Train, 2003). When the IV parameter assumes that $\mu_k = 1$ for all k, the NMNL is reduced to the standard MNL. For the sake of simplicity, we do not consider the branch level equation and omit V_{nk}. We define eleven alternative specific constants in order to avoid multicollinearity among the attributes of fuel type, fuel availability, and refueling time. The conventional GV is treated as the base alternative. We consider three types of tree structures that are determined by fuel types, refueling times, and fuel availability. Comparing the estimated IV parameters among the tree structures nested by the four branches of GV, HEV, EV, and FCV (Log likelihood -11663.9, BIC = 1.937), nested by two branches whether zero-emission vehicles, EVs and FCVs, or not (Log likelihood = -11669.9, BIC =1.937), and nested by two branches whether conventional GVs or "green" vehicles (Log likelihood -11663.7, BIC = 1.935), we settled on the tree structure with the smallest Bayesian information criterion (BIC); Figure 3.1 presents this tree structure. As is evident, although numerous other tree structures could be hypothesized, a more comprehensive discussion of the NMNL model structures and the selection of functional forms is beyond the scope of this paper.

Figure 3.1: Tree structure of NMNL

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4 Estimation results

We estimated two MNL models and one NMNL model; Table 4.1 presents the estimation results of these models. In MNL model 2 and NMNL, we analyzed the interaction effects between cruising ranges and establishment of infrastructures. Using a one-tailed asymptotic t-test at the 1% significance level, the IV parameter of NMNL is significantly lesser than one (the p-value in the NMNL is 0.000), so the hypothesis that the true model is MNL is rejected. Therefore, MNL is an unacceptable model, and the parameter estimates are biased. The estimated results of each coefficient of variable used in our models are as follows:

Alternative specific constants (ASCs): The difference between the coefficients of HEV1 and HEV2 indicates the utility difference between the different CO_2 emission levels of the two types of HEVs. The magnitude relationship between HEV1 and HEV2 indicates that, as expected, the reduction of CO_2 emission is beneficial for consumers. The difference between the coefficients of EV1 and EV2 represents the utility of reducing time for recharging batteries at home. Reducing the time taken for recharging EVs would be beneficial for consumers. The magnitude relationship between the coefficients of EV1 and EV2 is consistent with expectations. The difference between the coefficients of EV3 and EV4 represents the utility difference between the different recharge durations for recharging batteries at home and supermarkets. The magnitude relationship between the coefficients of EV3 and EV4 is as per expectations. The difference between the coefficients of EV5 and EV6 represents the utility difference in the extent of infrastructural support provided. Increasing the number of service stations that provide battery exchange services for EVs would be beneficial for consumers. The magnitude relationship between the coefficients of EV5 and EV6 is as per expectations.

Furthermore, the difference between the coefficients of FCV1 and FCV2 represents the utility difference in the extent of infrastructural support provided. Increasing service stations that provide refueling services for FCVs would be beneficial for consumers. The magnitude relationship between the coefficients of FCV1 and FCV2 is in line with expectations. Because the available infrastructures differ between different types of engines and the marginal utilities of cruising range are influenced by infrastructure development, it is valid to assume that the marginal utilities of cruising range of AFVs are not equal to that of GV and HEV. On the other hand the number of attribute level of cruising range is one in GV and HEV. Since the ASCs of both GV and HEV include the utility for cruising range, we cannot evaluate them separately.

Prices and annual maintenance costs: The signs of the coefficients of price variables and annual fuel costs are as expected. These values indicate that for reducing

1,000 yen (11.1 dollars) of annual fuel costs, the car users' willingness to pay (WTP) is approximately 11.6 thousand yen (128 dollars).

Fuel availability: The coefficient of EV6 is larger than that of EV5 and the coefficient of FCV2 is larger than that of FCV1. These magnitude relationships are consistent with expectations and indicate that the utility of consumers increases with the increase in the number of stations where they can exchange the batteries of their EVs and refuel their FCVs.

Cruising range: As referred to above, the estimated coefficient of cruising range and the squared term of it are the marginal utilities of them in the utility function of EVs and FCVs. As expected, the coefficient of cruising range and the squared term of cruising range between refueling/recharging are positive. The coefficient of the squared term of cruising range is negative. The results indicate that consumers' maximum WTP for cruising range is represented by a certain value. We also estimated the parameters of cross terms between a few ASCs and cruising range. The coefficients of these cross terms represent the difference in the maximum WTP for cruising range.

