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Analysis of Vehicle Demand by Fuel Types including Hydrogen Vehicles†

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ABSTRACT : This study analyzes the potential demand for automobiles based on fuel type using survey data in Korea. The dependent variable of the model is the future desired fuel type, including gasoline, diesel, hybrid, electricity, and hydrogen. The main explanatory variables are the respondent demographic characteristics, key reasons for choosing vehicle fuel type and environmental awareness extracted via principal component analysis (PCA). Using a multinomial logit (MNL) model, we find that respondents who consider fuel economy and infrastructure increase the demand for a hybrid car but decrease the demand for electric and hydrogen vehicles. The denial-types increase the demand for gasoline (petrol) and diesel (light oil), and decrease the demand for electric vehicles. The anxiety-types increase the demand of hybrid vehicles, and decrease the demand for electric vehicles. In contrast, in the case of pro-types, the demand for diesel (light oil) hydrogen vehicles decreased.

Keywords : Vehicle demand, Eco-friendly vehicle, Multinomial logit model, Principal component analysis

JEL Classifications : C38, Q5

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수소차를 포함한 연료유형에 따른 자동차 수요 분석†

박유현* · 김지영** · 이윤***

요 약 : 본 논문은 서베이 데이터를 이용하여 한국의 연료유형에 따른 자동차의 잠재적 수요를 분석한다. 종속변수는 휘발유, 경유, 하이브리드, 전기, 수소를 포함한 향후 희망 자동차 연료유형이며, 주요 설명변수는 응답자의 인구학적 특성과 희망 자동차 연료 유형 선택 시 고려사항, 주성분분석으로 추출한 환경에 대한 인식이다. 다항로지스틱모델을 이용한 분석결과는 다음과 같다. 연비와 운행편의를 고려하는 응답자들의 하이브리드차에 대한 수요는 높아지는 반면에 전기차와 수소차에 대한 수요는 낮아진다. 환경에 대한 부정적인 인식이 있는 응답자들의 휘발유차와 경유차에 대한 수요는 높아지는 반면 전기차에 대한 수요가 낮아진다. 환경에 대한 우려를 표하는 응답자들의 하이브리드차에 대한 수요는 증가하는 반면에 전기차에 대한 수요는 감소한다. 이와 대조적으로, 환경 친화적인 응답자들의 경유차에 대한 수요는 감소한다.

주제어 : 자동차 수요, 친환경 자동차, 다항로짓모델, 주성분 분석

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Ⅰ. Introduction

As environmental issues, such as air pollution and global warming caused by greenhouse gas (GHG) emissions, have become global issues, the international community has established the Inter-governmental Panel on Climate Change (IPCC), and agreements to resolve climate change issues are steadily progressing through the Conference of the Parties (COP). At the third COP in 1997, the international community approved the Kyoto Protocol and agreed on the national commitments to reduce GHG emissions. The commitment to reduce GHG emissions was extended to developing countries under the Paris Agreement at the 21st COP in 2015. Furthermore, the Glasgow Climate Pact was adopted at the 26th COP in 2021, which strengthened individual countries' reduction targets and stated the phase-down of coal power generation. Furthermore, when the IPCC announced the "Global Warming 1.5°C Special Report" in 2018 and suggested the need for achieving "2050 Net-Zero," the global community's goal went beyond simple GHG emission reduction to zero net carbon emissions.

South Korea declared "Net-Zero 2050" in October 2020 and announced the "Net-Zero 2050 Promotion Strategy," which outlined a thorough strategic scenario for carbon neutrality implementation. As of 2019, the energy sector accounted for approximately 87% of total GHG emissions in the country, implying that the energy transition is critical to achieving carbon neutrality. Therefore, the government intends to increase the share of renewable energy to 60.9% or 70.7% by 2050, according to the final draft of the "Net-Zero 2050 Scenario" announced by the Carbon Neutrality Commission in 2021 (Yoon, 2021).

Renewable energy, which utilizes natural elements, such as wind, sun, and water, is an environmentally friendly energy that emits no GHG. However, renewable energy has a disadvantage of being difficult to use consistently compared to other energy sources due to seasonality or regional deviations. In this regard, hydrogen energy is a significant alternative that can offset renewable energy's drawbacks. Therefore, the International

Energy Association (IEA) identified hydrogen as a future energy source to replace fossil fuels in 2015. Furthermore, the IEA stressed that hydrogen could help develop an eco-friendly energy consumption society by reducing carbon emissions. Furthermore, hydrogen can be produced in various locations, such as a by-product gas generated by natural gas and steel firms or electrolysis of water.

