



Feasibility study on the Korean Government's hybrid conversion project of small diesel trucks for parcel delivery services

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ABSTRACT

The Korean government is planning an R&D project to convert existing small diesel trucks for parcel delivery services to diesel-electric hybrid trucks as part of its effort to reduce emissions of greenhouse gases and particulate matter (PM). This project started from the realization that parcel delivery trucks have become one of the main sources of PM emissions especially as the parcel delivery service industry has rapidly grown in Korea amid inefficient driving environment for delivery trucks. To evaluate the marketability and feasibility of the project, this study analyzed diesel truck owners' preferences for converting to hybrid vehicles. Hierarchical Bayesian choice-based conjoint analysis was employed to forecast conversion probabilities and willingness to pay for various vehicle attributes, and the influencing demographic factors were then analyzed. The demand forecasting results are expected to enable decision makers to set a reasonable budget for hybrid conversion. For policy implications, the findings suggest that truck owners should be allowed to pay for the conversion in installments, not in a lump sum, and it would be strategically effective to target the consumer segment that prioritizes fuel cost savings relative to other vehicle attributes to promote hybrid conversion.

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1. Introduction

The rising popularity of e-commerce and changing consumer behavior have spurred the growth of the parcel delivery service market in Korea. The number of packages delivered was about 1.3 billion units in 2011 which increased to more than 2.3 billion units in 2017, with a spectacular annual growth rate between 7.3% and 13.3% (Maritime Press of Korea, 2018). The average number of uses of parcel delivery services, by persons aged 13 years and older, soared from 3.0 times a year in 2000 to 35.7 times a year in 2013. As of 2013, the number of parcel delivery trucks of less than 1.5 tons was a total of 36,734 units, including 24,721 commercial vehicles and 12,031 privately owned vehicles. In 2014, sales increased by 6.4% from the previous year at KRW 3.97 trillion (Ministry of Land, Infrastructure and Transport of Korea, 2016). It is projected that the parcel delivery market will continue to grow as an increasing number of shoppers make online and direct overseas purchases.

Fig. 1 shows the prospects of domestic parcel delivery volume provided by the Ministry of Land, Infrastructure and Transport of Korea (MOLIT).

Last mile deliveries are usually made by small 1-ton trucks in Korea, most of which are diesel vehicles that emit particulate matter (PM) and greenhouse gases, which have serious social and environmental implications. To make matters worse, parcel delivery trucks generally drive in the city and thus frequently accelerate and decelerate. Consequently, their average fuel economy is only about 3 km/l, which is much lower than a commonly used combined fuel economy of about 9 km/l. Hence, parcel delivery trucks are considered to be a relatively more significant source of PM and greenhouse gas emissions. In fact, 52% of ultrafine particles in Seoul is from transportation vehicles of which diesel vehicles are responsible for 67% of emissions of oxides of nitrogen (NO_x), the primary source of ultrafine particles. By usage, freight cars and construction vehicles account for the highest proportion at 54%. Moreover, PM emissions of diesel vehicles amount to about 12,969 tons, accounting for about 62% of total vehicle emissions in the country. Diesel trucks, in particular, are responsible for about 68% of the total PM emissions produced by diesel vehicles (MOLIT, 2016).

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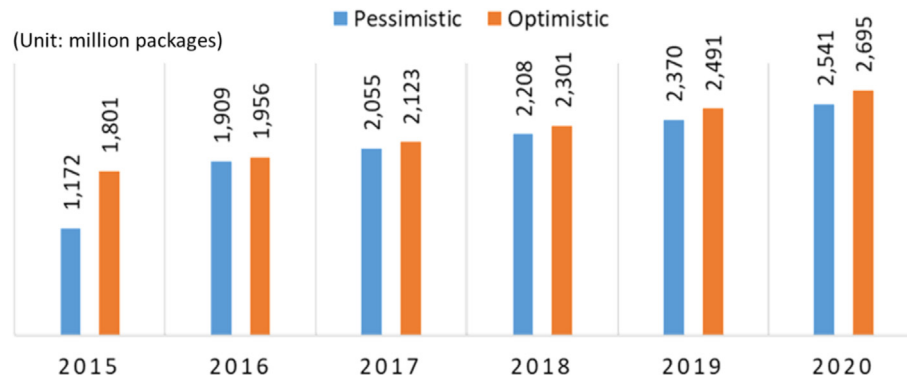


Fig. 1. Prospects of Domestic Parcel Delivery Volume (MOLIT, 2016)

Note: Pessimistic and optimistic estimates are produced by applying 3.0% and 3.5% of GDP growth rate, respectively, to the formula of demand forecasting.

In addition to greenhouse gases and PM emissions, rising logistics costs due to increases in international oil prices calls for development of core technologies that maximize fuel economy with low costs. However, such technologies cannot be developed without government involvement due to the high development costs. Globally, the introduction of hybrid and electric vehicles is a critical issue for policymakers. Countries with large domestic auto markets, such as the United States or China, have aimed to promote green cars through subsidies, and research on feasibility and effectiveness of relevant policies is ongoing (Zhang et al., 2018; Kang et al., 2016).

The Korean government is also trying to reduce PM and greenhouse gas emissions from parcel delivery trucks by developing a range of technologies as part of a national R&D project, and hybrid parcel delivery trucks have been selected as one of its short-term alternatives (MOLIT, 2016). The project targets small diesel trucks that have already been sold or that are yet to be sold in the market. The technology involves converting existing diesel trucks to diesel-electric hybrids, which are expected to produce lower PM and greenhouse gas emissions. Compared to purely electric trucks, the emissions of PM and greenhouse gases of diesel-electric hybrid trucks will be relatively higher. However, the technology of converting to hybrid trucks will involve a low installation cost per unit with an insignificant addition to vehicle weight, and it will be readily applicable to the vehicles already in the market. Thus, it can be implemented in a short period of time. Taking these advantages into account, the government project set the following technological aims: conversion cost of KRW 5 million or less, weight addition of 100 kg or less, fuel economy improvement of 30% or higher, and PM/greenhouse gas emissions reduction of 20% or more.

The government project agenda can be divided into three categories, as shown in Table 1: (a) policy, law, and institutional reforms to commercialize technologies, (b) conversion technology for diesel-electric hybrid trucks, and (c) control technology for diesel-

electric hybrid trucks. As part of the project agenda (a), this study focuses on assessing marketability and economic feasibility as part of the efforts to reform policies, laws, and institutions for technology commercialization.

To tackle this aim, this study employs Hierarchical Bayesian (HB) choice-based conjoint analysis to elicit diesel delivery truck owners' preferences on converting to hybrid trucks, specifically in modeling heterogeneous preferences of individual consumers (Green and Krieger, 1996; Lenk et al., 1996; Rossi and Allenby, 2003; Rossi et al., 2005). The study then conducts various post-analyses to understand truck owners' conversion preferences in depths such as through feasibility test and target consumer segmentation using estimates from the preference modeling stage. While previous research has used conjoint analysis to evaluate new purchase behavior of alternative fuel vehicles, to our knowledge, this paper is the first to address the topic of conversion of used cars to hybrid ones. This topic would be particularly practical for policymakers in addressing imminent environmental issues.

1.1. Research framework

Fig. 2 represents the research framework of our study which largely consists of four stages. At each stage, the input/data-output/parameter relationship is shown in arrows. First, in the survey stage, we sample the same number of diesel truck owners from each of five major cities in Korea to select respondents that evenly represent the geographical regions in Korea. We collect choice data from these respondents by conducting choice surveys showing several options of vehicle attributes to choose from should they decide to convert their trucks to hybrid ones. The survey process is explained in Section 3.

The second stage is the preference modeling stage. This stage uses choice data obtained from the previous survey stage, and estimates the parameters of the preference model defined for each

Table 1

Project Agenda of Converting Parcel Delivery Trucks to Hybrids by the Korean government (MOLIT, 2016).