Body types: The coefficients of body types relative to small types (where the small type includes both subcompact and compact cars) have either positive or negative signs. The vehicle types of SUV/pickup truck, sedan, wagon, and minivan offer consumers significantly higher utilities as compared to vehicle types such as subcompact, compact, coupe, convertible, and truck/bus. The coefficients of cross terms between household size or age and body types indicate that larger households significantly prefer the body type of coupe than subcompact/compact; younger people significantly prefer body types of convertible and sedan than subcompact/compact; males significantly prefer body types of coupe and truck than subcompact/compact.

Table 4.1: Estimation results of MNL and NMNL

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4.2 Establishment of infrastructure

Figure 4.1 provides the calculated WTP for the infrastructures for EVs and FCVs. The definition of each item and the interpretation are as follows:

Quick recharge at home (*WTP_1*): "Quick recharge" implies the transition in the time necessary for recharging batteries from 8 hours to 30 minutes. The WTP for quick recharge at home is calculated by the difference between the WTP for EVs with batteries rechargeable at home for 30 minutes and the WTP for EVs with batteries rechargeable at home for 8 hours, such that $WTP_1 = -10^4 \times (\alpha_3 - \alpha_4) / \beta_6$, where β_6 denotes price parameter. Although the WTP calculated by the estimated parameter is 73,000 yen (807 dollars), the 95% confidence interval includes zero.

Normal recharge at the supermarkets (WTP_2, WTP_3): "Normal recharge" implies that EV batteries require 8 hours for recharging. We define the WTP for normal recharges at supermarkets for the two cases where the consumers have normal recharge equipment (C1) or quick recharge equipment (C2) at their homes. The WTPs for the two abovementioned cases are evaluated by calculating the difference between the WTP for EVs with batteries rechargeable at supermarkets for 8 hours and the WTP for EVs with batteries rechargeable at home for 8 hours, such that $WTP_2 = -10^4 \times [(\alpha_6 - (\alpha_4 + \beta_3 \times 0.124)] / \beta_6$, or by calculating the difference between the WTP for EVs with batteries rechargeable at supermarkets for 8 hours and the WTP for EVs with batteries rechargeable at home for 30 minutes such that $WTP_3 = -10^4 \times [(\alpha_6 - (\alpha_3 + \beta_3 \times 0.124)] / \beta_6$, where β_3 is the interaction effect of cruising range and recharging an EV at home, and 0.124 is the average cruising range of EVs in our data. Both WTP_2 and WTP_3 are negative and have confidence intervals including zero. Moreover, the magnitude relationship between them indicates that if an EV user possesses the quick recharge instrument, his/her WTP for a normal recharge at supermarkets decreases.

Quick recharge at the supermarkets (WTP_4 and WTP_5): "Quick recharge" implies that EV batteries require 30 minutes for recharging. We define the WTP for a quick recharge at supermarkets for the two cases where the consumers have normal recharge equipment (C1) or quick recharge equipment (C2) at their homes. The WTP for a quick recharge at supermarkets is given by the difference between the WTP for EVs with batteries rechargeable at supermarkets for 30 minutes and the WTP for EVs with batteries rechargeable at home for 8 hours, such that $WTP_4 = -10^4 \times [(\alpha_5 + \beta_4 \times 0.118) - (\alpha_4 + \beta_3 \times 0.124)] / \beta_6$, or the difference between the WTP for EVs with batteries rechargeable at supermarkets for 30 minutes and the WTP for EVs with batteries rechargeable at home for 30 minutes, such that $WTP_5 = -10^4 \times [(\alpha_5 + \beta_4 \times 0.118) - (\alpha_3 + \beta_3 \times 0.124)] / \beta_6$. As in the relationship between WTP_2 and WTP_3, our results indicate that if an EV user possesses a quick recharge instrument, his/her WTP for a quick recharge at a supermarket decreases.

The WTP for installing recharge stations in supermarkets was found to be negative in all the cases. The results indicated that if policy makers establish recharge instruments in the car parking spaces of supermarkets, they will be required to establish more rapid recharging instruments, that is, faster than those that take lesser than 30 minutes (e.g., recharge for 15 minutes), or give users the option to choose shorter recharging durations. Alternatively, though we did not consider in our survey locations for installing recharging instruments, they would also be an important issue to consider.

Battery exchange stations (WTP_6): The WTP for establishing battery exchange stations for EVs is calculated by the difference between the WTP for EVs with batteries exchangeable at 50% of current service stations and the WTP for EVs with batteries exchangeable at 10% of current service stations, such that $WTP_6 = -10^4 \times (\alpha_8 - \alpha_7) / \beta_6$. The WTP for the battery exchange stations is 679,000 yen (7,521 dollars) and does not include zero in the 95% confidence interval.