Unlike vehicles using fossil fuels, hydrogen cars generate no exhaust gases, such as carbon monoxide or nitrogen oxides, and have a function to purify more than 90% of the fine dust in the air, thereby attracting attention as next-generation eco-friendly vehicles. In other words, hydrogen energy can play a critical transitional role in shifting from a fossil-fuel-based economy to a renewable-energy economy. As the benefits of hydrogen become more widely known, several countries are considering various measures to develop the so-called "hydrogen economy"[1] (Austmann and Vigne, 2021).

Consequently, the South Korean government is actively pushing for the growth of the hydrogen car industry to achieve a hydrogen economy. According to Greenhouse Gas Inventory and Research Center in Korea, road traffic currently accounts the largest proportion of the carbon dioxide, approximately 96.5%, generated by the transportation sector, which is the largest. As a result, the growth of the hydrogen vehicle market is predicted to significantly contribute to reducing domestic carbon dioxide emissions. The Korean government has developed a specialized supply plan to expand hydrogen vehicles and hydrogen charging stations, thus, investing heavily in this area. It ultimately intends to build a hydrogen economy by developing hydrogen-related technologies. However, the government's expectations for hydrogen vehicle purchases have not been realized. It must first evaluate the present market conditions and consumer market demand to increase the supply of hydrogen vehicles.

Therefore, based on consumer preferences, this study examined vehicle demand by fuel, including hydrogen. In April 2022, a survey of adults aged ≥ 20 living in Seoul and

1) The hydrogen economy refers to an economic system that uses hydrogen as an energy carrier instead of conventional fossil fuels in the entire energy demand and supply value chain.

Gyeonggi Province was conducted. A total of 1,226 valid samples were analyzed, and the multinomial logit (MNL) model was used as the analytical model. The type of vehicle fuel desired in the future was the dependent variable. The study included eight types of vehicle fuels: gasoline, electricity, hybrid, hydrogen, LPG, CNG and other fuels. The environmental awareness questions and key considerations for choosing vehicle fuel types were introduced to the questionnaire as explanatory variables in addition to the respondents' population-specific factors. The environmental awareness values derived from the analysis of questionnaire responses using principal component analysis were used in the final model.

Chapter 2 explores the current state of eco-friendly vehicle policies and reviews past research. The model used in the analysis and the questionnaire's composition is explained in Chapter 3. Following is the presentation of the research results in Chapter 4. Finally, chapter 5 concludes this study with a summary and conclusions.

II. Background

1. Current State of Domestic Eco-Friendly Vehicle Support Policies, focusing on hydrogen vehicles

The "Five-year (2006 – 2010) Basic Strategy to Encourage the Development and Supply of Eco-friendly Vehicles" was established in December 2005, starting the legislation related to eco-friendly vehicles. The second master plan, the Green Car Industry Development Strategy and Tasks to Be Global Top 4 (2011 – 2015), was established in December 2010. Subsequently in December 2015, the third Master Plan for the Development and Distribution of Eco-Friendly Vehicles (2016 – 2020) was unveiled. Finally, the fourth Master Plan for Eco-Friendly Vehicles (2021 – 2025) was announced in December 2021 and is currently underway.

The government is attempting to reduce GHG emissions in the transportation sector by offering a variety of detailed policies centered on purchase subsidies and tax benefits, with the main goal of increasing the supply of eco-friendly vehicles. The vision of the recently announced Fourth Master Plan (2021 – 2025) is to reduce GHG emissions by increasing the supply of eco-friendly vehicles and growing the eco-friendly vehicle sector. The 2050 Net-Zero Promotion Strategy has established a path toward carbon neutrality. The objective is to supply 3.62 million electric vehicles, 880,000 hydrogen vehicles, and 4 million hybrid vehicles by 2030 for a total of 8.5 million vehicles. It also seeks to reduce the GHG emissions from the transportation sector by approximately 29.7 million tons.[2] The Fourth Master Plan comprises a variety of government-announced support policies. Representative examples include the Hydrogen Economy Activation Roadmap, Strategy for the Growth of the Future Automotive Industry, and Comprehensive Plan for South Korean New Deal.

The Fourth Master Plan consists of 17 detailed tasks in three sectors promoted as financial projects for 2021 and 2022. The contents of these three sectors are (1) building a social system that accelerates the supply of eco-friendly vehicles, (2) pioneering a carbon-neutral era through technological innovation, and (3) accelerating the transition to a carbon-neutral industrial ecosystem. In particular, the largest budget was invested in (1) establishing a social system that accelerates the supply of eco-friendly vehicles, which included seven detailed tasks, such as economic improvement, establishment and deployment of electric and hydrogen vehicle chargers, and conversion of commercial vehicles to eco-friendly vehicles.

