Consumer preferences for hydrogen fuel cell vehicles in Japan

Abstract

After the successful adoption and deployment of electric vehicles in Norway with the support of generous government-led incentives, several other countries began introducing policy incentives for environmental-friendly vehicles. In light of Japan's goal of becoming a hydrogen society, this paper examines the preferences of Japanese citizens for hydrogen fuel cell vehicles (HFCVs) through a stated preference discrete choice experiment involving carefully chosen vehicle attributes and incentives. To this end, it uses mixed logit model on the choice scenario data to elicit the behavioral responses. Governmental incentives such as free public parking and free public transport significantly impact the preferences for HFCVs. In terms of socio-demographic characteristics, education and apartment parking remarkably affect the adoption of HFCVs. Although the preference of Japanese consumers for HFCVs is significantly lower than that for conventional vehicles, a well-designed package of policy incentives involving free public parking and public transport can drive Japan's push for HFCVs in the long run.

Keywords: Consumer preferences in Japan, Fuel cell vehicles, Governmental incentives, Hydrogen society, Mixed logit model, Stated preference discrete choice

1. Introduction

In the wake of the recent fuel technological advancements in the automotive sector, it is crucial for automakers to understand consumers' preferences for these fuel technologies and effectively forecast the adoption of new developments. This paper thus aims to address this need by modeling consumers' preferences for hydrogen fuel cell vehicles (HFCVs) using a stated preference (SP) discrete choice experiment on a dataset collected from a sample of individuals in Japan.

This research aims to predict respondents' future behavior towards hydrogen-powered vehicles in the presence of governmental policy incentives. In the choice task for the SP discrete choice experiment for potential car buyers, we introduce the chosen vehicle attributes along with government financial and non-financial incentives and then determine their effectiveness. This research seeks to answer two questions: (i) What are the most important vehicle attributes that supplement the SP for hydrogen fuel cell vehicles (HFCVs) (ii) How can government incentives stimulate the preference for HFCVs among Japanese consumers?

Japan is at the forefront as the world's first hydrogen society (eco-friendly society) for the 2020 Summer Olympics to be held in 2021. Hydrogen-powered buses will be officially used to transport staff between venues at the games. As such, the 2020 Olympic and Paralympic Games are a chance for the hydrogen advocates in Japan to showcase this advanced fuel technology, while the Japanese government is keenly focused on increasing public awareness and accessibility of HFCVs. Japan hosted the world's first Hydrogen Energy Ministerial Meeting in 2018 and recently conducted the second round of the cabinet-level meeting, where participants discussed the future direction of the policies for the utilization of hydrogen at a global level and released a “Global Action Agenda” as an action guideline for the development of hydrogen fuel cell infrastructure (METI, 2019).

In consideration of the 2015 Paris climate agreement, Japan established the “Basic Hydrogen Strategy” in 2017 as an action plan to cut greenhouse gas emissions. In 2018, its top automakers and energy firms formed a consortium to promote the development of hydrogen stations. This consortium, named “Japan H2 Mobility” (JHyM), aims to build 80 new hydrogen stations by 2021 in a bid for the country to become the world leader in cutting carbon-emissions amid the global transition towards a carbon-free society.

Following the March 2011 Fukushima nuclear disaster, Japan struggled for sustainable energy security. The challenge for policymakers was not only to decarbonize the energy systems but to ensure the continuous supply and safety of the energy systems during future natural disasters. Now, in Fukushima Prefecture, the world’s largest-scale hydrogen production facility has been inaugurated and is fully functional to support JHyM’s goal of 40,000 hydrogen-powered fuel cell vehicles by 2020 (METI, 2017).

The Japanese government is providing substantial financial subsidies to increase HFCV ownership. Currently, in Japan, government provides different financial incentives on clean fuel vehicles to promote shift towards environmentally friendly vehicles. Originally, the Toyota Mirai (one of the only three commercially available hydrogen-powered vehicles) cost around USD 70,000 and a subsidy reduced it to USD 50,000. Significant difference in the number of sales of HFCVs and other fuel technologies represent the behavioral differences among the respondents. Rational choice theory has a major role in individuals’ social and economic behavior during decision making process. California’s hydrogen market is larger than Japan’s in terms of number of hydrogen vehicles, and hydrogen buses, though, Japan has the largest hydrogen stations network in the world with more than double the number of refueling stations as that of California. Financial subsidy is almost the same in both the geographies, but people tend to behave differently based on their socio-economic preferences, and cultural norms. Consumers perceive policy incentives differently based on their personal preferences irrespective of the fact that policy incentives such as national tax rebates (vehicle registration or road tax) or subsidies apply to everyone in a country equally. On the contrary, the effectiveness of the policy incentives on different technologies, as well as their feasibility depends on several factors and cannot guarantee the positive effect on any specific vehicular technology.

There are approximately 11,000 hydrogen-powered vehicles in use worldwide; half of them are in California (which has stringent vehicle emission regulations), while Japan has only around 3,400 (JHyM, 2019). Japan aims to reach 160 hydrogen recharging stations by 2021 and 800,000 HFCVs sold by 2030 (JHyM, 2019). Similarly, Germany is also bracing for hydrogen development and is the second country worldwide in terms of the number of hydrogen recharging stations, with 43 in operation.

In the international auto market, the debate continues over whether the future belongs to HFCVs or battery electric vehicles (BEVs) in the wake of the cynical remarks made by Tesla's Elon Musk regarding hydrogen-powered vehicles (businessinsider.com, 2016). In 2017, KPMG surveyed 1,000 auto executives; 78% believe that HFCVs have a more promising long-term future than electric cars (KPMG, 2017). Although BMW has canceled its plans to develop HFCVs given the low consumer preferences towards these vehicles, Toyota, as the largest player in the consumer market for HFCVs, is expecting a boost in sales with the increase in the number of fueling stations (Fuel Cell & Hydrogen Energy Association, 2019).

In the past, SP surveys have been extensively used in fields such as environmental economics, marketing, healthcare, and transportation studies for forecasting decisions and suggesting possible choices in hypothetical situations given a specific set of attributes and alternatives to respondents. The ability of SP surveys to study individual preferences in a context that efficiently reduces the cognitive effort of respondents has made them a potent data paradigm to study consumers' decision-making processes (Cherchi and Hensher, 2015) and is thus suitable for a study of this nature.

The remainder of this paper is organized as follows. The next section reviews the literature on consumer preferences for AFVs and justifies the need for this study to examine consumer preferences for HFCVs in the Japanese market. The third section presents the survey design and describes the survey dataset, while the fourth section reports the modeling approach used. The results of the model estimations are presented in the fifth section and policy implications and conclusions are delineated in the sixth and final sections, respectively.

2. Literature Review

Over the past decades, many empirical studies on consumer preferences for alternative fuel vehicles (AFVs) including plug-in electric/hybrid vehicles (PHEV/HV) and BEVs have been conducted. Researchers used discrete choice experimental studies (DCEs) for evoking preferences based on hypothetical scenarios where individuals are provided alternatives with multiple attributes and policy incentives (Hensher et al., 2005; Carson and Louviere, 2011). The conjecture is that governments can draft and implement effective policies based on a better understanding of respondents' decision-making processes. Following the rise in greenhouse gas emissions, the international commitment to cut carbon emissions and the development of new fuel technologies led to consumer behavior research using new modeling approaches and choice scenarios under new fuel technologies and their attributes. This research builds on the rich body of literature on consumer preferences for new fuel technologies, which has primarily focused on the US, Canada, and Europe.

2.1. Adoption of BEVs and PHEV/HVs

Earlier studies on AFVs before and after the 1990s focused on the demand of BEVs, and hybrid vehicles (HVs). For instance, Beggs et al. (1981) studied the demand for BEVs by applying an ordered logit model to SP data. Train (1980) and Hensher (1982) estimated the potential demand for BEVs in the US and Australia, respectively. Bunch et al. (1993) estimated the demand for BEVs using nested logit and multinomial probit models. Train (1986) included hydrogen and hybrid vehicles in his SP survey for the first time, along with three types of BEVs. Brownstone et al. (1996) forecasted the demand for AFVs using SP data on 4,747 urban Californian households. Ewing and Sarigollo (1998) studied the preferences for cleaner fuel vehicles in a discrete choice stated preference study, and reported a large potential demand for electric vehicles.