Division	Sub-division
Policy, law, and institutional reforms to commercialize technologies	Institutional supplementation for the conversion project Legal and institutional support Study on marketability and economic feasibility (the objective of this study)
Conversion technology for diesel-electric hybrid trucks	Logistics environment analysis technology Diesel-electric hybrid power-train design technology Diesel-electric hybrid truck conversion technology
Control technology for diesel-electric hybrid trucks	Diesel-electric hybrid power-train control technology Electric system management technology Controller implementation technology

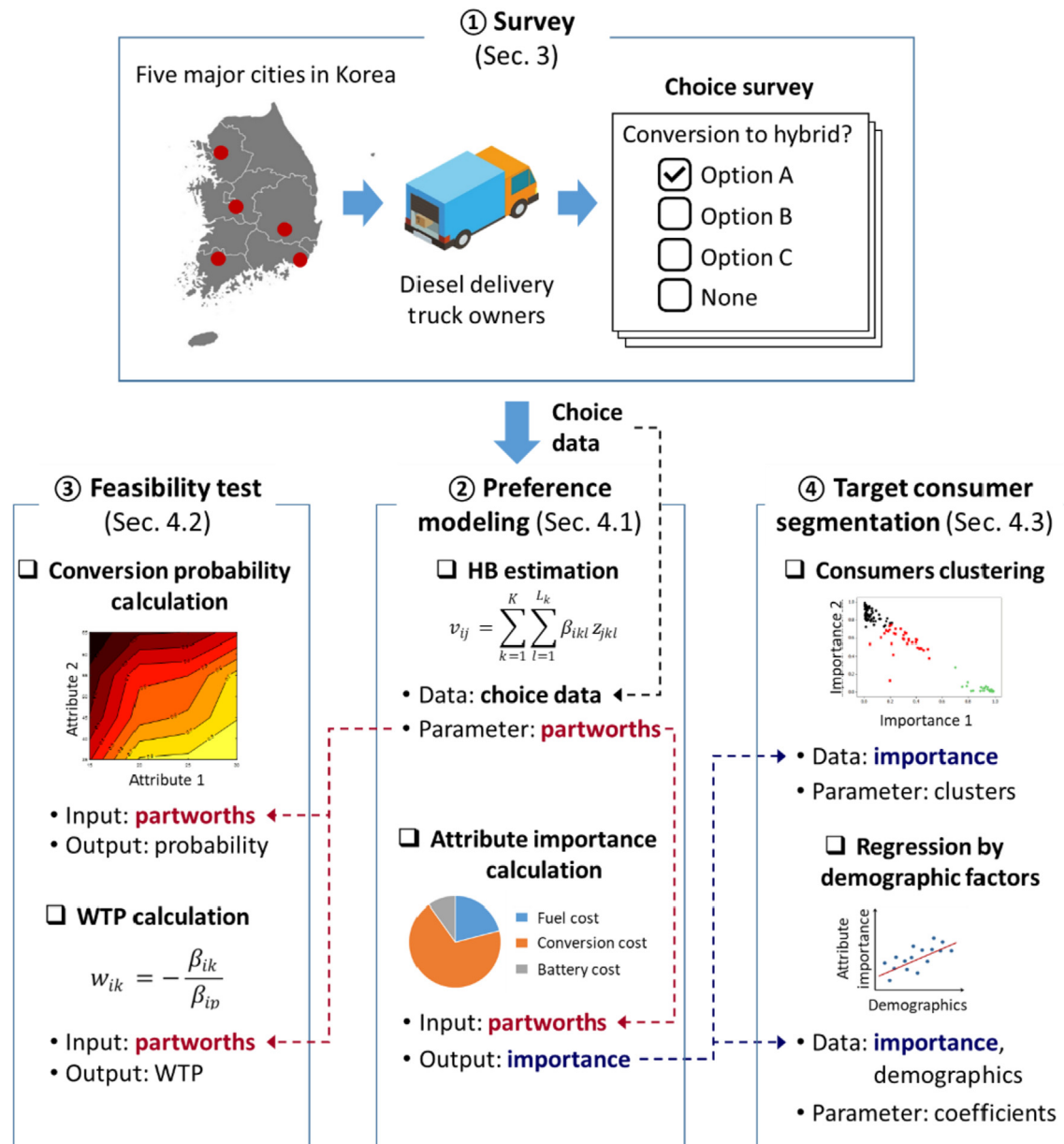


Fig. 2. Research framework.

truck owner through HB estimation. The parameter to be estimated is partworths, which denote the values that each owner places on each attribute. Then, using the estimated partworths as input, the attribute importance is calculated for each attribute and for each truck owner, which refers to how much a consumer values one attribute relative to others when deciding to convert to hybrid trucks. This stage is explained in Section 4.1.

The third and fourth stages can be considered post analyses that utilize estimates from the preference modeling stage. In the feasibility test stage, we calculate (a) the conversion probabilities for various levels of attributes and (b) willingness to pay (hereafter, WTP) for an improvement in an attribute. The former allows policymakers to examine which levels of attributes bring about desired conversion probabilities. The latter helps us gauge whether the target levels of attributes proposed by the government are feasible or not. Both calculations use the previously estimated partworths as inputs, and are explained in Section 4.2. Lastly, in the target

consumer segmentation stage, we group the truck owners into clusters based on (a) their attribute importance and (b) demographic characteristics, respectively, in order to determine which groups to target hybrid conversion. This stage is explained in Section 4.3.

This paper is organized as follows: Section 2 explains the methodologies used in this study focusing on HB choice-based conjoint analysis; Section 3 shows how data was collected by surveys; Section 4 presents the analysis results in three parts; Section 5 analyzes the results and provides related insights; and Section 6 draws conclusions while noting the limitations of the study.

2. Methodology

2.1. Overview

This section provides an overview of the methodologies used in

Table 2
Methodologies used in the study.

Purpose	Methods	Estimation (statistical model)		Computation (post analysis)	
		Data	Parameter	Input	Output
Preference modeling	HB estimation	x: attribute levels of options y: choice results	Partworths for attribute levels		
	Attribute importance calculation			Partworths	Relative importance of attributes: hybrid conversion cost, fuel cost savings, and battery maintenance cost
Feasibility Test	Choice probability calculation			Partworths	Hybrid conversion probability according to attribute levels
	Willingness to pay calculation			Partworths	Willingness to pay for fuel cost savings and battery maintenance cost
Target consumer segmentation	K-means clustering	x: attribute importance	Consumer groups by attribute importance		
	Linear regression	x: demographic factors y: attribute importance	Coefficients for demographic factors influencing attribute importance		

the study. The methodologies can be grouped under three main parts divided by their purpose: preference modeling, feasibility test, and target consumer segmentation. They can also be categorized into two groups by nature: estimation that uses a statistical model to estimate parameters using data, and computations which simply performs additional calculations as post analyses utilizing already obtained estimates. Table 2 groups the methodologies used in this study by purpose and nature noting the important elements used for each method.

First, in preference modeling, the HB estimation is the core methodology used. A truck owner considers a number of attributes (here, hybrid conversion cost, fuel cost savings, and battery maintenance cost) before making the decision to convert their diesel vehicles to hybrid ones, and each owner values each attribute differently. This is reflected in the utility function defined for each truck owner where one's utility is assumed to be a linear function of the partworths for each attribute. The partworths that an owner places on each attribute is estimated using survey data, or more specifically, HB choice-based conjoint analysis that uses survey data to elicit preferences of truck owners. Once these partworths are estimated for each individual, one can draw inferences from the distribution of the values of all respondents for each attribute. We are able to understand, for instance, how an average or median truck owner values each attribute, or compute attribute importance which represents how much an attribute affects consumer preferences on conversion relative to other attributes.