Since the growth of eco-friendly vehicles is essential, the budget for related policies has also increased steadily. As a result, the budget for 2021 – 2022 increased by approximately 43% during the fourth plan period, from KRW 906.871 billion in 2021 to KRW 1,298.629 billion in 2022. In the Fourth Master Plan for 2022, the 'domestic supply' budget was KRW 773.547 billion, accounting for 59.6% of the total; followed by the 'technology development' budget of KRW 309.458 billion (23.8%) and 'infrastructure'

2) The target has been raised from the 2030 National Greenhouse Gas Reduction Goals (NDC) Upward Plan announced in October 2021.

budget of KRW 215.624 billion (16.6%).

The government's purchase subsidy support budget increased six times over the five years between 2018 and 2022. As of 2022, KRW 1.7 trillion for electric vehicles and KRW 0.7 trillion for hydrogen vehicles were planned as part of a total budget of KRW 2.4 trillion. Nevertheless, due to issues, such as procuring local finances, a lack of demand, and delayed shipment, the actual execution rate of the purchase subsidy has been slow. In the case of electric vehicles, the actual execution rate of the budgeted purchase subsidy was 71.3% in 2020, but it increased to 100.7% in 2021. In contrast, the actual execution rate of hydrogen vehicles was 54.6% in 2021. The absence of a purchasing demand was recognized as the main cause of the abovementioned issues. In addition to subsidies, there are other benefits, such as tax reductions. However, they are scheduled to be reduced gradually to account for the supply of eco-friendly vehicles and market maturity (Son and Kim, 2022).

2. Previous Research

Previous studies were conducted in South Korea using on-demand analysis for alternative fuel vehicles. Prior to the full-scale introduction of electric vehicles in South Korea, Chae et al. (2016) calculated the life cycle cost of electric vehicles, to determine the time at which they may be introduced, by vehicle type and applied this to a diffusion model to predict future changes in demand for electric vehicles. Hahn (2016) calculated the MNL-based vehicle type selection model to assess the impact of the eco-friendly vehicle supply policy adopted in 2015 and the GHG reduction effect. Kim et al. (2018) established a virtual market, conducted a survey, and examined the demand for electric vehicles based on household characteristics. Car ownership was considered a major household characteristic. According to the analysis, elasticity was high for factors related to actual use, such as fuel cost and charging time, in the case of households that owned cars. However, households that did not own cars had high elasticity to vehicle prices. Lastly, Ko (2020) employed a Mixed Logit Model to predict demand for hydrogen vehicles per the government's hydrogen vehicle supply policy. In addition, they modeled geographical disparities in the charging station's infrastructure and analyzed the influence of improving the charging station's usage circumstances on consumer vehicle selection. However, their preference poll did not consider individual consumer characteristics, such as income, education level, occupation, or individual perceptions about climate change or environmental factors.

Among overseas literature, Potoglou and Kanaroglou (2007) used the Nested Logit Model to analyze the effects of various incentive policies on customers' choice of eco-friendly vehicles. According to the analysis, pricing, and vehicle performance were the most crucial aspects for buyers when buying a vehicle. In terms of incentives, it was discovered that consumers are more drawn to tax benefits and choose vehicles with low emissions. In contrast, the incentives for driving permits in lanes designated for free parking and multi-occupant vehicles had no substantial impact on the selection of eco-friendly vehicles.

Based on online survey data, Qian and Soopramanien (2011) compared the demand for alternative fuel and gasoline vehicles in China using MNL and the Nested Logit Model.[3] They showed that the higher the income, the higher is the probability of choosing an alternative fuel vehicle. However, gasoline vehicles were favored when there were children or more than two drivers in a home for reasons such as safety technology. Hackbarth and Madlener (2013) used survey data and a mixed logit model to examine the potential demand for private alternative fuel vehicles among German citizens. They found that high car prices and fuel costs had the greatest detrimental impact on selecting alternative fuel vehicles. In contrast, the selection of alternative fuel vehicles was positively impacted by the large density of charging stations. However, the impact was minimal if the charging time was shorter than 10 minutes. Furthermore, younger buyers were more inclined to choose hybrid or electric vehicles.

3) Alternative fuel vehicles refer to vehicles that operate through alternative energy of fossil fuels such as electricity, hydrogen, and biodiesel.

These studies focused on vehicles with specific fuel types and did not identify consumer demand by expressing preferences between fuel kinds. Therefore, this study evaluated consumers' desires for automobiles based on fuel type by incorporating numerous choices in the questionnaire when purchasing a car, such as gasoline, diesel, LPG, electricity, hybrid, and hydrogen. Furthermore, several studies have shown that eco-friendly awareness is vital in increasing individual consumption of eco-friendly products (Wang and He, 2011; Liu et al., 2017). Therefore, we hope to guide future eco-friendly vehicle-related projects and policy development to minimize GHG emissions by examining the effects of individual environmental awareness on vehicle choices.[4)]