In DCEs, consumers are provided choice sets containing vehicle attributes such as purchase price, driving range, vehicle fuel type and consumption, battery charging time, maintenance cost, CO2 emissions, motor power, and governmental incentives. According to the reviewed literature, some researchers solely focused on vehicle attributes and individual socio-economic characteristics for eliciting consumer preferences towards AFVs (Hensher and Greene, 2001; Train, 2008; Dagsvik and Liu, 2009; Hackbarth and Madlener, 2011; Hidrue et al., 2011;

Musti and Kockelman, 2011; Achtnicht, 2012; Daziano, 2012; Lebeau et al., 2012; Daziano and Achtnicht, 2013; Ida et al., 2013; Ito et al., 2013; Nie et al., 2018; Shin et al., 2019).

Kudoh and Motose (2010) investigated Japanese consumer preferences for BEVs by applying conjoint analysis on a dataset collected by the questionnaire survey during 2009–10. Lin and Greene (2011) assessed the potential impact of improved recharge availability and highlighted the greater impact of home recharging improvement on BEV-PHEV sales. In a survey conducted on adult drivers in large US cities, Carley et al. (2013) reported greater interest for PHEVs than all electric vehicles. Results showed positive impact of environmental concerns, previous experience of hybrids, and education on stated preference of PHEVs. Other studies also reported a strong correlation between pro-environmental attitudes and stated preferences for alternative fuel vehicles (Zielger, 2012; Schuitema et al., 2013). Ito et al. (2013) examined the potential demand for infrastructure investment in AFVs based on Japanese consumers' WTP for this type of vehicle under various refueling scenarios. Potential PHEV respondents viewed climate change as a greater threat to humanity (Krupa et al., 2014). Hoen and Koetse (2014) discussed the characteristics of BEV adopters, such as consumers with low annual mileage, parking spaces at home, and those who do not use a vehicle on vacation. Furthermore, Tanaka et al. (2014) performed comparative discrete choice analysis to estimate Japanese and US consumers' WTP for BEVs and PHEVs based on an SP survey conducted in 2012. In the discrete choice experimental study of Wang at el. (2017), the license plate incentive significantly impacts the promotion of BEVs. Carlucci et al. (2018) explored the preferences for hybrid fuel technology and identified the Japanese market as having the world's highest market penetration in terms of HVs. The exploratory research conducted by Huang and Qian (2018) on Chinese consumer preferences for electric vehicles mentions the behavior of the respective population sample as being more sensitive to vehicle price, purchase subsidies, and coverage of fuel/charging stations. Long et al. (2019) concluded that the lack of awareness of BEV technology is a hindrance in the wide-spread adoption of electric vehicles globally. Yoshida (2019) concluded that Japanese consumers seem to prefer HVs over other AFVs, considering the gasoline, hybrid, PHEV, and BEV technologies. Kurani (2020) mentioned the positive impact of awareness e.g., charging infrastructure, incentives, and costs on plug-in electric vehicles evaluations.

2.2. Overview of policy attributes

Policy incentives have been proved to have a positive impact on individual adoption intention of electric vehicles in Norway (Hannisdahl et al., 2013; Carranza et al., 2013; Zhang et al., 2016; Haugneland et al., 2016; Bjerkan et al., 2016). After the successful adoption of electric vehicles in the Norwegian market based on different financial and non-financial policy measures, several other countries also started introducing substantial package of incentives to promote clean fuel vehicles. However, when we consider the characteristics of the consumer market, incentives vary across regions. China, considered as the world's largest market for BEVs, is promoting the BEV technology through different government-led policy incentives that differ from the incentives instrumented by the Norwegian government.

This paper mainly focuses on the impact of policy incentives on the diffusion of HFCVs in the Japanese consumer market. We summarize the studies that elicited consumer preferences for AFVs considering governmental policy incentives in Table 1.

[Table 1 here]

From Table 1, it is evident that most of the previous research is focused on the adoption of BEVs or PHEV/HVs. This is justifiable for western countries, where the hydrogen fuel-cell market is not yet well-developed and consumers are not fully aware of this technology. As stated in the introduction, automakers and governmental agencies in Europe and the US mainly focus on the promotion of BEVs and/or PHEV/HVs, also succeeding to a certain extent among Norwegians, Germans, Chinese, and North Americans. Our research mainly focuses on the impact of policy incentives on the diffusion of HFCVs in the Japanese consumer market.

2.3. Overview of consumer perception on HFCVs

In the literature, there are some significant studies on the behavioral response and perception towards HFCVs across Europe, and North America. Hardman (2019) correlated HFCV households with high incomes, previous experience in driving AFVs, higher education levels, and greenhouse gas emission concerns. Lopez Jaramillo et al. (2019) interviewed twelve HFCV drivers to investigate their perspective on this technology; respondents preferred HFCVs due to their long-range, shorter refueling time, price incentives, and environmental concerns. Lipman et al. (2018) highlighted the importance of hydrogen fueling infrastructure and HOV lane access in the purchase decision. A study on early adopter attitudes towards HFCVs highlights predominant consumer barriers, which include the lack of hydrogen infrastructure, the source of hydrogen, inability of HFCVs to be recharged from home, cost, and concerns on hydrogen safety (Hardman et al. 2017). The study on Londoners by Hardman et al. (2016) in an attempt to investigate attitudes towards HFCVs highlights a lack of knowledge on hydrogen technology, cost, and lack of refueling infrastructure as a major barrier in successful adoption of this technology. O'Garra et al. (2005) concluded that the knowledge of hydrogen technology was an important determinant of support for wider application in transportation. Mourato et al. (2004) correlated willingness to pay (WTP) with higher education levels, knowledge of hydrogen FCV technology, and environmental concerns for HFCVs. Altmann et al. (2003) mentioned price, and vehicle performance as the key influencing factor on decisions to purchase cleaner vehicles.

On the other hand, only a few empirical research studies on Japanese consumer preferences for hydrogen vehicles have been conducted. Deloitte conducted a comparative research study in 2014 on a dataset from six countries to examine AFV preferences. The alternative powertrains in their research were HV/PHEV, BEV, and fuel cell electric vehicle. The report concluded that 26% of the Japanese respondents preferred to be driving HVs in the next five years, while only 5% showed an interest in fuel cell electric vehicle (Brown et al., 2014). Itaoka et al. (2017) conducted a public perception survey in March 2015 in Japan regarding hydrogen, hydrogen infrastructure, and HFCVs. Investigations revealed a large increase in awareness and a relatively small improvement in understanding of hydrogen infrastructure, hydrogen as an energy source, and HFCVs. Ono and Tsunemi (2017) explored public acceptance of hydrogen refueling stations in Japan using binomial regression analysis. The results show that around sixty-five percent of the respondents were unbiased to accepting installation of hydrogen refueling stations. The acceptance rate for male respondents was more than thirty-four percent that of female respondents in terms of risks associated with the hydrogen station. Hienuki et al. (2019) found the positive relationship between exposure to hydrogen technology, and the acceptance in a study conducted on participants in a hydrogen energy technology introduction event in Yokohama, Japan.

In summary, the literature on Japanese consumer preferences does not fully reflect the key behavioral characteristics of respondents towards HFCVs nor the impact of policy incentives for the adoption of this technology. Therefore, this study fills the research gap by opening the door for new research in the field of Japanese consumer preferences for HFCVs. To the best of our knowledge, there is limited stated choice survey research investigating Japanese consumer preferences for HFCVs and considering policy incentives. This study fills this gap by taking into consideration carefully chosen vehicle attributes and policy incentives in a SP DCE for identifying Japanese respondents' preferences for HFCVs. To this end, it applies the mixed logit (MXL) model, which accounts for the correlation of unobserved factors that affect multiple-choice alternatives, as well as heterogeneity in consumer preferences. This could be particularly helpful for policymakers and the private investors aiming to increase the number of HFCVs and hydrogen recharging stations by adjusting their incentive schemes. Despite the fact that Japanese government has spent billions of dollars to promote green technologies, generally, it is considered that Japanese people are less oriented to environment when it comes to their discretionary spending, and the success of the nominally eco-friendly hybrid cars, like Toyota's Prius, in Japan was due to a confluence of factors that were economic in nature; better gas mileage, comparable purchase price, and government incentives. The incentives are also available for BEVs, and hydrogen vehicles; but the number of BEVs, and HFCVs sold in Japan is significantly lower as compared to their sales outside Japan. Respondents in different geographic markets i.e., Japan, Europe, and the US perceive governmental incentives differently. Public transportation systems, local transportation laws, country demographics, and people's distinctive attitudes, all influence in a distinct reaction to the policy incentives.