Hydrogen stations (WTP_7): The WTP for establishing hydrogen stations for FCVs is calculated by the difference between the WTP for refueling FCVs at 50% of current service stations and the WTP for refueling FCVs at 10% of current service stations, such that $WTP_7 = -10^4 \times [(\alpha_{10} + \beta_5 \times 0.435) - \alpha_9)] / \beta_6$. The WTP for the hydrogen stations is 406,000 yen (4,502 dollars) and does not include zero in the 95% confidence interval.

Figure 4.1: WTP for establishing each infrastructure

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To compare the benefits of infrastructures between different AFVs, we consider the forecasts by The Ministry of Economy, Trade and Industry (METI) of Japan when it announced the Next-Generation Vehicle Strategy 2010 (NGVS2010) in April 2010. The forecasts in the report indicated that in 2020, in the absence of any government supports, the diffusion rate representing the percentage of new vehicle sales of HEVs will be between 10% and 15%, that of EVs and plug-in hybrid electric vehicles (PHEVs) will be between 5% and 10%, and that of both FCVs and clean diesel vehicles will be miniscule. The governmental targets for the diffusion of AFVs lie between 20% and 30% for HEVs, between 20% and 30% for EVs and PHEVs, up to 3% for FCVs, and between 5% and 10% for clean diesel vehicles. The strategy suggests that the government needs to support the provision of incentive policies aggressively, including development support, purchase subsidies, tax reform, and infrastructural development. The strategy proposes to establish recharging facilities for EVs at dealer shops, convenience stores, commercial facilities, service stations, and the rest areas of expressways. Furthermore, the report stated that local governments must synchronize the planning and installation of recharging equipment with their regional development plans. There is a high possibility that actions such as establishing infrastructure or supporting technological innovation would promote purchases of EVs and FCVs.

To compare the benefits of infrastructure between different AFVs, we consider the NGVS2010 forecasts in a scenario without any government supports.

Annual passenger vehicle sales stood at approximately 2.6 million in Japan in 2009. On the other hand, there were approximately 40,000 domestic service stations as of 2009 (Web source: Agency for Natural Resources and Energy). Forty percent of that number would be 16,000. If we assume that vehicle sales will not change from 2009 to 2020, the number of annual EV purchasers that will account for 5% to 10% of the new vehicle purchasers in 2020 will be between 132,000 and 264,000. Let us assume that there will be 10,000 FCV purchasers annually, who will thus account for 0.38% of the new vehicle purchasers in 2020.

Thus, the aggregated EV purchasers' WTP for an additional service station that can provide battery exchange services is 5.55 [1.75, 9.68] million yen (61,500 dollars) per station and 11.1 [3.51, 19.3] million yen (123,000 dollars) per station in the two cases in which EV purchasers are 5% and 10% of total new vehicle sales, respectively (the values in square brackets are 95% confidence interval). The aggregated FCV purchasers' WTP for an additional service station that can refuel FCVs is 4.06 [0.54, 8.43] million yen (45,000 dollars) per station (values in square brackets are 95% confidence interval).

Although the WTP for each of these infrastructures is rather small, access to the infrastructures is a public good; therefore, all purchasers of EVs or FCVs can share the benefits derived from any infrastructural establishment. According to Better Place, Japan, the construction costs of battery exchange stations for EVs range between 50 million yen and 100 million yen[3] (between 554,000 and 1,108,000 dollars). Thus, the annual depreciation expenses, assuming an 8-year depreciation period, ranged between 6.25 million and 12.5 million yen (between 69,000 and 138,000 dollars) in 2009. These results indicate that infrastructural development of battery exchange stations can be socially efficient when the percentage of EV purchasers exceeds 5.63%.

4.3 Interaction effect of cruising range and infrastructure

Investment in infrastructure directly and indirectly increases benefit through the following two pathways. One is the utility from the infrastructure itself. Since infrastructure is a public good, AFV users can derive benefits from its use. The other is the indirect effect that the establishment of infrastructure increases the benefit of vehicles' cruising ranges. Therefore, WTP for cruising ranges changes according to the extent of infrastructural establishment. Figure 4.2 illustrates such an interaction effect between cruising range and infrastructure. Infrastructure development moves the maximum WTP for cruising ranges to the right.