Ⅲ. Analysis Model and Data

1. Multinomial Logit (MNL) Model

The MNL model is a discrete choice model developed to understand the consumer's selection process for alternatives and to predict the selection probability. It was proposed by McFadden (1980) based on Luce (1959) choice axiom and Thurstone (1959) random utility model. Among various discrete choice models, the MNL model is most widely used in empirical research in various fields, including statistics, tourism, psychology, marketing, and economics, because of its simplicity and ease of calculation (So, 2012; Lee, 2010).[5)]

According to the random utility theory, the MNL model represents the random utility ($U_{n,j}$) felt by the consumer (n) for three or more hypothetical alternatives (j) as the sum of the deterministic component ($V_{n,j}$) and stochastic component ($\epsilon_{n,j}$) as follows (Train, 2009):

4) The reason why many studies use survey data on whether they are willing to buy an eco-friendly car rather than actual purchase data is that it is difficult to obtain a sufficient sample size due to the low share of eco-friendly car ownership. (Zhang and Bai, 2017).

5) In the discrete choice model, if the number of alternatives that can be selected as a dependent variable is two, it is classified as a binary choice model, and if it is three or more, it is classified as a multinomial choice model.

$$U_{n,j} = V_{n,j} + \epsilon_{n,j} = \sum_{k}^{K} \beta_k X_{n,j,k} + \epsilon_{n,j} \tag{1}$$

$$P_{n,j*} = \frac{\exp V_{n,j*}}{\sum_{j=1}^{J} \exp V_{n,j}}, \ j = 1, 2, 3 \cdots, J \tag{2}$$

The deterministic component ($V_{n,j}$) is a utility described as an attribute or level a researcher can observe. It can be expressed as the product of $X_{n,j,k}$, an attribute of the alternative (j). β_k is a coefficient for individual attributes that affect respondent utility. Furthermore, the stochastic component ($\epsilon_{n,j}$) is the respondent's preference that the research cannot observe and denotes the error term.

Equation (2) represents the probability of selecting the alternative (j) in a set of options for which the consumer (n) is given under the assumption of utility maximization. Here, $P_{n,j*}$ is the probability of the selection of a specific alternative ($j*$) among the alternatives (J) by the consumer (n). $V_{n,j*}$ denotes the utility that the consumer (n) has for the alternative ($j*$).

The probability of choosing each alternative is constant because the error terms of the MNL model do not correlate according to the assumption of Independence of Irrelevant Alternatives (IIA). Therefore, consumers choose an alternative with the largest utility by independently judging each alternative. The error term is assumed to follow type Ⅰ extreme distribution according to the Identically and Independency Distribution (IID) (Train, 2009; Park, 2021).

2. Principal Component Analysis (PCA)

The goal of principal component analysis (PCA) is to summarize the overall characteristics by reducing the dimensions while conserving as much information about the existing vectors as possible and to reveal the multivariate structure between the characteristics (Moon and Lee, 1999; Lee et al., 2002). To that end, the axis of the data is converted into the axis of eigenvectors with large eigenvalues using the variance-covariance relationship between the numerous quantitative variables to generate the principal component. Then, a few key principal components explain the total variance to the greatest extent feasible. For an N-dimensional symmetric matrix A, the covariance matrix can be represented as follows:

$$A = V\Lambda V^T = [v_i v_2 \cdots v_N] \begin{bmatrix} \lambda_1 & 0 & \dots & 0 \\ 0 & \lambda_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \lambda_N \end{bmatrix} \begin{bmatrix} v_1^T \\ v_2^T \\ \vdots \\ v_N^T \end{bmatrix} = [\lambda_1 v_1 \lambda_2 v_2 \cdots \lambda_N v_N] \begin{bmatrix} v_1^T \\ v_2^T \\ \vdots \\ v_N^T \end{bmatrix} \quad (3)$$

When an eigenvalue is decomposed, it is expressed by the orthogonal matrix of the eigenvector (V^*), square matrix of the eigenvalue (Λ^*), and transposed matrix (V^T) of the eigenvector's orthogonal matrix. The eigenvector generated here is the principal component vector. It indicates the direction in which the variance is large in the data distribution, and the corresponding eigenvalue indicates the magnitude of the variance. A linear combination of variables represents the principal component. The first principal component is the linear combination explaining most sample variance. Furthermore, the second principal component is a linear combination that explains most of the variance unrelated to the first principal component.

The contribution to the total variance, the size and shape of the eigenvalue, and other factors can be utilized to determine the number of principal components. However, the most popular method is to employ Kaiser's rule (K1), which uses an eigenvalue larger than one. Most principal component analyses employ a correlation matrix when variables have different units of measurement. The sum of the eigenvalues is equal to the number of variables. Because the diagonal element of the correlation matrix is one, the average of the eigenvalues, which is the variance of the principal component, is one. As a result, the principal component with an eigenvalue less than one contains less information than any of the original variables; thus, it is not worth considering (Lee, 2015). The principal component analysis is now widely used as a statistical analysis and processing tool for multivariate data in various industries (Jung and Kim, 2012).