The sample data are from Aichi Prefecture, Japan (home to Toyota), where the investigation of preferences for HFCVs is thus essential and had not been undertaken previously. Aichi Prefecture has the largest number of HFCVs, and hydrogen refueling stations, in Japan (Statistics Japan: Prefectural Comparisons, 2019).

Overall, this research investigates consumer preferences for HFCVs in the presence of policy incentives using a discrete choice analysis and the influence of other factors in the decision-making process such as socio-economic characteristics and specific vehicle attributes. In our SP DCE, policy incentives and vehicle attributes are carefully selected, considering previous studies on AFVs as well as the characteristics of the Japanese automobile market.

3. Survey Design and Data

Computer-assisted web interviewing was used to collect the data from 500 potential car buyers in Aichi prefecture, Japan. To further increase the reliability of our survey, we screened the respondents by asking a question about their intention to buy any of the mentioned items (e.g., refrigerator, washing machine, car, and house) in the following two years. Only those respondents who selected "car" were able to complete the remainder of the questionnaire. The survey was comprised of two parts; the first part included questions on socio-economic characteristics such as age, income, education level, household size, job status, information on current and future vehicle ownership, frequency of traveling, familiarity with HFCVs, and the second comprised the SP experiment. A sample size of 500 respondents facing four choice tasks each yielded 2,000 observations. These observations have been used to estimate the multinomial logit (MNL), nested logit (NL), and MXL models, which will be explained in detail in the methodology section.

Respondents were presented hypothetical choice scenarios, containing comparable attributes for four types of fuel technologies, namely conventional vehicle (CV), PHEV/HV, BEV, and HFCV. Basic descriptions of these different fuel technologies were also shown to the respondents in an attempt to achieve unbiased responses[1]. In the choice scenario, PHEV and HV were coupled as one alternative owing to the mere difference in technology. PHEVs are similar to conventional hybrids in that they have both an electric motor and internal combustion engine; however, PHEV batteries can be charged externally. These four alternatives, each characterized by six attributes, generate a large number of vehicle choice combinations and sets, which is impractical for the respondents. As such, the attribute levels were designed using an orthogonal fractional factorial design by blocking as explained in Langbroek et al. (2016) and Hensher et al. (2001), thus reducing the number of possible cases while also maintaining orthogonality among attributes. The orthogonal design ensures independence among attributes to avoid parameter estimation biases, which tend to result from multicollinearity.

Orthogonal fractional designs remained the most widely used type of design for DCEs in the market research study. Some researchers also discussed D-efficient design in transportation surveys, which is an alternative to a simple orthogonal design, seeks to minimize standard errors, and yields more reliable parameter estimates. These designs attempt to maximize the information from each choice situation. In the literature review, we found that most of the previous researchers employed orthogonal designs to elicit consumer preferences. For this study, we relied on orthogonal design based on the assumption of zero correlation between the attributes, following the impetus of previous studies. Hess et al. (2008) found, in their comparative research, that the efficient design performed only marginally better than the orthogonal design.

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[1] Descriptions of the different fuel technologies shown to the respondents are as the followings. PHEV is a hybrid electric vehicle whose battery can be recharged by plugging it into an external source of electric power, as well as by its gasoline engine. HV combines a gasoline engine system with an electric propulsion system, which cannot be recharged by plugging. BEV exclusively uses energy stored in battery packs recharged by plugging. HFCV uses a fuel cell to power its electric motor, emitting only water and heat.

Bliemer and Rose (2011) empirically examined the differences between data sets collected using different experimental designs and found that D-efficient designs produce better estimates and recommend that studies must explore the power of D-efficient designs.

While many standard orthogonal arrays are available, each is meant for a specific number of independent design variables and levels. We generated our design of experiments using L36 orthogonal arrays to better understand the main effects. Orthogonal arrays refer to designs that are both orthogonal and balanced, hence optimal. Each design is balanced—each level occurs the same number of times within each factor—and orthogonal—every pair of levels occurs the same number of times across all pairs of factors in each design. The main effects design is sufficient to explain the choices made by respondents. According to Louviere et al. (2000):

- Main effects typically account for 70–90% of the explained variance;
- Two-way interactions typically account for 5–15% of the explained variance; and
- Higher-order interactions account for the remaining explained variance.

The vehicle attributes in our SP design were carefully chosen based on an extensive literature review on the preferences towards AFVs, especially in the Japanese auto market. Yoshida (2019) mentioned that Japanese consumers emphasize CO_2 emissions and the purchase price in his study on consumer preferences for AFVs. Tanaka et al. (2014), in his comparative discrete choice analysis among Japanese and US consumers, highlighted Japanese consumers' sensitivity towards driving range and emissions. Ito et al. (2013) examined the potential demand for infrastructure investment by applying an SP survey and mentioned the importance of fuel infrastructure for the market penetration of new vehicle technologies. Based on this evidence, the attributes in our choice task include purchase price, fuel availability (Hoen and Koetse, 2014; Ziegler, 2012; Qian and Soopramanien, 2011), driving range (Liao et al., 2017; Langbroek et al., 2016), refueling/recharging time (Liao et al., 2017; Hackbarth and Madlener, 2013), and pollution level (Tanaka et al., 2014; Jensen et al., 2013; Ziegler, 2012). To depict realistic purchase decisions, purchase price was customized using the pivoting design methodology, which enables the respondent to input their intended vehicle price for various fuel technologies, ranging from -10% to +20%.

To ensure realism and reduce potential hypothetical bias, we only introduced specific attributes that have been characterized as the most important in the successful adoption of HFCVs (Hardman, 2017; Lipman et al., 2018; Wang 2015; Park et al. 2011) to make it easier for the respondents to choose the vehicle in the choice task without a high burden or risking the quality of responses. An excessive number of attributes and levels can result in the disengagement of the respondent's interest from the questionnaire survey; therefore, maintaining the balance between realism and complexity is critical in building an SP survey.

The literature shows the importance of reoccurring and non-financial incentives for the successful diffusion of AFVs, as well as how these policy incentives impact consumer purchase decisions. Egnér and Trosvik (2018) concluded that the impact of parking is more cost-effective than offering purchase subsidies in their research on Swedish consumers. Bjerkan et al. (2016) concluded that toll fee waivers, free parking, and bus lane access are the most important incentives in promoting PEVs in Norway. Huang and Qian (2018), in their SP experimental study on China, showed that consumers are more sensitive to purchase incentives and charging infrastructure availability than to congestion charge exemptions. Based on these previous studies on the importance of policy incentives, we introduced specific policy incentives for HFCVs in our SP design experiment, considering the need for such policy interventions for the successful diffusion of this technology. As a result, we included the following governmental policy incentives in the light of previous research on the adoption of BEVs and PHEV/HVs (Hardman, 2019; Liao et al., 2017; Wang et al., 2017):

- Free public parking;
- Tax discounts;
- Toll exemption on expressways; and
- Free public transport on weekends.

Other than tax discount, all these incentives are notional, as they are not implemented for any AFVs in Japan. In the past, Japan introduced a variety of financial incentives to purchase green vehicles (e.g., PHEV/HV and BEV), including exemptions from acquisition tax at purchase and some reductions in tonnage tax, both totaling approximately 5.7% of the purchase price (JAMA, 2015). Additionally, we also determined the impact of consumers' socio-economic characteristics on the SP for different fuel technologies. **Table 2** shows these attributes and their levels for the different fuel technologies presented in the choice task, while **Figure 1** presents the actual choice set, translated into English.