Second, in the feasibility test part, choice probability and WTP are calculated using the partworths estimated from the HB estimation. Choice probability refers to the probability that consumers would opt for hybrid conversion. In order to calculate this probability, we first interpolate discrete partworths corresponding to their discrete attribute levels to obtain continuous partworth values for continuous attribute levels. Then, by employing a logit model, we ultimately calculate the conversion probabilities for continuous levels of each attribute. This allows us to determine what the attribute levels for each attribute have to be in order to attain a certain level of conversion probability. In addition to calculating choice probability as a post analysis to preference modeling, we compute the truck owners' WTP for fuel cost savings and battery maintenance cost savings. Dividing the estimated partworths for fuel cost savings by the partworths for hybrid conversion cost provides the WTP for increasing fuel cost savings by 1%. Similarly, dividing the partworths for battery maintenance cost by the partworths for hybrid conversion cost by gives the WTP to reduce battery maintenance cost by 1 won. Since the unit for WTP values are expressed as increased units of hybrid conversion costs,

the WTP calculations allow us to evaluate the tradeoffs between the improvements in attributes and conversion costs.

Third, in the target consumer segmentation part, we employ K-means clustering using attribute importance as input to divide consumers into three clusters. Analyzing these clusters, we examine which consumer segmentation is the most effective target for hybrid conversion. In addition, we examine the coefficients of a linear regression that use attribute importance as dependent variables and demographic factors are independent variables. We particularly look at the directions of the coefficients that are statistically significant in order to understand the characteristics of consumer clusters.

2.2. Hierarchical Bayesian choice-based conjoint analysis

This section introduces previous literature that employs conjoint analysis, which our study essentially stems from. In addition, it explains the HB estimation method used to analyze heterogeneous preferences, and the WTP for improvements in attributes.

2.2.1. Literature review

Conjoint analysis is one of the most widely used statistical methods in a variety of disciplines, including marketing, economics, and engineering to model consumer preferences for a product or service. Related to the topic under study, the method is also frequently used to examine consumer preferences and estimate WTP regarding green products (Kaufmann et al., 2013; Lieder et al., 2018; Meyerding and Merz, 2018; Olson, 2013) and sustainable energy infrastructure (Álvarez-Farizo and Hanley, 2002; Zaunbrecher et al., 2017). Moreover, conjoint analysis is used in studies on environmentally friendly policy making decisions beyond simply evaluating green products (Lüthi and Prüssler, 2011; Gao et al., 2016; Shin and Hwang, 2017; Peterson and Feldman, 2018).

An increasing number of studies are using conjoint analyses to evaluate consumer preferences on alternative fuel vehicles, such as one in this study (Brownstone et al., 2000; Dagsvik et al., 2002; Heywood et al., 2004; Bolduc et al., 2008; Struben and Sterman, 2008; Diamond, 2009; Lee and Cho, 2009; Axsen and Kurani, 2010; Lee et al., 2013; Olson, 2018). Consumer preferences regarding alternative vehicles may vary depending on the region or country. Therefore, it is necessary to compare consumer preferences in different markets in order to make a decision suited for a given market (Helveston et al., 2015; Kang et al., 2016). Furthermore, a consumer preference model on alternative vehicles

established with conjoint analysis can also be applied to the engineering design of optimized green cars (Kang et al., 2015, 2016, 2017a, 2018, Lee et al., 2019).

Much previous research has centered on examining consumer preferences regarding new purchase decisions for electric and hybrid vehicles. There are also studies that investigate the optimal timing of replacing current vehicles with hybrid ones (He et al., 2017), but little attention has been devoted to examining consumer preferences with respect to conversion of the vehicles that they already drive. Therefore, this paper contributes to the existing literature by analyzing preferences of converting used vehicles. Furthermore, the study is expected to provide various policy implications for policymakers in that the consumer decision involves converting diesel trucks to diesel-electric hybrid vehicles, which are considered to be more environmental friendly.

2.2.2. Hierarchical Bayesian estimation

Considered an advanced version of conjoint analysis, HB choice-based conjoint analysis is the most widely used method to predict consumers' heterogeneous demands for new products in economics and marketing research (Lenk et al., 1996; Rossi and Allenby, 2003; Rossi et al., 2005). Consumers' choice data are collected through surveys, and HB estimation is used to establish a model of individual consumer's utility. Recently, the model accuracy has been improved with the application of a variety of machine learning methods (Toubia et al., 2007; Kang, 2014).

A random utility model to quantify consumer preference is represented as follows (Green and Krieger, 1996).

$$u_{ij} = v_{ij} + \varepsilon_{ij} \quad (1)$$

u_{ij} denotes utility, v_{ij} , a deterministic component of utility, ε_{ij} , an error component that cannot be observed for, i , an individual, and j , an alternative from which to choose from. It is assumed that consumers choose a product that maximizes their utility among the available options. v_{ij} , the definitive component as a utility of observables, can be represented as a linear function of attributes, such as product price and performance, as follows.

$$v_{ij} = \sum_{k=1}^K \sum_{l=1}^{L_k} \beta_{ikl} z_{jkl} \quad (2)$$

z_{jkl} is a binary variable that is equal to 1 for alternative j with level l of attribute k . A level refers to a value from a range of variation an attribute can take. β_{ikl} refers to a partworth of level l of attribute k for individual i . This represents the partial utility that a consumer assigns for a certain attribute level. Partworth β_{ikl} can be estimated through consumer survey data and HB estimation. Consumer survey data are gathered using a choice-based survey, which is conducted by presenting three product alternatives to consumers and asking them to choose the most preferred product of a bundle of attributes. These alternatives specify three possible combinations of different levels of attributes of a product. The choice of "none" is also given when none of the options is preferred.

HB estimation to measure partworth by consumer, β_{ikl} , consists of two levels. In the higher level, it is assumed that β_i , the utility of an individual, follows a multivariate normal distribution, $N(\theta, \Lambda)$. θ denotes the mean vector of the individual distribution, while Λ denotes the covariance matrix of the distribution. In the lower level, probability is used with a logit model, which is represented by the following equation.

$$P_{ij} = \frac{e^{v_{ij}}}{\sum_{j' \in J} e^{v_{ij'}}} \quad (3)$$

P_{ij} in the equation represents the probability of individual i choosing alternative j within the set of alternatives J . Markov Chain Monte Carlo (MCMC) is used to estimate the utility of an individual. This study discarded the initial 50,000 iterations of the total 100,000 iteration results, and only the first of ten iteration draws were used. This is a frequently used method to lower autocorrelation in the chain. With information on probability P_{ij} , it is possible to predict the market share of a new product. In addition, an importance of an attribute can be computed, which is a measure that indicates how much an attribute contributes to one's utility relative to other attributes. More precisely, with the utility function modeled, an attribute importance is calculated as a range of partworths of a given attribute (i.e., difference between maximum and minimum partworths of a given attribute) divided by the total sum of partworth of each attribute.

2.2.3. Willingness to pay

In addition to their conversion probabilities, truck owners' WTP for unit improvement of each attribute can be derived using the partworth values calculated above from the HB analysis (Train, 2003; Kang et al., 2017b). By definition, the WTP denotes the price consumer is willing to pay in exchange for an improvement of an attribute holding one's utility constant. Although the estimation methods vary, many studies assume a random utility model, and calculate WTP from stated preference surveys to predict consumer demand for a product (See Greene et al., 2018 for a meta-analysis on WTP for vehicle attributes). The current study takes the same approach and uses partworth estimates to derive the WTP for conversion attributes. Our study is similar to previous studies that estimate WTP for vehicle attributes, but differ in that the consumers under study are all diesel truck owners who are considering converting their vehicles to hybrid trucks. Therefore, note that the WTP estimates are not directly comparable to those from previous studies as this project targets a specific consumer group.