The WTP for cruising ranges of EVs that are rechargeable at home for 8 hours or 30 minutes reaches its maximum when cruising range is at zero kilometers. The WTP for cruising ranges of EVs that are rechargeable at home and supermarkets for 30 minutes reaches its maximum when cruising range is at 639 kilometers; since this is an extrapolation beyond our maximum attribute level of 200 kilometers it is not shown in Figure 4.2. The WTP for cruising ranges of FCVs that are refuelable at 50% of service stations reaches its maximum when cruising range is at 570 kilometers. Moreover, the WTP for cruising ranges of EVs that are rechargeable at home and supermarkets for eight hours, or EVs with exchangeable batteries, or FCVs that can be refueled at 10% of service stations, reaches its maximum when cruising range is at 311 kilometers. These results indicate that consumers' WTP for certain cruising ranges increases with the

[3] The costs of building battery exchange stations are based on the articles by Galbraith (2009) and Schwartz (2009).

increase in infrastructural development. Thus, cruising range bears a complementary relationship with infrastructure in the case of both EVs and FCVs.

Since both infrastructure improvement and an increase of cruising range reduce the time to recharge or refuel AFVs and increase the leisure time of the consumer, there should be a substitute relationship between them. Thus, it might be intuitively predicted that the WTP for the cruising ranges decrease as infrastructures are improved. However, our estimation results are not consistent with this prediction. A possible reason for this is the influence of a change in the total distance respondents travel in their cars. While we assume that the attributes omitted in the choice experiments are the same between alternatives, some respondents might assume a different total distance between alternatives. If the infrastructure for an AFV is so inadequate that the consumer will switch to public transportation, the total distance traveled in the AFV decreases and the value of the vehicle also decreases. When this is the case, the substitute relationship between cruising range and infrastructure improvement changes into a complement relationship as cruising range increases. Consider the case that the cruising range is longer than travel distance per month; in this case there would be a substitute relationship between them, since infrastructure improvement only reduces the time it takes the consumer to recharge or refuel his/her AFV, but does not cause him/her to switch from AFV transportation to public transportation.

Figure 4.2: WTP for cruising range of EVs and FCVs

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5 Scenario forecasts

To understand the estimation results intuitively we simulated two scenario forecasts of market shares. The difference between them is whether there are alternatives of EVs of exchangeable battery type, or not. In Scenario 1, the infrastructure of recharge equipment is so set up that drivers can fully recharge their EVs at their homes or at supermarkets for 30 minutes and refuel their FCVs at 10% of service stations. In Scenario 2, the infrastructure of battery exchange stations at 10% of service stations is added to the infrastructure of Scenario 1. HEVs in both scenarios are types of HEVs that can reduce CO_2 emissions by 40% from the current level. Table 5.1 describes the results of scenario forecasts of market shares of Toyota's compact or subcompact cars, where we assume that the prices of a GV, HEV, and FCV are 1.5 million yen, 1.8 million yen, and 10 million yen, respectively; and that the cruising ranges of a GV, HEV, EV, and FCV are 800 kilometers, 1,000 kilometers, 200 kilometers, and 600 kilometers, respectively. The annual fuel cost of a GV is assumed to be equal to the sample mean. Those of a HEV, EV, or FCV are assumed to be that amount cut by 28% (which equalizes market share between HEVs and GVs), 50%, and 50%, respectively. The means of age, gender, and household size are also used for the computations. These forecasts demonstrate that the infrastructural development of battery exchange stations for EVs will increase the total market share of EVs, and that the decrease in market share by GVs will be largest, with that of HEVs the second largest. Though there will be decreases in the share of EVs with a rechargeable battery (EV3), EVs using exchangeable batteries will not suffer a decrease.

A scenario forecast can help a policy maker decide how much subsidy should be provided to increase the market share of AFVs. For instance, a subsidy of 250,000 yen (2,770 dollars) for EVs whose price is 4 million yen (44,400 dollars) increases the market share of EVs by 1.81% in Scenario 1. Furthermore, the governmental targets set down in NGVS2010 for the market share of EVs can be achieved by a subsidy policy of one million yen (11,100 dollars) and 500,000 yen (5,540 dollars) for each EV in Scenario 1 and Scenario 2, respectively. However, since in reality the properties of AFVs such as body types and design are limited, the market share of AFVs would be less than our scenario forecasts even if infrastructures are established.