[Table 2 and Figure 1 here]

Table 3 shows the basic demographic characteristics of the potential 500 car buyers. Female respondents comprised 36% of the sample, and in line with the population statistics of the Aichi Prefectural Government, our dataset is dominated by male respondents that account for 64% of the sample population. Aichi is one of the only prefectures in Japan where male population is larger than female population (Statistics Bureau of Japan, 2018). In the National Livelihood Survey conducted by the Ministry of Health, Labour and Welfare in 2017, the average yearly income of Japanese households was between JPY 5.5–6 million (USD 50,000–55,000), while the households in our dataset have an average yearly income of JPY 4.8 million, which is a rough estimate of the average household income of the population in Aichi Prefecture. A recent survey by a Japanese online job-search website published the average annual salary in Japan as JPY 4.14 million (Doda, 2018) and showed the difference in the maximum and the minimum average salaries counted through different surveys and conditions. The employment status survey in 2017 by the Bureau of Statistics showed that 59.7% of the population was engaged in work, either as regular or irregular office staff, and 62.6% was engaged as company employees; this shows the consistency of the questionnaire survey.

However, the demographic characteristics of our survey respondents do not correspond to the rest of the population of Japan. The average household size in our investigation sample is 3.03, which is above the 2018 average as mentioned in the Statistics Bureau of Japan. Furthermore, the average household owns 1.7 cars, which is in disparity with the statistics of Japan's Automobile Inspection and Registration Information Association (2019), according to which, on average, a Japanese household owns 1.06 cars, down from 1.12 in 2006. This contrast is explicable, as car ownership primarily depends on the location of the household. In any case, our sample outlines the demographics of the population in Aichi prefecture only (home to Toyota), in which cars remain in higher demand.

[Table 3 here]

Figure 2 shows the comparative analysis of respondents' preferences for different fuel technologies. To gain a deeper insight into the respondents' adoption of different fuel technologies, a question asking for respondents' interest in fuel technologies was answered with multiple responses. The rate of respondents with interest in conventional vehicles is lower than the rate of current conventional vehicle ownership, which may imply the increase in the rate of AFV ownership in the near future. In the SP experiment, 16.6% of respondents chose HFCVs as their future vehicles compared to only 6.4% of the population showing interest in this fuel technology. Furthermore, 21.2% of the population showed their interest in BEVs compared to 9.5% in the SP experiment. As such, to increase the market share of BEVs and HFCVs, lawmakers should consider generous incentives for the development and adoption of these fuel technologies.

[Figure 2 here]

Norway framed a clean environment goal back in the 1990s by introducing financial and non-financial incentives for the adoption of BEVs and achieved the desired number of BEVs before the deadline; now, it is due to revoke some of the policy incentives introduced in the earlier BEV adoption phase. For HFCV adoption, these types of policy incentives can be beneficial in the Japanese market as well.

4. Analysis

In this study, consumer preferences for HFCVs and the impact of policy interventions are studied through parameter estimates generated through discrete choice models. This section is derived from the pioneering works in discrete choice modeling by several authors (e.g., McFadden, 1974; Brownstone et al., 2000; Bhat and Castelar, 2002; Hensher and Greene, 2003). In discrete choice modeling, the most widely used model is the MNL due to its fast and straightforward parameter estimations.

McFadden (1974) computed the necessity for the logit's unobserved part to follow a type I extreme value (Gumbel) distribution. This means that the error term for one alternative is uncorrelated with the error term for the second alternative in the choice task. Due to the restriction in substitution patterns in the use of the MNL model, researchers introduced models flexible in handling the unobserved part of utility. One such model is the NL model, which was also used by Soopramanien (2011) for determining consumer preferences for AFVs in China. MNL and NL also take closed-forms, as they are derived with the assumption of i.i.d. extreme value and a type of generalized extreme value, respectively.

For the MXL model, the researcher can set any distribution for the unobserved portion of utility and the resulting integral is not closed-form. In other words, the MXL model is highly flexible and relaxes the limitations, as it accounts for the random taste variation and correlation in unobserved factors over time (McFadden and Train, 2000). Most researchers prefer the MXL model due to its reliable estimates and flexibility. Unlike the probit model, where a researcher is restricted to the normal distribution, MXL can use normal, log-normal, triangular, or uniform distributions in line with the researcher's specification.

The MXL model is the generalization of the standard logit model as follows:

$$P_{ni} = \int \left[\prod_{t=1}^{T} \frac{e^{\beta X_{nit}}}{\sum_{j \varepsilon C} e^{\beta X_{njt}}}\right] f(\beta | b, W) d\beta, \qquad (1)$$

where

P_{ni} = *probability of choosing alternative it at scenario t (t = 1 to T) for decision-maker n;*

C = *choice set*;

$j \,\mathcal{E}\, C$ = *alternative j in the choice set C*;

T = *total number of scenarios*; *and*

$f(\beta | b, W) = density\ of\ \beta, assumed\ to\ be\ normal\ for\ random\ parameters\ with\ mean\ b\ and\ covarience\ W.$

MXL models can be estimated through fast simulations, whose robustness can be ensured with a higher number of Halton draws for maximum likelihood estimation. Choice probabilities in MXL models take the form of a multidimensional integral over a mixing distribution (see, e.g., Brownstone and Train, 1999). The integral generally does not have a closed-form, and so it must be evaluated numerically. Hole (2007) mentions that the accuracy of the results increases with the number of draws; as such, we estimated models with 100, 125, 500, 750 points to assess convergence and our final model is fitted using 1,000 Halton draws for the maximum simulated likelihood estimation.

The predictors in our SP experiment are divided into attributes linked to alternatives in the choice task and the socio-demographic characteristics of the respondents. The literature shows mixed results regarding the policy incentives for AFVs (e.g., Huang and Qian, 2018; Wang et al., 2017; Bjerkan et al., 2016; Li et al., 2016).

The data gathered through computer-assisted web interviewing included a SCE. To recruit the respondents, the services of a marketing research company were used. As previously mentioned, we obtained 2,000 observations from 500 potential car buyers, with no incomplete answers. We transformed the data using dummies coded for certain categorical events. Following **Table 4** shows the variables considered in the deterministic part of the utility for our model estimation.

[Table 4 here]

5. Results

This study exerted a Mixed logit model (MXL) that explicitly accounted for correlations in unobserved utility over repeated choices by each respondent[2]. **Table 5** shows the estimation results of the MXL model. First, the log-likelihood value significantly improved with the inclusion of preference heterogeneity. We observed highly significant negative coefficients for alternative specific constants (ASCs) for the third and fourth alternatives, and w.r.t. to the reference alternative, that is, CV. The ASCs are negative as expected since one's current vehicle is likely a good preference as compared to other alternatives. Conventional vehicles are generally preferred among respondents as compared to other alternatives. Large standard deviation values for these constants signify the preference heterogeneity w.r.t. these parameter estimates.

[Table 5 here]

The coefficients on the purchase price and recharging time show consumer behavior towards low priced cars and recharging time. Both low price and recharging time have a positive impact on the uptake of HFCVs, as low recharging time draws positive consumer attitudes. Free public transport on weekends is significant for current non-owners at the 95% confidence level, while toll exemption on expressways is significant for current multiple vehicle owners at the 90% confidence level. Previous studies on consumer preferences for the adoption of AFVs considering policy incentives discussed the insignificant coefficients of policy attributes for their samples (e.g., Ščasný et al., 2015; Soopramanien, 2011).

[2] We also estimated MNL and NL models for comparison purpose; the results are presented in the Appendix. The results show that NL models are statistically significantly better than MNL, and suggest significant error correlations between CV and PHEV/HV as well as BEV and HFCV. The correlation structure of NL models is consistent with that of the MXL model developed in this study. The results also suggest that the MXL model statistically fits our data better than the NL models.

Regarding individual characteristics, there is variance in the literature regarding their impact (either positive, negative, significant, or insignificant) based on the location of the sample and the choice modeling technique (e.g., Hoen and Koetse, 2014; Hackbarth and Madlener, 2013; Soopramanien, 2011). A discrete choice analysis conducted on a Danish sample by Mabit and Fosgerau (2011) shows that female respondents chose HFCV and BEV over CV in the SP experiment. Our results show negative preferences for HFCVs by male respondents.