So far, the utility function was defined as a non-linear function of binary variables that indicate a level of an attribute and its partworths as in equation (2). When computing WTP, this equation is simplified by assigning one partworth value for an attribute instead of for all its levels, and this results in a linear functional form of utility. In other words, each attribute - fuel cost savings, hybrid conversion cost, and battery replacement cost - would have one partworth utility coefficient instead of for each level of an attribute. The HB estimation method is then applied to obtain the partworth estimates as before. This is done because the denominator when calculating WTP should be unified to a single value for ease of interpretation. WTP is then computed by dividing the partworth value of a product attribute by the price and switching the sign as in equation (4). Here, the price, or the unit of WTP, is expressed as hybrid conversion costs, i.e. one of the three attributes:

$$w_{ik} = -\frac{\beta_{ik}}{\beta_{ip}} \quad (4)$$

where w_{ik} denotes individual i 's WTP for attribute k , β_{ik} indicates individual i 's partworth value for attribute k , and β_{ip} is individual i 's partworth value for the price, or hybrid conversion cost. A negative (−) sign is added because β_{ip} is always negative (the higher the price, the lower the value). This allows the sign or direction of WTP

to be determined by the sign of the attribute on the numerator, and correctly reflect the tradeoffs that exist between improvements of two different attributes. w_{ik} denotes how much the individual is willing to pay to change a unit of attribute k . This is expressed as additional hybrid conversion cost that is incurred to improve attribute k that ultimately makes a consumer indifferent, or which brings about the same utility.

3. Survey design

3.1. Conjoint survey

There are largely three ways in which a researcher can elicit consumer preferences in surveys: ranking, rating, or choice. Nowadays, choice surveys are known to be the best predictor of consumer behavior since they closely resemble consumers' actual behavior. To evaluate small parcel delivery truck owners' and drivers' willingness and preferences for conversion to hybrid vehicles, the respondents were presented with hypothetical profiles with multiple choices and asked to indicate their most preferred alternative. Each choice represents a bundle of levels of attributes. In order to obtain respondents' preference data, attributes that are deemed essential when making decisions before converting to hybrids were included, and those related to the conditions after conversion were also considered. Transportation experts in government and universities were interviewed, and key attributes related to conversion decision narrowed down to the following three: fuel cost savings, hybrid conversion costs, and battery replacement costs. The definitions and levels of each attribute are as follows and are summarized in Table 3.

- Fuel cost saving effect (%): This is the degree of fuel cost savings after converting a truck to a hybrid. This consists of four levels of savings, including a 15%, 20%, 25%, and 30% reduction in fuel costs from that of the previous diesel truck.
- Hybrid conversion cost: This is incurred when converting a truck to a hybrid vehicle such as manufacturing costs, installation costs, etc. Four levels of cost are suggested: 100, 250, 450, and 600 (unit: KRW 10,000).

- Battery replacement cost (four-year cycle): This is generated by replacing battery every four years after conversion. Four levels of cost are considered: 35, 45, 55, and 65 (unit: KRW 10,000/4 years)

After determining the attributes and levels related to hybrid truck conversion technology, profiles with a combination of attributes and levels are generated using the D-optimal design methodology to create questionnaires for a conjoint survey. Fig. 3 shows an example question from the survey of the study.

The conjoint survey was designed by associating general preference trends (e.g., higher fuel cost savings are better) with respect to three elements of fuel cost savings, hybrid conversion costs, and maintenance costs. Respondents were asked to consider a variety of levels of attributes with respect to the hybrid truck conversion profiles and to choose the most preferred from the three options. A 4th option, "No conversion," could also be selected. The 10th question, of a total of 16 conjoint survey questions, was used to determine whether respondents answered the questions sincerely (i.e., sanity check). This question had one conversion option superior in all attributes compared to the other choices, and evidently, there was only one rational answer.

3.2. Subjects of the survey

One of the main challenges of this study was locating a pool of survey respondents that were representative parcel truck owners. It is ideal that the respondents are chosen randomly, but due to physical limitations and the mobile nature of truck drivers, the surveys were conducted in rest areas of highways in major cities so that interviewers can survey truck drivers who intermittently stopped by. It was relatively difficult to survey drivers who owned their trucks since most drivers were employed as employees, but the interviewers were trained to search and select owners through face-to-face interviews. The surveys were conducted in Korea's five major cities to sample respondents evenly across different geographical regions in Korea. The survey was commissioned by Metrix, a research and polling organization in Korea, in 2017 (Metrix, 2017).

In order to increase credibility of the survey process,

Table 3
Attributes and levels of hybrid truck conversion.

Attribute (unit)	Description	Attribute level (Level 1–4)
Fuel cost saving (%)	Fuel cost saved after hybrid conversion	15/20/25/30
Hybrid conversion cost (unit: KRW 10,000)	Cost required for hybrid conversion	100/250/450/600
Battery replacement cost (unit: KRW 10,000/4 years)	Cost generated every four years after conversion for replacing the battery	35/45/55/65

Note: KRW 10,000 was equal to approximately USD 8.85 as of 2017.

(Source: <https://data.oecd.org/conversion/exchange-rates.htm>).

Q: Please choose one that you prefer the most from the following options.
If there is none, choose "no conversion."

(unit: KRW 10,000)

Attributes	Option A	Option B	Option C	No Conversion
Fuel cost savings	20%	30%	30%	(keep the current diesel truck)
Hybrid conversion cost	250	600	100	
Battery replacement cost (4-year cycle)	35	35	45	
Choose (v)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Fig. 3. Example of the conjoint survey.

interviewers were required to attend three individual and group educational sessions to understand the conjoint surveys to be conducted. Field managers supervised and monitored the interview process administered by the interviewers and reported to the agency if any problems arose. After the surveys were completed, the collected surveys were sent to a third party institutions and survey inspectors to thoroughly check respondents' answering logic, response omissions, and response errors. Surveys that were determined to be invalid were disposed.

In total, the survey was completed for 245 owners of small parcel delivery trucks (1.5 tons or less) sampled equally from the five major cities in Korea, including Seoul, Busan, Daejeon, Daegu, and Gwangju. All the respondents selected were owners of their vehicles, while drivers of business-owned trucks were excluded from the survey. After they were filtered using a sanity check question, 191 valid subjects were obtained as the final sample.

In addition to the conjoint survey questions, the respondents were presented with questions regarding their demographic and vehicle information, such as annual income, average monthly fuel cost, average daily mileage, and fuel economy of one's vehicle. In total, 191 respondents have worked in parcel delivery services for 7 years and 8 months on average. The highest portion of respondents make KRW 30.01 to 35 million a year (29%), followed by those earning KRW 25.01 to 30 million (27.3%) and those earning KRW 35.01 to 40 million (14.3%). According to the survey, the average monthly fuel cost is KRW 348,000, and the average daily mileage is 49.6 km. The fuel economy of the parcel delivery trucks of the respondents is 7.0 km/l on average. This is probably because parcel delivery trucks mostly operate around cities which contributes to their lower fuel economy. Also, 91.6% of the respondents are self-employed, and 8.4% own trucks as a representative of a company. In all, the survey results showed that 28.8% of 191 respondents had a positive view towards converting their vehicles to hybrid ones, citing reasons such as fuel cost savings and emissions reduction.

4. Results

4.1. Preference modeling

4.1.1. HB estimation

The individual utility function results, i.e. average partworths by attribute level, of the hybrid conversion of parcel delivery trucks are summarized in Table 4. Again, these are calculated from HB estimation using survey data.