3. Questionnaire and Survey Design

The study's population consisted of adults aged ≥20 residing in Seoul and Gyeonggi Province. The survey was performed over seven days, from April 6 to April 12 2022.[6)] The survey design details are summarized in Table 1. Convenience sampling was the most often used non-probability sampling approach as a survey method. A total of 1,226 valid samples were used for analysis, with 155 unusable copies excluded from the 1,381 questionnaires collected. The questions in the questionnaire were broadly grouped into three categories: questions about future vehicle fuel preferences, environmental awareness, and demographics, such as income and education level. For environmental awareness, 11 questions were chosen whose content validity was confirmed via expert consultation, and a 5-point Likert scale was employed.

〈Table 1〉 Survey design details

Classification	Details
Main survey contents	Types of fuel desired for future use, environmental awareness, and demographic characteristics
Survey subject	Adults aged ≥20 residing in Seoul and Gyeonggi Province
Survey period	April 6 – 12, 2022
Survey method	Convenience sampling
Valid samples (recovered)	1,226 copies (1,381 copies)

6) Sample population was selected for the Seoul and Gyeonggi regions by reflecting the regional characteristics of high population and vehicle usage.

Ⅳ. Analysis Results

1. Demographic Characteristics

The demographic characteristics of the respondents for the 1,201 samples used for analysis, out of the 1,226 valid samples gathered by the survey, are summarized in Table 2.[7] Although a convenience sample with equal partition was used, the respondent's gender, age, and residential area were evenly distributed. Regarding gender and residential area, the male-to-female and the respondents living in Seoul and Gyeonggi Province ratios were nearly identical, with a difference of less than 1% each. Regarding age group, the 20s-to-60s proportion was even, at approximately 20% each. Regarding average monthly income, the proportion of individuals earning of KRW 2–3 million was the highest, accounting for approximately 23%. Overall, the proportion of individuals earning KRW 2–5 million accounted for more than 50% of the total. Regarding the final level of education, the proportion of university graduates was the highest at 66.44%, followed by graduate school and high school graduates at 15.98% and 13.91%, respectively. Finally, in terms of occupation, administrative and office workers accounted for the largest proportion (37.22%), whereas housewives and professionals accounted for 17.65% and 13.49%, respectively.

〈Table 2〉 Summary of the demographic characteristics of the 1,201 respondents used for analysis

Demographic characteristics		Frequency	Ratio (%)
Gender	Male	597	49.71
	Female	604	50.29
Age	20s	234	19.48
	30s	244	20.32
	40s	240	19.98
	50s	241	20.07
	60s	242	20.15

7) In the analysis, a total of 1,201 samples were used, excluding LPG, CNG, and other fuel types with fewer than 30 responses among 1,226 valid samples.

〈Table 2〉 Summary of the demographic characteristics of the 1,201 respondents used for analysis (Continued)

Demographic characteristics		Frequency	Ratio (%)
Income (KRW)	<1,000,000	104	8.66
	1,000,000－2,000,000	101	8.41
	2,000,000－3,000,000	276	22.98
	3,000,000－4,000,000	214	17.82
	4,000,000－5,000,000	165	13.74
	5,000,000－6,000,000	125	10.41
	6,000,000－7,000,000	55	4.58
	7,000,000－8,000,000	56	4.66
	≥8,000,000	105	8.74
Residential area	Seoul	610	50.79
	Gyeonggi	591	49.21
Education	Elementary school graduate or lower	17	1.42
	Middle school graduate or lower	27	2.25
	High school graduate or lower	167	13.91
	College graduate or lower	798	66.44
	Higher than a college graduate	192	15.98
Occupation	Management/office worker	447	37.22
	Self-employed	75	6.24
	Public official	38	3.16
	Professional	162	13.49
	Sales/service	77	6.41
	Agriculture/forestry/livestock	2	0.17
	Education	46	3.83
	Housewife	212	17.65
	Student	47	3.91
	Other	95	7.91

2. Principal Component Analysis (PCA) Results of Environmental Awareness

Principal component analysis and reliability tests were performed to ensure the validity and reliability of the environmental awareness scale before applying the model. First, questions on environmental awareness used in the survey were divided into three groups depending on differences in awareness and attitude toward the environment and the nature of the questions. The three groups were: denial, anxiety, and pro. Subsequently, the eigenvalue and reliability were measured for each group.