Respondents' current vehicle price positively impacts the adoption of PHEV/HVs; this is quite rational, as the average price for the current vehicle reported by respondents is JPY 2.57 million, which is a large difference in monetary value compared to the commercial price of the Toyota Mirai. AFV owners are more likely to adopt environmentally friendly fuel technologies in the SP experiment than others, while homemakers are unlikely to adopt AFVs. Concerning the impact of education on the SP for HFCVs, we obtain the expected significantly positive response for HFCVs from respondents with graduate-level education. This is in line with the outcome of other DCEs, where respondents with higher education levels chose HFCVs (e.g., Hardman, 2019; Martin et al., 2009).

For PHEV/HVs, we obtained highly significant negative SP for the respondents with apartment associated parking. They seem to be reluctant due to the unavailability of charging infrastructure in the apartment blocks. Furthermore, respondents showed a significant positive SP towards HFCVs, as hydrogen is similar to conventional gasoline/diesel fuel in that no charging infrastructure is required. Interestingly, non-owners showed a higher SP for PHEV/HVs over BEVs and HFCVs. We allowed for the correlation of a set of alternatives and obtained the matrix with Cholesky decomposition elements. The terms in this covariance matrix are highly significant, underpinning the correlation in the stochastic part of the utility due to repeated observations by the same individual. This shows the flexibility of the MXL model over simple logit in addressing consumer preference heterogeneity in the SP choices.

We compared the arc marginal effect of policy incentives with the arc marginal effect of the purchase price being reduced by JPY 1 million. The arc marginal effect of policy incentive x_i is:

$$AME(x_i) = P_r(choice = 4th|x_i = 1) - P_r(choice = 4th|x_i = 0).$$

The arc marginal effect of reducing the purchase price by JPY 1 million is represented by the following equation with P^O as the original purchase price in million JPY:

$$AME(p) = P_r(choice = 4th|P = P^O - 1) - P_r(choice = 4th|P = P^O).$$

Figure 3 represents the impact of the altered purchase price for the fourth alternative and the change of probabilities with and without incentives.

[Figure 3 here]

The arc marginal effect of the purchase price shows consumer sensitivity towards price and the importance of policy incentives along with a decrease in purchase price. Policy incentives are intended for the successful inclusion of new technologies.

However, such initiatives, either financial or non-financial, are initially costly for the government. Currently, non-financial incentives are lacking in the Japanese consumer market for HFCVs, and policymakers should consider their implementation while keeping in mind the success story of Norway in terms of BEV adoption. Financing consumer incentives is one way to encourage the market adoption of HFCVs. Often manifesting in the form of tax breaks, government incentives can effectively bring the price of alternative fuel vehicles down to more affordable price ranges. The consumer valuation of non-financial incentives such as free parking or access to bus lanes makes these incentives an efficient alternative to expensive subsidies. For Japan, a reliance on foreign sources of petroleum is an overriding concern for most of the past 50 years; other factors such as promotion of clean energy and environmental concerns, have also encouraged institutions to subsidize these technologies for a successful market adoption. If some consumers adopt HFCVs due to generous policy incentives, a majority of consumers can also adopt HFCVs; this is termed as a threshold effect, which indicates an association between a risk factor and a defined outcome above the threshold value. These financial and non-financial consumer incentives can be termed as market-pull policies that could help the new technology become successfully adopted in the market. This strategy had been proven highly practical, as it has been practiced over the last 30 years in the automotive sector.

Some people are unaware of the financial benefits of purchasing HFCVs. To change this, the government must propose policy incentives to boost early adoption of HFCVs. The stepwise imposition of these incentives in the market can be beneficial with the outcome of HFCV adoption. **Table 6** shows the average marginal WTP for specific policy incentives. Free public parking accounts for a higher WTP compared to other incentives due to the higher SP by respondents, while free public transport on weekends has the lowest WTP. For instance, as parking fees in Japan are high as compared to Germany, proposing this incentive as a measure to boost HFCV sales could be beneficial.

[Table 6 here]

6. Conclusions

In the wake of Japan's government striving to lead the world in HFCV adoption, we identified consumer preferences for HFCVs through an SP discrete choice experiment for 500 potential car buyers. Most prior studies highlight the impact of policy incentives on the diffusion of AFVs; this study indicates the importance of the provision of non-financial incentives to foster an early transition to hydrogen-powered vehicles. We focused on the preference for HFCVs under the support of generous incentives. In line with previous research (e.g., Hoen and Koetse, 2014; Hackbarth and Madlener, 2013; Achtnicht et al., 2012; Qian and Soopramanien, 2011; Potoglou and Kanaroglou, 2007), we included vehicle attributes and governmental incentives in our SP experiment that are considered as imperative in the consumer market for vehicle adoption (e.g., such as characterized purchase price, fuel availability, recharging time, tax discount, free parking, and toll exemptions).

The estimation results support the notion of introducing non-financial incentives in the Japanese auto market for the successful diffusion of HFCVs. The provision of non-financial policy measures can act as a dominant factor in the widespread adoption of HFCVs, if considered as a non-financial policy measure along with providing financial incentives including tax discounts, and purchase price. Currently, HFCV purchase in Japan comes with a generous financial support that includes subsidy, and a tax exemption as a policy measure to introduce a new technology. These financial incentives combined up to ¥3M per vehicle, and can cut the HFCV price by 40% from the current cap of ¥7M. Despite these financial inducements that are in place since the commercial roll-out of world's first mass produced HFCV, Toyota Mirai, the government is still struggling to meet the initial sales target of 40,000 HFCVs on roads by 2020, that seems a distant dream. A package of financial, and non-financial incentives for electric cars, including exemption from public parking fees, toll charges, and funding for normal charging stations in shared apartment building, shopping malls, and parking garages stimulated Norway's electric vehicle success. In Japan, non-monetary incentives were never considered as a policy measure to incentivize HFCV public uptake. This study finds respondents greater valuation of free public parking, and free public transport than tax discounts. Accordingly, incentives such as free public parking, toll exemption, and free public transport may prove to be beneficial in building buyers' positive attitude towards HFCVs. AFV owners and those with higher education would prefer AFVs as their vehicles of choice. We can deduce that these policy incentives may be helpful if implemented alongside the availability of hydrogen fuel-cell infrastructure. Investment in the hydrogen sector by JHyM may not be perceived well if consumer preferences are not considered in the policy design and implementation stages. Most consumers are risk adverse and therefore, cannot adopt new technology against the ongoing market trend. Importantly, policy incentives such as tax credits and subsidies may have little impact on HFCV market if consumers have low confidence in HFCV technology (Egbue and Long, 2012). The main technical factors affecting the wide spread adoption of HFCV most often include (1) high prices, (2) lack of charging infrastructure, (3) awareness, and (4) lack of non-financial incentives. Currently, it can be said that adoption of HFCVs are bottlenecked by higher purchase prices. The descriptive statistics for the knowledge on HFCVs accentuate the lack of awareness of hydrogen fuel infrastructure and governmental incentives.

The Japanese government wishes to reduce the CO2 emissions in the transportation sector by 25% by 2030. This goal encourages stakeholders to invest heavily in hydrogen-related infrastructure to overcome the barriers to successful adoption. Full-fledged dissemination of hydrogen FCVs remains an issue, and the government wants reduce the prices of HFCVs by incentivizing the sector. Large-scale hydrogen fuel cell technology exhibitions are planned in the future to attract consumer support and awareness.

Extensions of this research may include a comparison between the estimates of revealed preferences and SP as well as the introduction of new business models in the SP discrete choice experiment for hydrogen-powered vehicles to make it easier for consumers to cover the monetary gap between income and vehicle price.

Limitations

This study has a potential limitation by the fact that two different fuel technologies were combined together and treated as the same alternative fuel technology in the hypothetical choice scenarios, containing comparable attributes for four types of fuel technologies, namely conventional vehicle (CV), PHEV/HV, BEV, and HFCV. Though, plug-in hybrid electric vehicles (PHEVs) are similar to hybrid vehicles (HVs) in that they have both an electric motor and internal combustion engine, except batteries in PHEV can be charged by plugging into an external charging outlet unlike HVs. This shortcoming in the SP choice scenario may have influenced the research findings as respondents may have different attitudes towards PHEVs and HVs. In order to gain a greater understanding of consumer attitudes towards HFCVs, authors intend to treat all fuel technologies available in the market, separately, in the future SP experiment. A future study will also gather data from the early adopters of HFCVs, in Japan, to explore in-depth consumer attitudes, and underlying barriers toward widespread adoption of HFCVs.