Note: The average values of partworth and importance of 191 respondents are presented, and their standard deviations are in parentheses. Partworths are the estimated β coefficients in equation (2) using the HB method. Importance is computed by the difference between the maximum and minimum partworths of each

attribute divided by the sum of the differences between the maximum and minimum partworths of each attribute. Note that the importance in Table 3 is the average of the importance of 191 individuals for each attribute. KRW 10,000 was equal to approximately USD 8.85 as of 2017.

The table shows the partworth for the levels of each attribute (fuel cost saving, hybrid conversion cost, battery replacement cost), or the β_{ikl} of level l of attribute k averaged over individuals i 's in equation (2). The partworth refers to the degree of preference for a level of a certain attribute, where a larger value indicates higher preference. The partworth is expressed in the same unit as total utility, and the total utility of a product can be calculated as the sum of the partworths of all its attribute levels. The highest partworth is at 7.03 when the hybrid conversion cost is KRW 1 million, and it falls sharply as the cost increases. It reaches the lowest at -11.90 when the conversion cost is KRW 6 million.

Fig. 4 illustrates the partworth analysis of 191 respondents by the level of each attribute in box plots. It graphically shows the ranges of the values by quartiles with the median indicated by the central line in each box. One can see that the distributions of partworths for each level are mostly skewed with different spreads. Since the distributions are not considered normal, when computing hybrid conversion probabilities below in Section 4.2.1, analyses in both mean and median values are conducted.

4.1.2. Attribute Importance

With the estimated values of partworths, the importance of each attribute can be calculated. The importance of an attribute is defined by the relative value of an attribute contributing to one's utility. The numerator of the importance measure is the difference between the maximum and minimum partworths of each attribute, while the denominator is the sum of the differences between the maximum and minimum partworths of each attribute. Therefore, the sum of the importance of each attribute adds up to 100%. The importance shown in Table 4 represents the averages and standard deviations of 191 respondents computed for each attribute. The importance for hybrid conversion cost computed is 69.1%, 21.0% for fuel cost savings, and 9.9% for battery maintenance cost.

In order to check the internal validity of our survey results, we check the quantitative results against other evidence established from the interviews (Yin, 2003). In addition to the conjoint surveys, this study inquired the respondents, "What is the most important factor in deciding whether to convert or not convert your truck to a hybrid?" Then we compared their answers with the results obtained from the attribute importance calculation. Indeed, for those drivers who answered "fuel cost savings" as the most important factor, their attribute importance calculated for fuel cost savings was high. Similarly, for those who answered that "hybrid conversion cost" was the impeding factor in converting to hybrids or who

Table 4
Partworth analysis of attribute levels and importance.

Attributes	Importance	Level	Partworth
Fuel cost savings	21.0% (31.0)	Level 1	15%
		Level 2	20%
		Level 3	25%
		Level 4	30%
Hybrid conversion cost (unit: KRW 10,000)	69.1% (29.7)	Level 1	100
		Level 2	250
		Level 3	450
		Level 4	600
Battery replacement cost (unit: KRW 10,000)	9.9% (7.5)	Level 1	35
		Level 2	45
		Level 3	55
		Level 4	65
No conversion		—	7.17 (9.52)

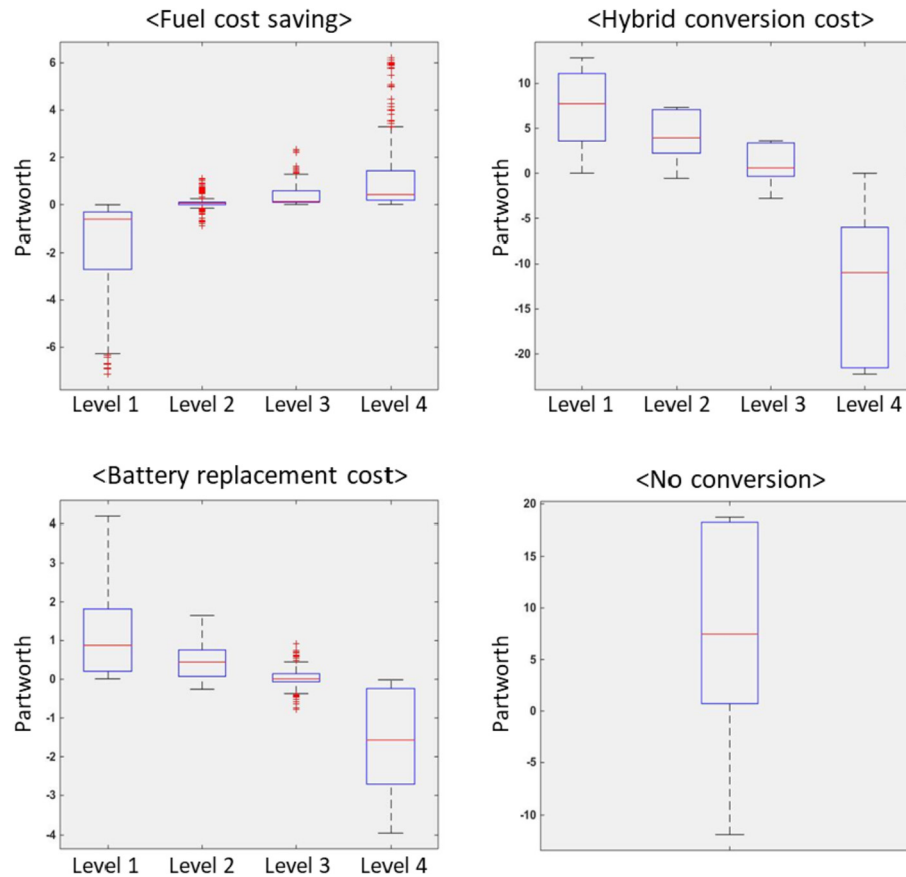


Fig. 4. Box Plot for Attributes and their Levels of Hybrid Truck Conversion Technology

Note: The central line shows the median of the partworths. The bottom and top lines that border the box show the 25th and 75th percentile values, and the bottom and top whiskers indicate the minimum and maximum, respectively. Points beyond the minimum and maximum are outliers.

noted that “the conversion costs are most burdening”, their importance for that attribute was high as well. This confirms that the interview responses were consistent with the results obtained from the conjoint analysis.

4.2. Feasibility test

4.2.1. Conversion probability

The probability of choosing to convert to hybrid trucks is calculated using equation (3) and the HB estimation results in Section 4.1.1. A respondent chooses between converting his truck to a hybrid from three different options of specifications presented (each with different levels of attributes), or keeping his truck as it is now. Table 5 summarizes the probability of conversion across different levels of hybrid conversion costs, fuel cost savings, and battery replacement costs. It shows four different cases with various levels of hybrid conversion costs, and for each case, the conversion probability for each combination of different levels of battery replacement cost (rows) and fuel cost savings (columns) are displayed. The probability can be analyzed with either its average or median value. The left values represent the median, and the right values represent the average probabilities of 191 respondents.

First, we examine the results based on the median conversion probabilities. Overall, the conversion probabilities are substantially higher when the hybrid conversion cost is KRW 1 million in Case i) than when it is KRW 2.5 million in Case ii). If the hybrid conversion cost is KRW 4.5 million or higher (Case iii) or iv)), the probabilities are closer to zero, and neither the fuel cost savings nor the battery

replacement costs influences truck owners’ choice of conversion much. Compared with the median values, the average conversion probability distribution is smoother, and the gap between the highest and the lowest probability is smaller. From the perspective of the hybrid conversion cost, the average conversion probabilities drop sharply when the cost increases from KRW 1 million (Case i)) to 2.5 million (Case ii)). When the conversion cost becomes KRW 2.5 million or higher, the probability decreases relatively gradually. As the hybrid conversion cost increases, the influence of fuel cost savings and battery replacement costs on the choice of conversion decreases more sharply.