The results of inspecting the adequacy of the environmental awareness questions and the scale used in the PCA are summarized in Table 3. PCA was conducted using the Varimax orthogonal rotation approach. Only variables with a factor loading higher than 0.5 were recovered during the factor extraction, which factorizes items with eigenvalues larger than one. In addition, Cronbach's α value, which reflects the reliability of whether the combination of attributes within the factor category has internal consistency, was calculated. Since the reliability coefficients of all factors were higher than 0.5, the internal consistency of the factors was found to be at a high level.[8)]

〈Table 3〉 Adequacy of the environmental awareness questions and the scale used in the principal component analysis

Factor	Variables	Factor loading	Eigenvalue	Reliability (Cronbach's α)
F1 Denial type[9)]	My livelihood is threatened by environmental preservation.	0.7366	4.241	0.7494
	Environmental laws restrict my options and liberties.	0.7554		
	The claim that we are causing climate change is exaggerated	0.7091		
	The harm done to animals and plants by environmental destruction is globally negligible	0.6919		
	There is no reason to be concerned because future generations can handle environmental issues	0.6669		
F2 Anxiety type	Modern developments endanger animals	0.8232	1.063	0.7517
	Many plants and animals will go extinct over the next few decades	0.7936		

8) The Bartlett's sphericity test statistic was 4777.00 ($p < 0.00$), and the KMO (Kaiser-Meyer-Olkin) coefficient was 0.8399, ensuring the validity of the results of the factor analysis.

9) Denial type is defined as not taking environmental problems such as climate change seriously and thinking negatively about protecting the environment.

〈Table 3〉 Adequacy of the environmental awareness questions and the scale used in the principal component analysis (Continued)

Factor	Variables	Factor loading	Eigenvalue	Reliability (Cronbach's α)
F3 Pro type	A clean environment provides better recreational options	0.6001	1.696	0.7741
	Environmental conservation is helpful to my health	0.6775		
	The quality of life is improved by environmental conservation	0.8063		
	Everyone benefits from environmental conservation	0.8330		

3. Description of Variables

The dependent variable input to the MNL model is one of the questions, "the type of automotive fuel desired in the future." LPG, CNG, and other fuel types with fewer than 30 responses were excluded from the eight fuel types, and a total of 1,201 samples, out of 1,226 valid samples, were selected for the final study. Regarding the frequency of vehicle selection by fuel type among the 1,201 responses, the number of diesel and hydrogen vehicle responses were 49 (4%) and 71 (5.9%), respectively, representing less than 10% of the total. In contrast, the number of electric car responses was 653 (54%), accounting for more than half of all responses.

The explanatory variables were environmental awareness variables factored with the six demographic characteristics gender, age, marital status, education level, occupation, and average monthly income. Among the demographic characteristics, gender, marital status, and occupation were considered as dummy variables with the values zero and one.[10)]

Table 4 provides detailed explanations and descriptive statistics for the model's input variables. The average age of the respondents was 44.6 years, and the average monthly income was KRW 3.95 million. The gender variable had an average of 0.497, indicating

10) As occupational variables, 'management and office work', 'public servant', and 'education job' belonging to the white-collar occupational group were set to 1, and 'other' occupations were set to 0.

that the male-to-female ratio was nearly equal. However, there were more married people compared to single persons, and white-collar workers outnumbered other respondents. Meanwhile, for factored environmental awareness variables, the average and standard deviation values did not have a significant interpretation.

〈Table 4〉 Detailed explanations and descriptive statistics for the model's input variables

<table>
<tr><th colspan="3">Variable name</th><th>Definition</th><th>Average</th><th>Standard Deviation</th></tr>
<tr><td>Dependent variables</td><td colspan="2">Future desired vehicle fuel</td><td>1 = Gasoline
2 = Diesel
3 = Hybrid
4 = Electricity
5 = Hydrogen</td><td>-</td><td>-</td></tr>
<tr><td rowspan="9">Explanatory variables</td><td rowspan="6">Demographic characteristics</td><td>Gender</td><td>Male = 1
Female = 0</td><td>0.497</td><td>0.500</td></tr>
<tr><td>Age</td><td>$\geq$20 years</td><td>44.643</td><td>13.353</td></tr>
<tr><td>Marital status</td><td>Married = 1
Single or other = 0</td><td>0.650</td><td>0.477</td></tr>
<tr><td>Educational level</td><td>1~7 = Elementary school (including 'none')
8~10 = Middle school
11~13 = High school
14~17 = College
18~21 = Higher than college</td><td>16.195</td><td>2.605</td></tr>
<tr><td>Occupation</td><td>White collar = 1
Others = 0</td><td>0.442</td><td>0.497</td></tr>
<tr><td>Average monthly income</td><td>Average monthly income intervals (KRW 500,000 – 8,500,000, with nine intervals with one million won units)</td><td>394.879</td><td>224.631</td></tr>
<tr><td rowspan="3">Environmental awareness</td><td>Denial</td><td rowspan="3">Factorization to a 5-point Likert scale</td><td>0</td><td>1</td></tr>
<tr><td>Anxiety</td><td>0</td><td>1</td></tr>
<tr><td>Pro</td><td>0</td><td>1</td></tr>
</table>

4. Multinomial Logit (MNL) Model Estimation Results

Table 5 shows the estimated outcomes obtained using the MNL model. Among the demographic factors, marital status and education level did not have a statistically significant effect on the automotive demand by fuel. The respondent's gender had a positive (+) effect of demand for hydrogen vehicles and a negative (−) effect on demand for diesel and hybrid vehicles at a significance level of 5% and 10%, respectively. In addition, age had a negative (−) effect on demand for diesel vehicles and a positive (+) effect on demand for electric vehicles at a significance level of 10%. Finally, respondents' occupation had a positive (+) effect on demand for hybrid vehicles and a negative (−) effect on demand for electric vehicles at a significance level of 10%.