6 Concluding Remarks

Over the past few decades, it has been found that cruising ranges, fuel availabilities, time taken for refueling/recharging, annual or maintenance costs, and purchase prices of AFVs are important factors for encouraging consumers to switch from conventional GVs to AFVs. However, although infrastructure development is an important requirement for AFVs to be adopted, it entails significant costs to the community. No study has attempted to compare the benefits of establishing different types of infrastructures for AFVs. Our study focused on the impact of the availability of fuel among different infrastructures. We found that it would not be beneficial to install normal and quick recharging equipment that takes over 30 minutes for recharging batteries in the parking spaces of supermarkets. Further research is required to investigate whether it is beneficial to invest in recharging equipment that takes under 30 minutes to recharge batteries in these places.

The provision of purchase subsidies has been instrumental in supporting fuel-efficient cars, including HEVs and EVs around the world. Our results indicated that, although the per-person benefit of the establishment of infrastructure and the support for innovation is small, the benefit is large because they are public goods. The magnitude of benefit depends on the amount of the future market share of AFVs. The economic incentives that are provided by governments in numerous countries also have a dimension of being a short-term policy to deal with an economic crisis (OECD 2009). The potential benefits of establishing green infrastructures and promoting innovation would give policy makers an opportunity to shift to a long-term economic and environmental policy.

On the other hand, there are numerous alternate locations for installing charging instruments for EVs. London aims to make itself the EV capital of Europe by carrying out the Electric Vehicle Delivery Plan announced in 2009. This plan aims to establish 25,000 charge points by 2015, as a result of which no Londoner will be more than a mile away from a charging point. Of the 25,000 charge points, 500 are on-street, and 2,000 are in off-street public car parks or in train station car parks. The remaining 22,500 will be provided in partnership with businesses and be located in companies' car parks or retail/leisure locations (London’s website on electric vehicles; London Assembly Environment Committee, 2012). In this paper, we considered only one of the possible locations in our survey and found that it was not beneficial for consumers. How much the recharge time should be shortened and where these recharge instruments should be located are subjects for future investigation.

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Appendices

Table 2.1: The attributes and levels of choice experiments

Attributes		Levels			
Fuel type		GV	HEV	EV	FCV
Body type		Base 1	Base 2		
Manufacturer	GV	Base 3			
	HEV/EV/FCV	Toyota	Honda	Nissan	Mitsubishi
Cruising range (km)	GV	800			
	HEV	1,000			
	EV	50	100	150	200
	FCV	300	400	500	600
Refueling rate	GV/HEV/FCV	5 minutes			
	EV	5 minutes (Exchange)	30 minutes	8 hours	
Carbon dioxide (% reduction of a present average car)	GV	5%			
	HEV	40%	60%		
	EV/FCV	100%			
Fuel availability	GV/HEV	All existing service stations			
	EV	10% of existing service stations (Exchange)	50% of existing service stations (Exchange)	Home	Home and Supermarkets
	FCV	10 % of existing service stations	50 % of existing service stations		
Purchase price (including tax)	GV	Base 4			
	HEV	Base 4+20%	Base 4+40%	Base 4+60%	
	EV/FCV	Base 4+40%	Base 4+60%	Base 4+80%	
Annual fuel cost	GV	Base 5			
	HEV	Base 5−10%	Base 5−20%	Base 5−40%	
	EV/FCV	Base 5−20%	Base 5−50%	Base 5−80%	

Note: Base 1, Base 2, Base 3, Base 4 and Base 5 are specified by respondents respectively and differ between respondents.

Figure 2.1: Example of choice set

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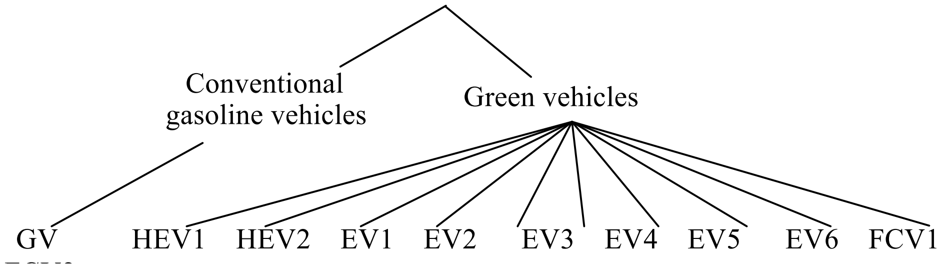
	Vehicle 1	**Vehicle 2**	**Vehicle 3**
Fuel type	Gasoline	Fuel cell	Electric battery
Body type	Coupe	SUV	Coupe
Manufacturer	BMW	Honda	Nissan
Cruising range	800 km	600 km	50 km
Refueling rate	5 minutes	5 minutes	8 hours
Fuel availability	All existing service stations	50% of existing service stations	Home and supermarkets
Carbon dioxide	5% less	100% less	100% less
Purchase price	1.2 million yen	1.44 million yen	2.16 million yen
Annual fuel cost	18,000 yen	3,600 yen	9,000 yen
	⇩	⇩	⇩
Choose one vehicle			