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Author Contributions

Khan Urwah: Conceptualization, Methodology, Software, Analysis, Investigation, Writing – Original Draft preparation,; Toshiyuki Yamamoto: Conceptualization, Validation, Investigation, Resources, Writing - Reviewing and Editing, Supervision, Funding Acquisition; Hitomi Sato: Resources.

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Table 1 Summary of the literature on the diffusion of AFV's considering policy incentives

Authors	**Policy incentives**	**Vehicle type & study area**	**Comments on policy intervention (conclusion)**
Hardman (2019)	1. Parking incentives 2. HOV lane access 3. Toll fee waivers 4. Licensing incentives 5. Tax exemption	PHEVs, BEV (Global)	Incentives can have a positive impact, but the effect differs between regions due to differences in travel patterns and consumer preferences
Wolbertus et al. (2018)	1. Daytime parking 2. Free parking	EVs (Netherlands)	Importance of charging and adaptation policy mix on EV adoption
Wang et al. (2017)	1. Discounted charging 2. HOV lane access 3. Driving restrictions 4. Tax exemption 5. Licensing incentives 6. Parking incentives	EVs (China)	Driving restrictions and licensing incentives significantly affect EV adoption compared to other incentives
Langbroek et al. (2016)	1. HOV lane access 2. Free parking 3. Purchase subsidies	EVs (Sweden)	Access to bus lanes and parking incentives are more effective than purchase subsidies
Ščasný et al. (2015)	1. Free public parking 2. Free public transport	PHEV/HVs (Poland)	Incentives such as free parking and public transport increases the probability of buying PHEVs
Hoen and Koetse (2014)	1. HOV lane access 2. Tax incentives 3. Parking incentives	FCVs and PHEVs, (Netherlands)	Lane access can significantly increase the adoption rate of AFVs
Ziegler (2012)	1.Electromobility subsidies 2. Tax incentives	FCVs, PHEVs, BEVs (Poland)	Adoption rate can be increased for AFVs with these policy instruments

Table 2 Attributes and levels for the stated choice experiment

Attributes	**Vehicle 1 (CV)**	**Vehicle 2 (PHEV/HV)**	**Vehicle 3 (BEV)**	**Vehicle 4 (HFCV)**
Purchase price (million JPY)	P (CV) = Specified by the respondent	(1) -10% of P (CV) (2) P (CV) (3) +20% of P (CV)	(1) -10% of P (CV) (2) P (CV) (3) +20% of P (CV)	(1) -10% of P (CV) (2) P (CV) (3) +20% of P (CV)
Fuel availability	100%	100%	100%	(1) 25% (2) 50% (3) 75%
Driving range	500 km	600 km	400 km	500 km
Refueling/recharging time	5 min's	(1) 30 min (2) 60 min (3) 180 min	(1) 30 min (2) 60 min (3) 180 min	5 min
Pollution level (% of a present-day average car)	85%	55%	No emissions	No emissions
Policy incentives	NA	NA	NA	(1) Free public parking (2) Tax discount (3) Toll exemption on expressways (4) Free public transport on weekends

Table 3 General characteristics of respondents (N = 500)

Social demographic predictor	**Level**	**Percentage (%)**
Gender	Male	64.0
	Female	36.0
Age (mean = 44)	21–30	21.4
	31–40	23.6
	41–50	23.0
	51–60	18.2
	61–70	13.8
Education level	Junior and high school	24.2
	Junior college and undergraduate	62.4
	Graduate school	11.2
	Others	2.2
Annual household income in million JPY (mean = 4.84 million JPY)	Less than 4	26.6
	4 to 9	44.4
	9 to 17	29.4
	Above 17	3.4
Employment status	Self-employed and part time job	16.4
	Company employee	62.6
	Homemaker	9.6
	Student	2.6
	Unemployed and others	8.8
Household size (mean = 3.03)	1	13.4
	2	23.0
	3	25.2
	4	27.2
	5	7.2
	6 or more	4.0
Car ownership (mean = 1.7)	0	3.6
	1	44.4
	2	36.8
	3	11.0
	4 or more	4.2

Table 4 Variable definitions

Variable	**Definition**
ASC PHEV/HV	1 if fuel type is PHEV/HV, and 0 otherwise
ASC BEV	1 if fuel type is BEV, and 0 otherwise
ASC HFCV	1 if fuel type is HFCV, and 0 otherwise
Purchase price	Purchase price in millions JPY
Fuel availability	Percentage of filling/recharging stations with proper fuel
Recharging time	Refueling time in hours
Free public parking	1 if incentive is granted, and 0 otherwise
Tax discount	1 if incentive is granted, and 0 otherwise
Toll exemption on expressways	1 if incentive is granted, and 0 otherwise
Free public transport on weekends	1 if incentive is granted, and 0 otherwise
Male	1 if the respondent is male, and 0 otherwise
Current vehicle price	Currently owned vehicle price in millions of JPY
Current ownership of AFVs	1 if the current fuel technology is AFV, and 0 otherwise
House husband/housewife	1 if the respondent is a homemaker, and 0 otherwise
Junior college and undergraduate	1 if the respondent has a junior college or undergraduate degree, and 0 otherwise
Graduate school educated	1 if the respondent is a university graduate, and 0 otherwise
Apartment associated parking	1 if the respondents currently have apartment associated parking, 0 otherwise
Current number of vehicles (0)	1 if the respondent currently owns no vehicle, and 0 otherwise

Table 5 Estimates for the MXL model

Explanatory variables		Coef.	Std. err.
Alternative specific constants			
ASC PHEV/HV	mean	-0.179	0.254
	std. deviation	3.176***	0.270
ASC BEV	mean	-3.247***	0.399
	std. deviation	3.963***	0.425
ASC HFCV	mean	-3.466***	0.641
	std. deviation	5.270***	0.485
Vehicle attributes			
Price	mean	-1.284***	0.170
	std. deviation	1.301***	0.264
Fuel availability (current CV owners and non-owners)		-1.201*	0.581
Fuel availability (current AFV owners)		0.633	1.362
Recharging time	mean	-0.219**	0.073
	std. deviation	0.437***	0.132
Governmental incentives			
Free public parking (current CV owners and non-owners)		-0.514(.)	0.282
Free public parking (current AFV owners)		1.896**	0.714
Tax discount (low income respondents)		0.302	0.298
Tax discount (others)		-0.881(.)	0.527
Toll exemption (current 0 or 1 vehicle owners)		0.016	0.362
Toll exemption (current 2+ vehicles owners)	mean	0.664(.)	0.388
	std. deviation	1.575**	0.592
Free public transport (current vehicle owners)		0.051	0.367
Free public transport (current non-owners)		1.107*	0.536
Socio-economic variables			
Male: PHEV/HV		-0.999***	0.212
Male: HFCV		-2.403***	0.370
Homemaker: PHEV/HV		-0.947***	0.352
Homemaker: HFCV		-1.974**	0.566
Apartment associated parking: PHEV/HV		-0.772***	0.212
Apartment associated parking: HFCV		0.352	1.029
Current vehicle price: PHEV/HV		0.185**	0.065
Current ownership of AFV: PHEV/HV		3.014***	0.340
Current ownership of AFV: BEV		1.867***	0.396
Current ownership of AFV: HFCV		0.352	1.029
Graduate school educated: HFCV		2.113***	0.507
Junior college and undergraduate: HFCV		0.833*	0.315
Current number of vehicles (0): PHEV/HV		1.565**	0.445
Error components			

Cholesky decomposition: BEV:BEV	3.963***	0.425
Cholesky decomposition: BEV:HFCV	3.526***	0.343
Cholesky decomposition: HFCV:HFCV	3.917***	0.438
Correlation: BEV:HFCV	0.669***	0.080
Log-likelihood value	-1,831	
Akaike's information criterion	3,732	

***, **, *, and (.) indicate statistical significance at the 0.5%, 1%, 5%, and 10% confidence levels, respectively.

Table 6 Average marginal WTP for the specific policy incentives

Attribute	**WTP (JPY)**
Free public parking (current AFV owners)	1,476,635
Toll exemption (current 2+ vehicle owners)	517,134
Free public transport (current non-owners)	862,150

Q16-1-1 Suppose you choose the next car to buy from the cars with the following conditions: Choose the car you want to buy the most.