Fig. 5 advances the results presented in Table 5 in a continuous form with a Heat Map showing the conversion probabilities for combinations of different attribute levels. Cubic spline interpolation is performed to obtain continuous values of partworths across attribute levels, from which the conversion probabilities for continuous attribute levels are then obtained. Again, the cases are divided into four levels of hybrid conversion costs (Case i) to iv)). The lighter the shade, the higher the probability of conversion, and vice versa. The median conversion probabilities represented on the left column are zero if the hybrid conversion costs exceed KRW 4.5 million regardless of the levels of the other two attributes, as shown by the shades that are completely dark in Case iii) and Case iv)). There are still positive probabilities of conversion in terms of average values even as the conversion costs increase, as displayed on the right column. Fig. 6 shows the relation between fuel cost savings and hybrid conversion costs when fixing the battery replacement cost to its minimum (KRW 350,000) and the

Table 5

Conversion Probability by Attribute Levels
Case i) Hybrid conversion cost of KRW 1 million.

		Fuel cost savings							
		15%		20%		25%		30%	
		Median	Mean	Median	Mean	Median	Mean	Median	Mean
Battery replacement cost (unit: KRW 10,000)	35	38.8%	45.9%	81.3%	57.7%	83.0%	58.8%	88.0%	62.9%
	45	20.7%	41.5%	55.3%	52.8%	62.3%	54.0%	79.5%	58.6%
	55	12.5%	38.8%	47.7%	49.8%	49.9%	51.0%	74.2%	55.8%
	65	2.6%	33.2%	18.5%	40.6%	20.3%	41.8%	37.3%	47.5%
Case ii) Hybrid conversion cost of KRW 2.5 million									
		Fuel cost savings							
		15%		20%		25%		30%	
		Median	Mean	Median	Mean	Median	Mean	Median	Mean
Battery replacement cost (unit: KRW 10,000)	35	0.7%	28.4%	6.2%	34.0%	7.8%	35.5%	21.5%	41.7%
	45	0.4%	27.4%	3.6%	32.3%	6.1%	33.5%	11.8%	39.6%
	55	0.3%	26.8%	2.4%	31.2%	3.4%	32.5%	10.4%	38.5%
	65	0.1%	25.4%	0.9%	28.6%	1.2%	29.5%	2.4%	34.4%
Case iii) Hybrid conversion cost of KRW 4.5 million									
		Fuel cost savings							
		15%		20%		25%		30%	
		Median	Mean	Median	Mean	Median	Mean	Median	Mean
Battery replacement cost (unit: KRW 10,000)	35	0.0%	21.8%	0.1%	23.2%	0.1%	23.6%	0.5%	24.1%
	45	0.0%	21.4%	0.1%	22.6%	0.1%	23.0%	0.4%	23.4%
	55	0.0%	20.9%	0.0%	22.0%	0.1%	22.3%	0.3%	22.7%
	65	0.0%	20.2%	0.0%	21.3%	0.0%	21.5%	0.1%	21.7%
Case iv) Hybrid conversion cost of KRW 6 million									
		Fuel cost savings							
		15%		20%		25%		30%	
		Median	Mean	Median	Mean	Median	Mean	Median	Mean
Battery replacement cost (unit: KRW 10,000)	35	0.0%	16.6%	0.0%	17.5%	0.0%	17.8%	0.0%	17.9%
	45	0.0%	16.5%	0.0%	17.3%	0.0%	17.5%	0.0%	17.6%
	55	0.0%	16.3%	0.0%	17.1%	0.0%	17.3%	0.0%	17.3%
	65	0.0%	16.1%	0.0%	16.9%	0.0%	17.0%	0.0%	17.1%

Note: KRW 10,000 was equal to approximately USD 8.85 as of 2017.

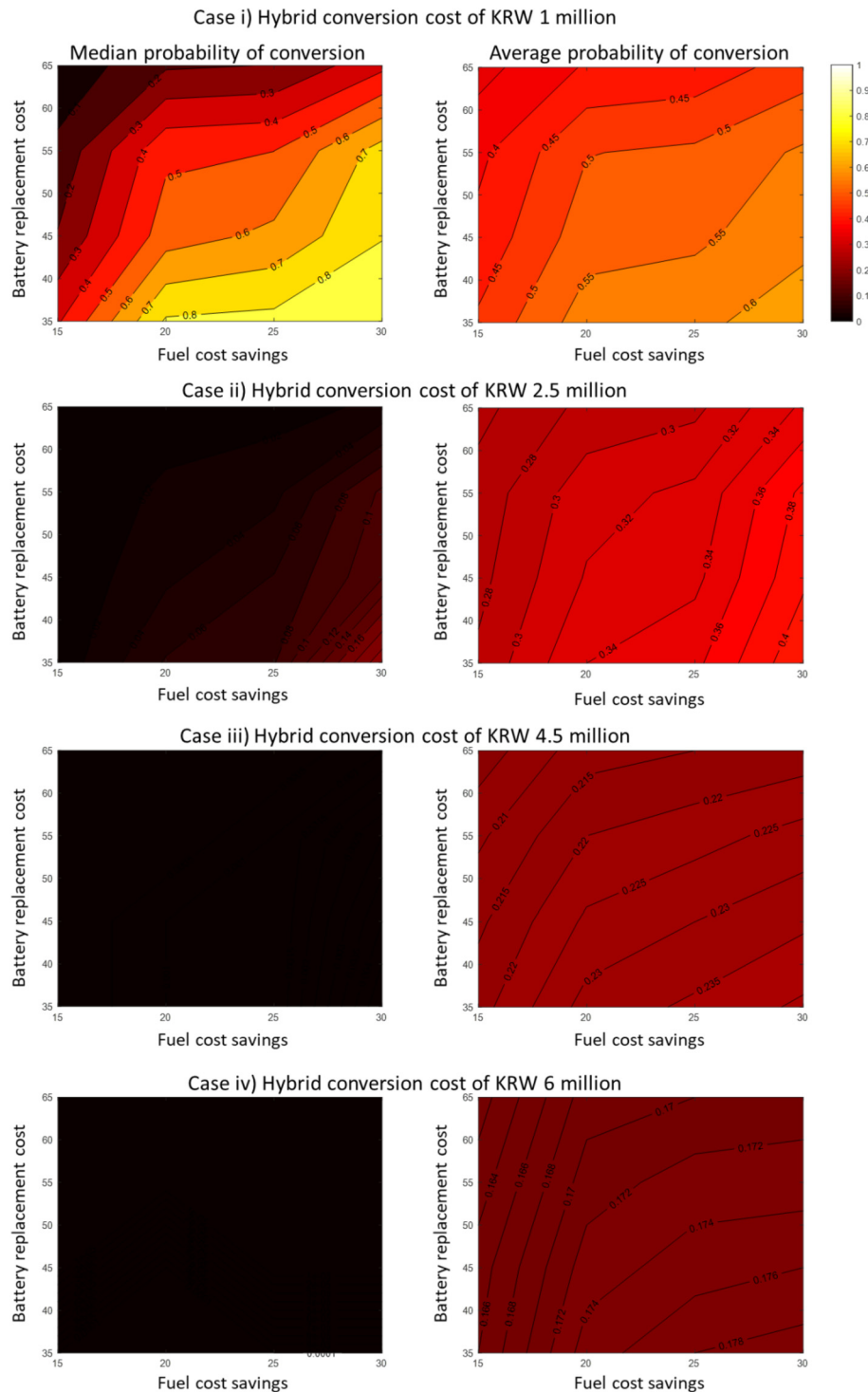


Fig. 5. Heat Map of the Conversion Probability by Attribute Levels
 Note: KRW 10,000 was equal to approximately USD 8.85 as of 2017
 (Source: <https://data.oecd.org/conversion/exchange-rates.htm>).

maximum (KRW 650,000) separately. The results show that the median value of conversion probability is extremely low when the battery replacement cost is KRW 650,000, which implies that the market demand is also sensitive to maintenance costs as expected.