Table 2.2: Summary statistics of respondents' characteristics

		Sample N=1527	**Census**
Gender [%] (Census data is as of 2010)	Females	43.42	49.93
Age group of respondents [%] (Census data is as of 2009)	19 to 30	13.23	18.85
	<40	22.46	21.81
	<50	22.66	19.40
	<60	22.66	19.70
	<70	18.99	20.23
Household income (10^3 yen) [%] (Census data is as of 2008; the samples of no response are 9.55%)	<3,000	18.99	34.73
	<5,000	22.99	27.10
	<8,000	28.88	22.65
	<15,000	24.62	13.59
	<20,000	2.49	1.18
	20,000≤	2.03	0.75
Number of household vehicles (Census data is as of 2008)	Average	2.43	1.10

Note: N denotes the number of respondents. The average of household vehicles owned by total respondents in our survey is 2.17.

Figure 3.1: Tree structure of NMNL



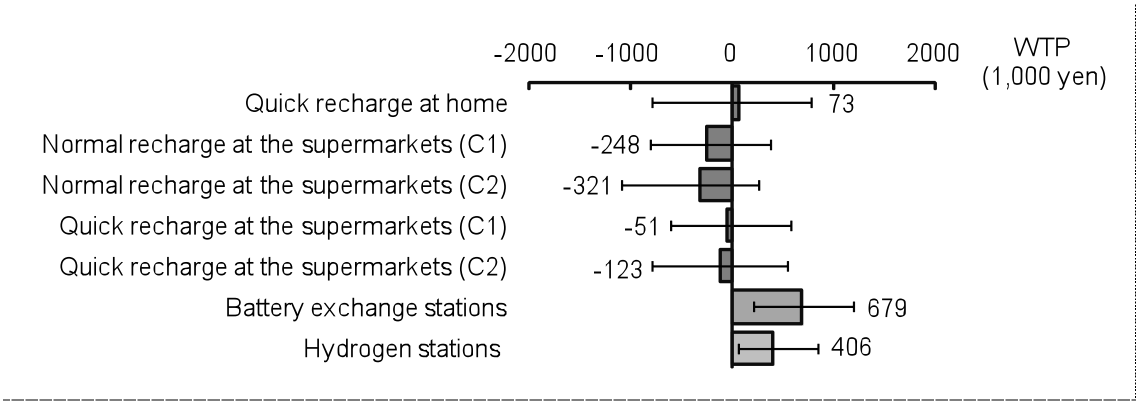
GV: Conventional gasoline vehicle	EV4: EV with battery rechargeable at home and supermarkets for 8 hours
HEV1: HEV reduced by 40 % from the current emission level	EV5: EV with battery exchangeable at 10% of service stations
HEV2: HEV reduced by 60 % from the current emission level	EV6: EV with battery exchangeable at 50% of service stations
EV1: EV with battery rechargeable at home for 30 minutes	FCV1: FCV refueled at 10% of service stations
EV2: EV with battery rechargeable at home for 8 hours	FCV2: FCV refueled at 50% of service stations
EV3: EV with battery rechargeable at home and supermarkets for 30 minutes	