Gasoline / light oil vehicles	Plug-in hybrid electric vehicle / hybrid vehicle	Electric car	Fuel cell vehicle
【Purchase price】	【Purchase price】	【Purchase price】	[Purchase price (Fuel cell vehicle price is subtracting subsidy)]
[Answer: Q15.c1] 4,000,000 Yen	[Answer: Q16HQ.c1] 4,000,000 Yen	[Answer: Q16HQ.c2] 4,800,000 Yen	[Answer: Q16HQ.c1] 4,800,000 Yen
[Gas station installation rate]	[Gas station / charging spot installation rate]	[Charge spot installation rate]	[Hydrogen station installation rate]
The same level as the current gas station	**The same level as the current gas station**	**The same level as the current gas station**	**1/2 of current gas station**
[Driving distance (km) with one refueling]	[Driving distance (km) with one refueling]	[Driving distance (km) with one refueling]	[Driving distance (km) with one refueling]
500 km	**600 km**	**400 km**	**500 km**
[Fuel filling time]	[Fuel filling time]	[Fuel filling time]	[Fuel filling time]
5 minutes	**in 30 minutes**	**3 hours**	**5 minutes**
【Environmental load】	【Environmental load】	【Environmental load】	【Environmental load】
85% of current situation	**55% of current situation**	**Zero emission**	**Zero emission**
[Preferential treatment]	[Preferential treatment]	[Preferential treatment]	[Preferential treatment]
nothing special	**nothing special**	**nothing special**	**1. public facilities of parking free 2. automobile tax free 3. highway toll the same as the current charge for 4. weekend public transport half price**

Figure 1 Actual choice set presented to respondents (English translation)

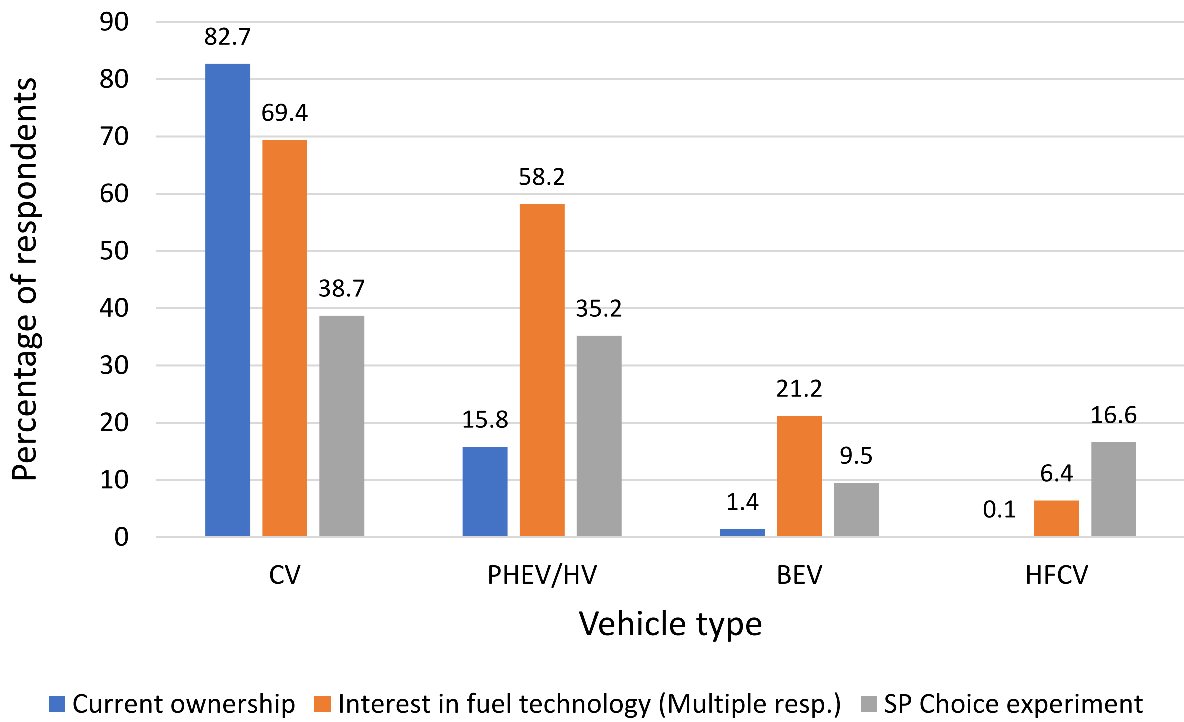

Figure 2 Comparison of vehicle fuel technology ownership

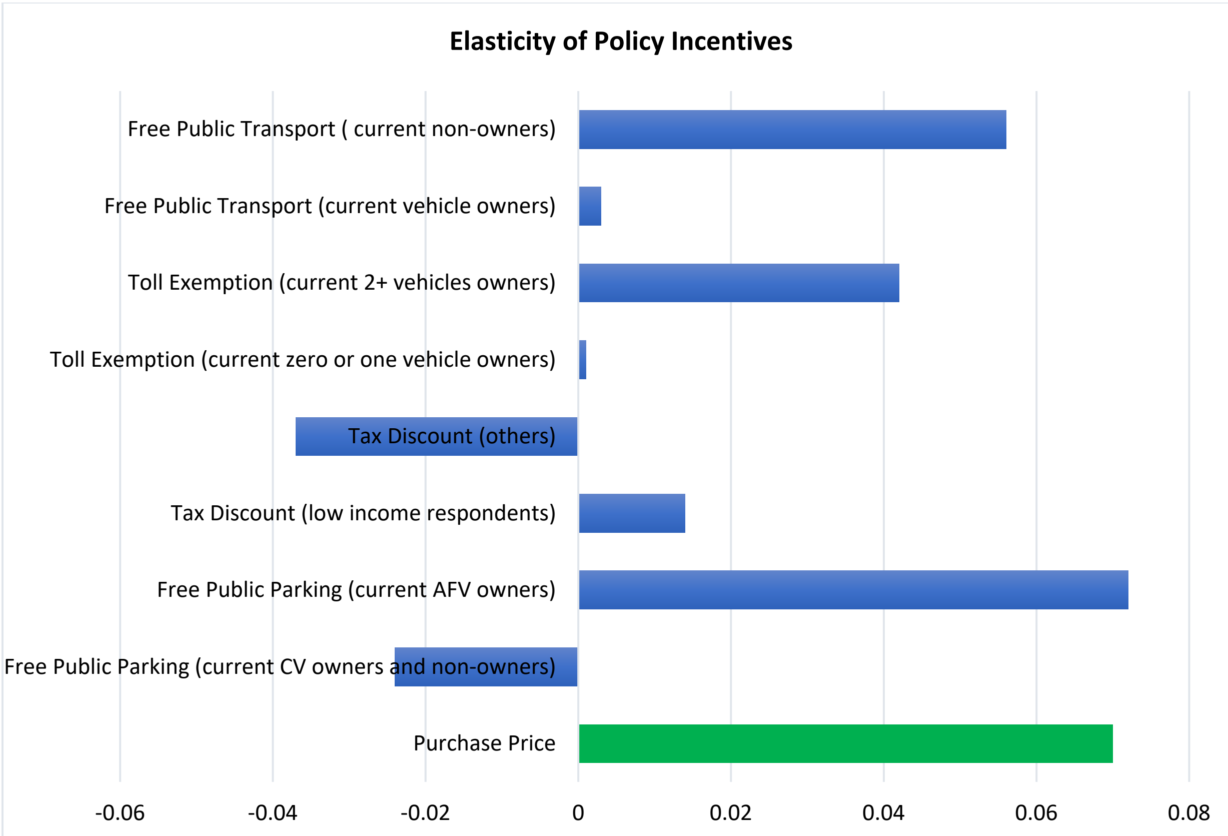

Figure 3 Comparison of arc marginal effects

Appendix

We considered five different nesting structures in our modeling analysis (see Figure A1). From the estimation, nesting structures b, c, and d were not fully consistent with the utility maximization criterion due to the large values of the log-sum coefficient.