4.2.2. Willingness to pay (WTP)

The WTP for improving one unit of fuel costs savings and battery

replacement costs, respectively, is shown in Table 6. The median value of individual WTP, instead of the average value, of 191 respondents is used to estimate the WTP of the population. This is because the value of the cost coefficient that is close to zero (i.e., when consumers are not sensitive to price) results in an arbitrarily and erroneously large WTP (Orme, 2009). The results show that a median respondent is willing to pay KRW 289,000 more in

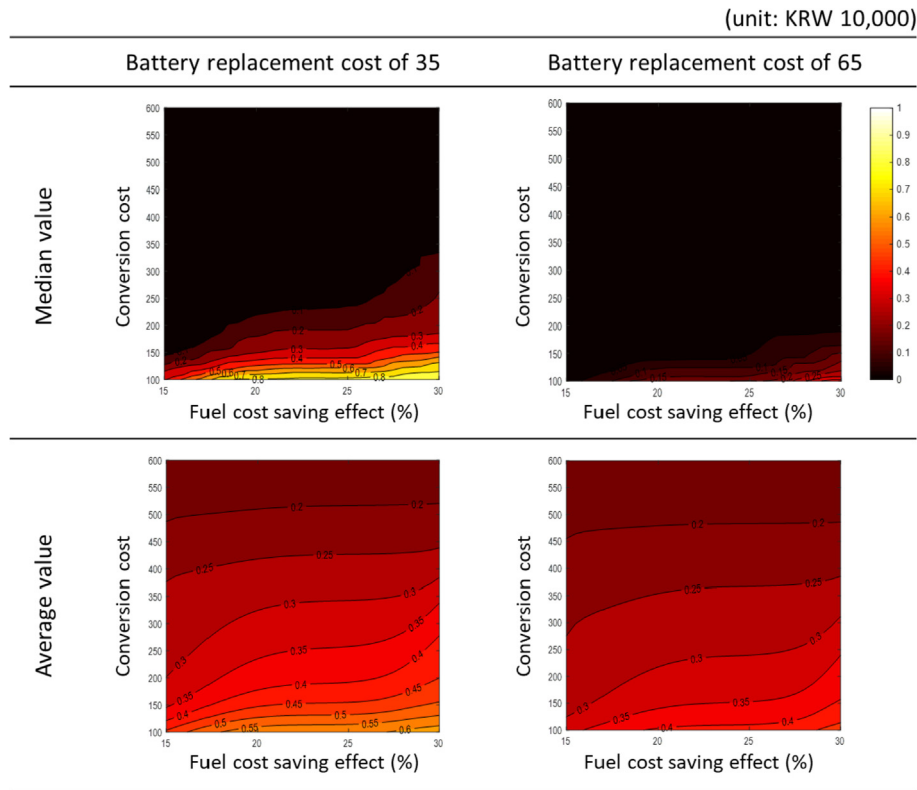


Fig. 6. Heat Map of the Conversion Probability by Battery Replacement Cost
Note: KRW 10,000 was equal to approximately USD 8.85 as of 2017.

Table 6

Calculating willingness-to-pay conversion cost by attributes (unit: KRW 10,000).

	Fuel cost savings (%)	Battery replacement cost (4-year cycle) (unit: KRW 10,000)
WTP (KRW 10,000)	28.9	−3.5

Note: KRW 10,000 was equal to approximately USD 8.85 as of 2017.

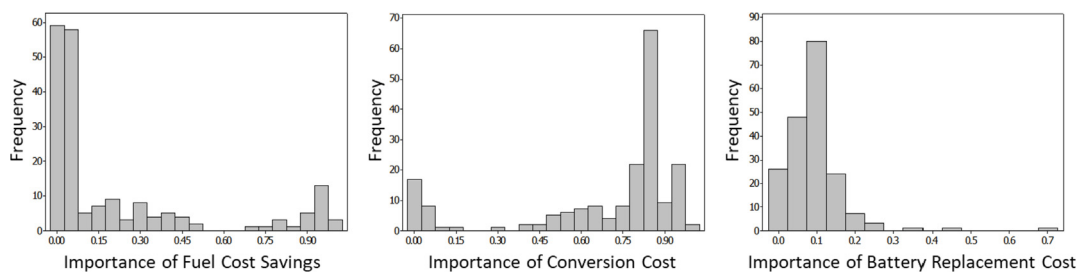


Fig. 7. Histograms of attributes importance.

conversion costs to increase fuel cost savings by 1%. In addition, he is willing to pay KRW 35,000 more for conversion to reduce KRW 10,000 of battery replacement costs.

4.3. Target consumer segmentation

4.3.1. Consumer clustering

The importance of each attribute of the 191 respondents calculated in Section 4.1.2 is displayed as histograms in Fig. 7. The distributions of the importance for fuel cost savings and hybrid conversion costs are polarized (i.e., either very important or very unimportant).

In addition, the 191 respondents can be divided into three groups using the K-means clustering method by the importance of the effect of fuel cost savings (x-axis) and hybrid conversion costs (y-axis), as shown in Fig. 8. These two attributes are selected for grouping since their distributions were polarized, whereas the distribution for battery replacement costs is not expected to affect consumer classification much based on results from Fig. 7.

- Black: A group that thinks that hybrid conversion costs are very important – 129 respondents (68%)
- Red: A group that considers that hybrid conversion costs and fuel cost savings are equally balanced – 35 respondents (18%)

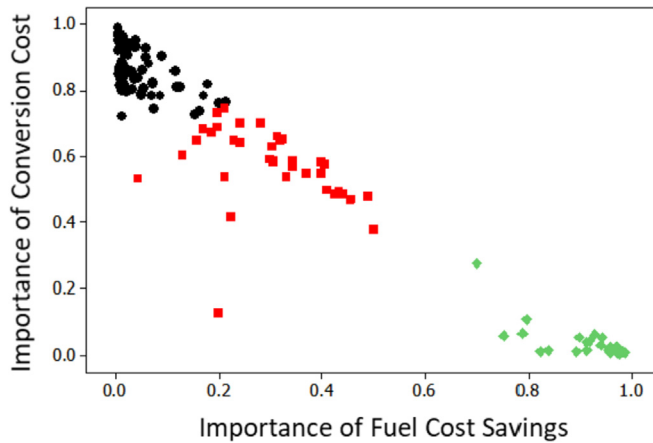


Fig. 8. Results of K-means clustering by attribute importance (three groups).

- Green: A group that thinks that fuel cost savings are very important – 27 respondents (14%)

The figure shows that most respondents consider hybrid conversion costs to be important, while the group that places importance on fuel cost savings only (Green) is distanced from the other two groups (Black and Red).

4.3.2. Regression by demographic factors

Lastly, ordinary least squares (OLS) regression is conducted to determine which demographic characteristics influence the importance of attributes among individuals as calculated in Section 4.1.2. The demographic characteristics can be used to understand and explain the properties of consumer groups presented in the previous section. In the regression analysis, the dependent variable (Y) refers to the importance of the three attributes (fuel cost savings, hybrid conversion costs, battery replacement costs), and the independent variables (X) are defined as respondents' demographic characteristics. Table 7 presents the results of the regression analysis on each attribute. A total of 10 demographic characteristics are used. All variables are continuous except truck ownership, which is equal to 1 if the truck is owned by the truck owner's company and 0 if individually owned, and car type at

purchase, which is equal to 1 if the truck was used at the date of purchase and 0 if it was new.