〈Table 5〉 Estimated outcomes obtained using the multinomial logit (MNL) model

Variables		Vehicle Fuel types				
		Gasoline [n = 155]	Diesel [n = 49]	Hybrid [n = 273]	Electricity [n = 653]	Hydrogen [n = 71]
Demographic characteristics	Gender	0.021 (1.26)	−0.025** (−2.07)	−0.045* (−1.82)	0.016 (0.57)	0.033** (2.29)
	Age	−0.001 (−1.13)	−0.001* (−1.91)	−0.001 (−0.86)	0.002* (1.84)	0.001 (0.88)
	Marital status	−0.025 (−1.19)	0.003 (−0.18)	0.004 (0.08)	0.027 (0.75)	−0.001 (−0.08)
	Educational level	0.004 (1.25)	−0.002 (−0.81)	0.005 (1.12)	−0.004 (−0.71)	−0.004 (−1.37)
	Occupation	0.003 (0.18)	−0.008 (−0.69)	0.067** (2.53)	−0.061** (−2.07)	−0.000 (−0.02)
	Average monthly income	−0.000* (−1.88)	0.000 (0.40)	−0.000 (−1.24)	0.000** (2.10)	0.000 (0.02)
Reason for selection	Fuel economy	0.047** (2.29)	0.036*** (2.70)	0.176*** (7.42)	−0.159*** (−4.95)	−0.101*** (−3.86)
	Driving convenience	0.216*** (11.34)	0.026 (1.49)	0.081** (2.18)	−0.266*** (−5.78)	−0.580* (−1.88)

〈Table 5〉 Estimated outcomes obtained using the multinomial logit (MNL) model (Continued)

Variables		Vehicle Fuel types				
		Gasoline [n = 155]	Diesel [n = 49]	Hybrid [n = 273]	Electricity [n = 653]	Hydrogen [n = 71]
Reason for selection	Economic incentives	−0.061 (−1.16)	0.007 (0.28)	−0.113** (−2.02)	0.188*** (3.57)	−0.021 (−0.98)
	Vehicle familiarity	0.434 (0.02)	0.114 (0.01)	0.252 (0.00)	0.093 (0.00)	−0.893 (−0.00)
	Others	0.589 (0.02)	−0.310 (−0.00)	−1.943 (−0.01)	2.318 (0.02)	−0.654 (−0.01)
Environmental awareness	Denial	0.031*** (4.15)	0.023*** (4.06)	0.006 (0.55)	−0.051*** (−3.74)	−0.009 (−1.21)
	Anxiety	0.002 (0.25)	0.004 (0.70)	0.029** (2.42)	−0.026* (−1.84)	−0.010 (−1.23)
	Pro	−0.003 (−0.32)	−0.017*** (−3.02)	0.018 (1.54)	0.008 (0.63)	−0.007 (−1.21)
Log-likelihood = −1180.0858						
LR chi2(56) = 841.99						
Prob > chi2 = 0.0000						
Number of obs = 1,201						

Notes: 1): The future desired vehicle fuel type is the dependable variable.
2) *, **, and *** indicate that the estimated coefficient is significant at 10%, 5%, and 1%, respectively.
3) The values in parentheses are t values.

Fuel economy had a positive (+) effect on demand for gasoline, diesel and hybrid vehicles and a negative (−) effect on demand for electric and hydrogen vehicles at a significance level of 1%. Driving convenience including infrastructure had a positive (+) effect on demand for gasoline and hybrid and a negative (−) effect on demand for electric and hydrogen vehicles. Economic incentives including subsidies and tax benefits had a positive (+) effect on demand for electric vehicles at a significance level of 10% and a negative (−) influence on demand for hybrid vehicles at a significance level of 5%.

The denial type had a positive (+) influence on demand for gasoline and diesel and a negative (−) effect on demand for electric vehicles, both of which were significant at a significance level of 1%. The anxiety type had a positive (+) influence on demand for hybrid and negative (−) effect on electric vehicles at a significance level of 5% and 10%, respectively. In contrast, the pro type had a negative (−) influence on diesel car demand at a significance level of 1%. As a result, it was established that the greater was the statistically significant rise in the likelihood of purchasing hybrid vehicle than hydrogen vehicle in the anxiety-type.