Table 4.1: Estimation results of MNL models and NMNL model

	MNL Model 1		MNL Model 2		NMNL Model	
Variables and notations of coefficients	**Coeff.**	**Std. Err.**	**Coeff.**	**Std. Err.**	**Coeff.**	**Std. Err.**
HEV reduced by 40 % from the current emission level (HEV1): α_1	0.162***	0.054	0.152***	0.055	-0.009	0.063
HEV reduced by 60 % from the current emission level (HEV2): α_2	0.244 ***	0.036	0.223***	0.036	0.106**	0.045
EV with a battery rechargeable at home for 30 minutes (EV1) : α_3	-1.034 ***	0.130	-0.562***	0.165	-0.660***	0.168
EV with a battery rechargeable at home for 8 hours (EV2); α_4	-1.111 ***	0.123	-0.558***	0.176	-0.706***	0.181
EV with a battery rechargeable at home and supermarkets for 30 minutes (EV3) ; α_5	-1.069 ***	0.121	-1.821***	0.243	-1.950***	0.247
EV with a battery rechargeable at home and supermarkets for 8 hours (EV4) ; α_6	-1.258 ***	0.123	-1.394***	0.138	-1.515***	0.144
EV with a battery exchangeable at 10% of service stations (EV5) ; α_7	-1.522 ***	0.121	-1.674***	0.140	-1.801***	0.146
EV with a battery exchangeable at 50% of service stations (EV6) ; α_8	-1.084 ***	0.104	-1.220***	0.120	-1.378***	0.127
FCV refueled at 10% of service stations (FCV1) ; α_9	-1.225 ***	0.177	-1.029***	0.226	-1.143***	0.234
FCV refueled at 50% of service stations (FCV2) ; α_{10}	-1.014 ***	0.175	-2.418***	0.292	-2.513***	0.303
Range$\times 10^{-3}$ [km] if EV or FCV, and 0 otherwise: β_1	2.786 ***	0.774	4.523***	0.979	4.477***	1.001
Range$^2 \times 10^{-5}$ [km] if EV or FCV, and 0 otherwise: β_2	-0.214 ***	0.092	-0.716***	0.130	-0.007***	0.001
Range$\times 10^{-3}$ [km] if EV1 or EV2, and 0 otherwise: β_3			-5.433***	1.383	-5.278***	1.406
Range$\times 10^{-3}$ [km] if EV3, and 0 otherwise: β_4			4.594**	1.814	4.733**	1.846
Range$\times 10^{-3}$ [km] if FCV2, and 0 otherwise: β_5			3.759***	0.617	3.732***	0.638
Price$\times 10^{-7}$ [yen] : β_6	-6.020 ***	0.128	-5.884***	0.128	-6.221***	0.236
Annual cost$\times 10^{-7}$ [yen] : β_7	-59.909 ***	3.669	-57.263***	3.694	-56.950***	3.789

	MNL model 1		MNL model 2		NMNL model	
Variables and notations of coefficients	**Coeff.**	**Std. Err.**	**Coeff.**	**Std. Err.**	**Coeff.**	**Std. Err.**
Continued						
Coupe (Dummy): γ_1	-0.608***	0.209	-0.564***	0.211	-0.547**	0.218
SUV/Pickup truck (Dummy) : γ_2	0.309***	0.076	0.327***	0.077	0.345***	0.079
Convertible (Dummy) : γ_3	-1.354 **	0.568	-1.406**	0.574	-1.396**	0.581
Sedan (Dummy) : γ_4	0.516 ***	0.170	0.562***	0.172	0.588***	0.174
Large type if Wagon or Minivan (Dummy) : γ_5	0.123 ***	0.047	0.130***	0.048	0.147***	0.049
Truck/Bus (Dummy) : γ_6	-0.898 ***	0.261	-0.892***	0.265	-0.869***	0.274
Toyota (Dummy) : γ_7	0.176 ***	0.061	0.174***	0.061	0.177***	0.063
Honda (Dummy) : γ_8	0.042 ***	0.013	0.045***	0.014	0.045***	0.014
Nissan (Dummy) : γ_9	-0.010 ***	0.003	-0.011***	0.003	-0.011***	0.003
Mitsubishi (Dummy) : γ_{10}	0.563 ***	0.154	0.563***	0.155	0.566***	0.161
Household size×coupe: γ_{11}	2.054 ***	0.502	2.136***	0.510	2.117***	0.530
Age×Open: γ_{12}	-0.370 ***	0.045	-0.395***	0.045	-0.438***	0.045
Age×Sedan: γ_{13}	-0.302 ***	0.049	-0.286***	0.049	-0.335***	0.049
Gender×Coupe (Gender=1 if female, and 0 otherwise) : γ_{14}	-0.326 ***	0.051	-0.284***	0.051	-0.333***	0.051
Gender×Truck: γ_{15}	-0.585***	0.055	-0.569***	0.055	-0.627***	0.056
IV parameter of green vehicle nest					0.911***	0.014
Number of observations	12216		12216		12216	
Log likelihood	-11708.1		-11672.4		-11663.7	

Figure 4.1: WTP for establishing each infrastructure



Note: The horizontal line on each WTP is the 95% confidence interval that is calculated using the Krinsky and Robb's (1986) procedure for 1000 draws of estimated parameter vector. C1 and C2 represent the reference points where the consumers only have normal recharge equipment or quick recharge equipment, respectively, at their homes.