The results in Table A1 suggest that the estimation of these three models yields similar coefficients in terms of significance levels and log-likelihood values. However, the NL model is flexible in terms of the IIA assumption, as the error terms of the alternatives in the same nest can be allowed to share unobserved effects, which the MNL model restricts. The significant log-sum value shows a positive correlation between the error terms of third and fourth alternatives. Estimates for the alternative specific constants (ASC) are highly significant for BEV and HFCV, and support the adoption of current vehicle technology. The estimates for the ASC are in line with the results of Maness and Cirillo (2012), who conducted an SP experiment for AFVs in Maryland, USA. All estimates are obtained by considering CV as reference in the model estimation. The parameter estimates for vehicle attributes such as purchase price and recharging time are significant and negatively impact consumers' preference for high priced vehicles and those with more recharging/refueling time, and these estimates are in line with Hoen and Koetse (2014) and Ziegler (2012). In NL model 2, the estimate for recharging time is significant at the 90% confidence level which is in contrast to the estimates from the MNL and NL model 1. The fuel availability for current CV ownership and non-owners negatively impact the preferences at the 90% confidence level in all three models. With respect to governmental policies, the estimates for free public transport for current non-owners and toll exemption on expressways for multiple vehicles owners are significant and positively impact the preference for HFCVs. Regarding socio-economic characteristics, male respondents negatively affect the stated preferences for AFVs, which contrasts with Hackbarth and Madlener (2013), where male respondents showed higher stated preferences for fuel cell and natural gas vehicles. The respondents with high education levels have higher SP for AFVs, as supported by previous research (e.g., Langbroek et al., 2016; Maness and Cirillo, 2012; Zeigler, 2012). Those decision makers who currently own no vehicles affect the stated preference for PHEV/HVs significantly and positively.

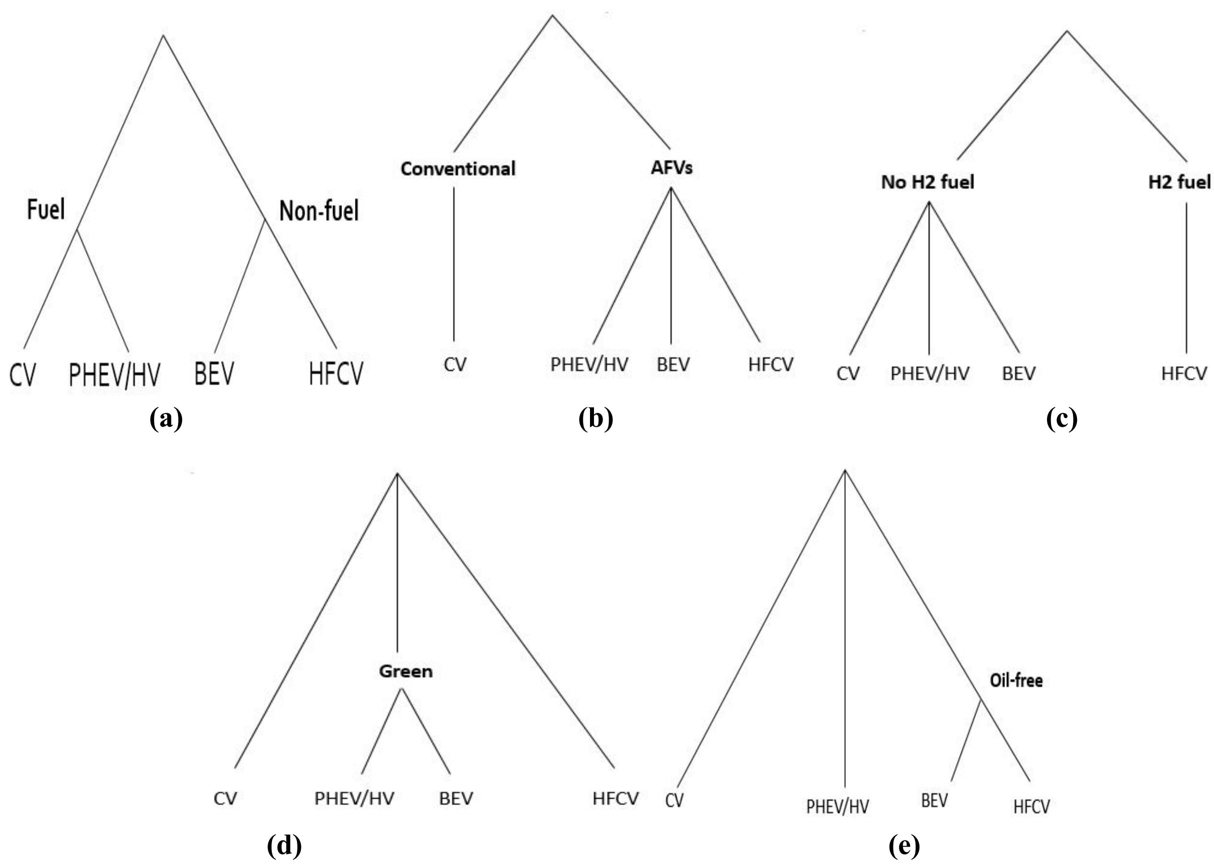

Figure A1 Tree structures of the five nested logit models

Table A1 Parameter estimates for the MNL and NL models

Explanatory variables	MNL	NL(1), C(3,4)	NL(2), C(1,2), C(3,4)
	Coef.	**Coef.**	**Coef.**
Alternative specific constants (ASC)			
ASC PHEV/HV	0.069	-0.017	0.015
ASC BEV	-1.407***	-0.999***	-1.242***
ASC HFCV	-0.646**	-0.566**	-0.860***
Vehicle attributes			
Price	-0.314***	-0.279***	-0.182***
Fuel availability (current CV owners and non-owners)	-0.520(.)	-0.416(.)	-0.376(.)
Fuel availability (current AFV owners)	0.212	0.210	0.160
Recharging time	-0.088*	-0.069*	-0.040(.)
Governmental incentives			
Free parking (current CV owners and non-owners)	-0.455***	-0.376***	-0.353**
Free parking (current AFV owners)	0.268	0.304	0.279
Tax discount (low income respondents)	-0.656*	-0.407(.)	-0.340(.)
Tax discount (other's)	0.148	0.071	0.065
Toll exemption (current 0 or 1 vehicle owners)	-0.084	-0.087	-0.072
Toll exemption (current 2+ vehicles owners)	0.328*	0.243*	0.222*
Free public transport (current vehicle owners)	-0.285	-0.215	-0.195
Free public transport (current non-owners)	0.628**	0.498**	0.446*
Socio-economic variables			
Male: PHEV/HV	-0.561***	-0.479***	-0.251**
Male: HFCV	-0.889***	-0.615***	-0.504***
Current vehicle price: PHEV/HV	0.081**	0.078**	0.043*
Current ownership of AFV: PHEV/HV	1.361***	1.353***	0.644***
Current ownership of AFV: BEV	1.020***	0.935***	0.477*
Current ownership of AFV: HFCV	0.581	0.596	0.144
Homemaker: PHEV/HV	-0.519**	-0.444*	-0.261*
Homemaker: HFCV	-0.689**	-0.435*	-0.347(.)
Graduate school educated: HFCV	0.645**	0.594**	0.544**
Junior college and undergraduate: HFCV	0.280 (.)	0.230*	0.202*
Apartment associated parking: PHEV/HV	-0.330**	-0.321**	-0.178*
Apartment associated parking: HFCV	0.438(.)	0.392*	0.364*
Current number of vehicles (0): PHEV/HV	0.619*	0.619*	0.342*
Log-sum coefficient		0.551***	0.480***
Log-likelihood value	-2,389.3	-2385.6	-2385.1
McFadden R^2	0.0493	0.0567	0.0569
Chi squared	248.05		
AIC	4,834.5	4,829.2	4,828.2

***, **, *, and (.) indicate statistical significance at the 0.5%, 1%, 5%, and 10% confidence levels, respectively.