The MNL estimation result can be interpreted as a probability. Men were 3.3% more likely to choose a hydrogen vehicle than women, but 2.5% and 4.5% less likely to choose a diesel car and a hybrid car, respectively. When age increased by one unit, the probability of choosing a diesel vehicle decreased by 0.1%, and that of choosing an electric car increased by 0.2%. Moreover, the demand for hybrid vehicles in white-collar occupations was 6.7% higher compared to that for other respondents, and that for electric vehicles in white-collar occupations was 6.1% lower compared to that for other respondents.

The respondents who considered economic incentives over environmental concerns when choosing vehicle fuel types were 18.8% more likely to choose electric vehicles and 11.3% less likely to choose hybrid vehicles. The respondents who consider the fuel economy than environmental issues when choosing car fuel types were 4.7%, 3.6% and 17.6% more likely to choose a gasoline car, a diesel car and a hybrid car, but 15.9% and 10.1% less likely to choose an electric car and a hydrogen car, respectively. An individual who considers driving convenience than environmental issues when choosing fuel types was 21.6% and 8.1% more likely to choose a gasoline car and a hybrid car, but 26.6% and 58% less likely to choose an electric car and a hydrogen car, respectively. A possible explanation for this result is that hydrogen vehicles and electric vehicles are not as fuel economy and infrastructure-rich as hybrid vehicles.

The estimation results of the environmental awareness factor were as follows: As denial type awareness increased by one unit, the probability of choosing a gasoline vehicle and a diesel vehicle increased by 3.1% and 2.3%, respectively, whereas that of choosing an electric car decreased by 5.1%. In contrast, pro type decreased the probability of choosing a diesel vehicle by 1.7% as the awareness level increased by one unit. Anxiety type increased the probability of choosing a hybrid car by 2.9%, whereas that of choosing an electric car decreased by 2.6% when the awareness level increased by one unit. However, anxiety-type awareness did not have a statistically significant effect on the demand for hydrogen cars. Therefore, it was confirmed that the acceptance of hydrogen vehicles differed from that of hybrid and electric vehicles. A plausible explanation for this result is the perception that hydrogen vehicles are still not up to the level of eco-friendly vehicles with almost zero GHG emissions. At the current level, the GHG emissions of hydrogen vehicles are known to be smaller than those of general internal combustion engine vehicles, but larger than those of hybrid vehicles.

Meanwhile, as for the demand for hydrogen vehicles, the estimation results for all three environmental awareness factors were statistically insignificant.

V. Conclusions and Implications

This study used survey data and the MNL model to examine automotive demand by fuel type based on customer preferences. A reliable sample of 1,201 people aged ≥ 20 living in Seoul and Gyeonggi Province was used for analysis. Variables related to environmental awareness, identified by the principal component analysis, and key considerations for choosing fuel types were included as main explanatory in addition to demographic characteristics variables. We attempted to derive implications by identifying the relationship between consumer's key considerations, environmental awareness and vehicle demand.

The MNL model estimation results can be summarized as follows: Respondents who value fuel efficiency and sufficient infrastructure were more likely to prefer a hybrid car to other types of eco-friendly vehicles. An individual who consider economic incentive was more likely to purchase an electric car. When environmental awareness was pro-type, demand for diesel vehicles declined. In contrast, denial-type awareness increased the demand for gasoline and diesel vehicles, but decreased the demand for electric vehicles. Anxiety-type awareness increased the demand for hybrid vehicles, but decreased for electric vehicles, thereby indicating that personal environmental awareness is statistically related to increased purchase demand for general internal combustion engine vehicles, and the demand for hybrid vehicles is higher than for electric vehicles. Furthermore, marital status and education level had no statistically significant effect on vehicle purchase choice by fuel type, whereas gender, age, and employment did. Males were more likely to prefer a hydrogen car than females, and the likelihood of choosing an electric car increased with age. White-collar workers were more likely to purchase a hybrid vehicle than other occupational groups.

Currently, the government is undertaking several efforts to achieve energy conversion in the transportation sector and reduce GHG emissions by increasing the supply of eco-friendly vehicles. In particular, the budget for hydrogen vehicle-related projects is rising dramatically yearly. However, as previously stated, the actual execution rate of the hydrogen vehicle purchase subsidy budget is still much lower than that of electric or hybrid vehicles. Therefore, in addition to tax and subsidy benefits, the findings of this study suggest that the government should create strategies to building infrastructure for electric and hydrogen vehicles and to increase distribution by increasing environmental awareness among consumer through educational programs, campaigns, and the media. In particular, efforts should be made to provide legislative support for related technology development related to electric and hydrogen fuel collection, storage, transportation, and use of renewable energy, as well as the supply of electric and hydrogen vehicles.

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