Figure 4.2: WTP for cruising range of EVs and FCVs

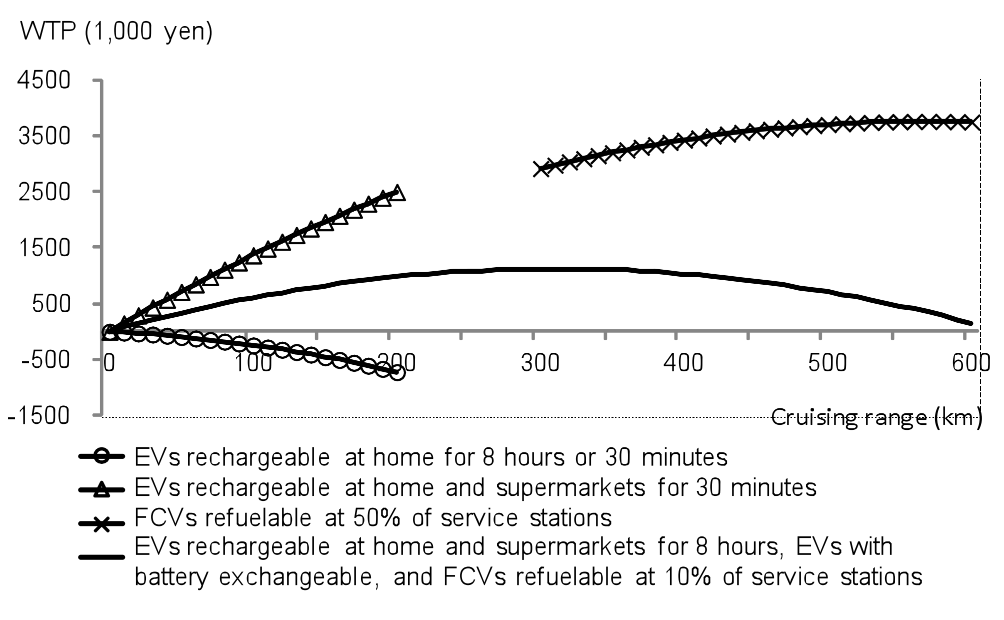


Table 5.1: Scenario forecasts of market shares of Toyota's subcompact/compact cars (%)

	GV		HEV		EV with rechargeable battery		EV with exchangeable battery		FCV	
Price of EV (million yen)	**S 1**	**S 2**	**S 1**	**S 2**	**S 1**	**S 2**	**S 1**	**S 2**	**S 1**	**S 2**
2	33.51	29.54	32.23	27.90	33.10	28.65	-	12.91	1.16	1.01
		(-3.97)		(-4.33)		(-4.45)	-	(+12.91)		(-0.16)
2.25	35.04	31.25	33.92	29.75	29.82	26.15	-	11.78	1.22	1.07
		(-3.79)		(-4.17)		(-3.67)	-	(+11.78)		(-0.15)
2.5	36.47	32.89	35.52	31.54	26.73	23.73	-	10.69	1.28	1.14
		(-3.58)		(-3.98)		(-2.99)	-	(+10.69)		(-0.14)
2.75	37.80	34.45	37.02	33.27	23.84	21.43	-	9.65	1.34	1.20
		(-3.35)		(-3.75)		(-2.42)	-	(+9.65)		(-0.14)
3	39.02	35.92	38.41	34.91	21.18	19.24	-	8.67	1.39	1.26
		(-3.10)		(-3.51)		(-1.93)	-	(+8.67)		(-0.13)
3.25	40.14	37.29	39.70	36.45	18.73	17.20	-	7.75	1.43	1.32
		(-2.85)		(-3.25)		(-1.53)	-	(+7.75)		(-0.12)
3.5	41.15	38.55	40.87	37.88	16.51	15.30	-	6.89	1.48	1.37
		(-2.60)		(-2.98)		(-1.21)	-	(+6.89)		(-0.11)
3.75	42.06	39.71	41.93	39.21	14.50	13.56	-	6.11	1.51	1.42
		(-2.35)		(-2.72)		(-0.94)	-	(+6.11)		(-0.10)
4	42.88	40.77	42.88	40.42	12.69	11.96	-	5.39	1.55	1.46
		(-2.11)		(-2.46)		(-0.73)	-	(+5.39)		(-0.09)

Note: The columns of S1 and S2 demonstrate the forecasts of market shares in Scenario 1 and Scenario 2, respectively. In Scenario 1 there is no alternative of EVs of exchangeable battery type. Scenario 2 adds the alternative of EVs of exchangeable battery type to Scenario 1. The values in parentheses denote the change in market share from Scenario 1 to Scenario 2.