The regression analysis results are summarized as follows. The first column shows that consumers on average consider fuel cost savings to be more important if they are representatives of companies, the vehicle at purchase was new, the current mileage is higher, current fuel economy is lower, the average load weight is lighter, the parcel delivery work period is shorter, and the annual income is higher. Second, hybrid conversion costs are considered to be important, as the truck owner is self-employed, the vehicle is second hand, the current mileage is lower, the average load weight is heavier, the parcel delivery work period is longer, and the annual income is lower. The last column reveals that battery replacement costs are considered more important if the vehicle was used at the date of purchase and the average load weight is heavier.

Note: The values are estimated coefficients from OLS regressions on importance of each attribute. Truck ownership is a binary variable equal to 1 if the truck is owned by the truck owner's company, and 0 otherwise. Car type at purchase is equal to 1 if the truck was used at the date of purchase and 0 if the truck was new. Standard errors are in parentheses. * p-value ≤ 0.05, ** p-value ≤ 0.01.

Table 8 summarizes these results showing only the sign, or direction of the relationship, and level of significance of the OLS coefficients. The table shows that demographic characteristics influence the importance of fuel cost savings and hybrid conversion costs in opposite directions. The factors that significantly influence the importance of both fuel cost savings and hybrid conversion costs are as follows: whether the truck owner is representative of a company or self-employed, whether the vehicle is used or new, the current mileage, the average load weight, the period of working in the parcel delivery service industry, and annual income.

5. Discussion

This section presents insights by topic based on the results of Section 4 that can help a hybrid conversion R&D project manager in the process of decision making.

5.1. Preference modeling

5.1.1. Heterogeneous demand

This study modeled heterogeneous preferences using the HB

Table 7
Demographic characteristics influencing the importance of attributes.

	Importance of Fuel Cost Savings	Importance of Hybrid Conversion Costs	Importance of Battery Replacement Costs
Truck Ownership (Company or Individual)	0.30875** (0.07382)	−0.29833** (0.07344)	−0.01042 (0.02217)
Model Year	0.00490 (0.00882)	−0.00361 (0.00877)	−0.00129 (0.00265)
Car Type at Purchase (Used or New Car)	−0.1826** (0.05402)	0.14826** (0.05374)	0.03434* (0.01622)
Average Monthly Fuel Cost	0.00151 (0.00152)	−0.00114 (0.00152)	−0.00037 (0.00046)
Current Mileage	0.00000116* (0.00000049)	−0.000001* (0.00000049)	0.00000 (0.00000015)
Average Daily Mileage	−0.00117 (0.00096)	0.00089 (0.00096)	0.00028 (0.00029)
Current Fuel Economy	−0.0301* (0.01472)	0.02188 (0.01464)	0.00822 (0.00442)
Average Load Weight	−0.07971** (0.01431)	0.06942** (0.01423)	0.01030* (0.00430)
Period of Working in Parcel Delivery Services	−0.00130** (0.00037)	0.00129** (0.00037)	0.00000 (0.00011)
Annual Income	0.03018* (0.01235)	−0.03154* (0.01229)	0.00135 (0.00371)

Table 8
Demographic characteristics and importance of attributes.

Demographic Characteristics	Importance of Fuel Cost Savings	Importance of Hybrid Conversion Costs	Importance of Battery Replacement Costs
Truck Ownership (Company or Individual)	+(**)	-(**)	–
Model Year	+	–	–
Car Type at Purchase (Used or New Car)	-(**)	+(**)	+(*)
Average Monthly Fuel Cost	+	–	–
Current Mileage	+(*)	-(*)	–
Average Daily Mileage	–	+	+
Current Fuel Economy	-(*)	+	+
Average Load Weight	-(**)	+(**)	+(*)
Period of Working in Parcel Delivery Services	-(**)	+(**)	+
Annual Income	+(*)	-(*)	+

Note: The signs of the coefficients that are statistically significant from Table 7 are shown in the current table. The significance levels are denoted in parentheses where * p-value ≤ 0.05 , ** p-value ≤ 0.01 .

method and derived an individual preference model for each of the 191 owners of parcel delivery trucks. As shown in Table 4, the standard deviation values of the partworth utility and importance are considered to be large, which indicates that there are considerable differences in preferences among consumers. Moreover, histograms of the importance of attributes in Fig. 7 show that consumer preferences are polarized. And Table 5 listing the conversion probability reveals that there is a large gap between its median and average values. This is because consumer preferences are again polarized. As an example, the distribution of conversion probability, when the hybrid conversion cost is KRW 2.5 million, fuel cost savings is 30%, and battery replacement cost is KRW 650,000, is represented in Fig. 9. According to this figure, the majority of respondents report a conversion probability of 0% or 100%, while the rest of the respondents are distributed equally in between these values. The average conversion probability of the 191 respondents is 34.4% while the median value is 2.4%. The findings reveal that preferences regarding hybrid truck conversion and conversion probability are heterogeneous, thus this needs to be taken into account for policy analyses.

5.1.2. Accuracy of demand forecasting

To evaluate the accuracy of this model in a market with high degree of heterogeneity, the survey questions are divided into a train set and a test set to determine how accurately a model that learned from the train set can predict the test set. This is a widely used method to evaluate the accuracy of a conjoint analysis model. In this study, two questions out of a total of 15 were selected for testing, while the remaining 13 questions were selected for training. The test questions were converted from multiple-choice questions with four options to three binary questions for use in the test. First, to calculate the hit rate of the individual preference model, cross-validation was conducted to test every possible combination of the two test questions selected among the total of 15 ($\frac{15 \times 14}{2} = 120$ combinations) and to compute the average of hit rate. The average hit rate of the 191 respondents was 88.3%. As the test was conducted using binary questions, a completely random prediction would produce a 50% hit rate. The result of 88.3% thus indicates that the model in this study forecasts a heterogeneous market relatively accurately.

5.2. Feasibility test

5.2.1. Differences between general preference and preference according to conversion attributes

At the end of the survey, we asked “Will you consider converting your parcel delivery truck to a hybrid?” This question was posed to simply determine the general preference of truck drivers without giving any information on vehicle attributes. In all, 28.8% of the

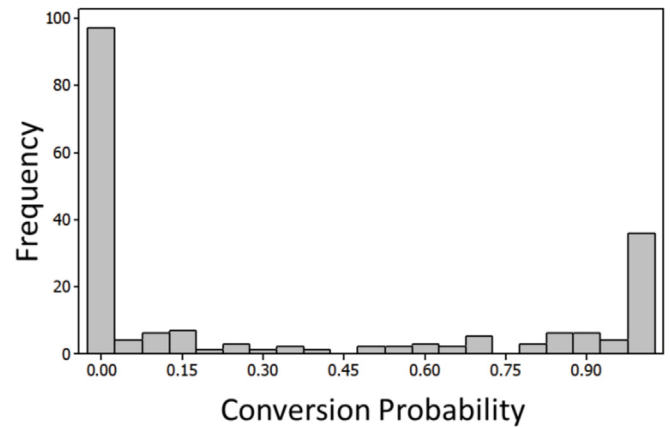


Fig. 9. Example of Conversion Probability Distribution
Note: KRW 10,000 was equal to approximately USD 8.85 as of 2017.

subjects answered “Yes” to this question. With this general preference (28.8%) as the baseline, the conversion probability predicted in Table 5 using HB estimation can be compared to analyze the level of expected costs and vehicle performance that is needed for 28.8% of the respondents to convert to hybrids. In the table, analysis using the average values shows that when hybrid conversion costs are KRW 2.5 million or lower and fuel cost savings are 20% or higher, over 28.8% of respondents will choose to convert their trucks regardless of the battery replacement cost (i.e., all possible combinations of Case i) and the last three columns of Case ii)). Analysis using the median values shows that when the hybrid conversion cost is KRW 1 million, fuel cost savings is 20% or higher, and the battery replacement cost is KRW 550,000 or lower, more than 28.8% of respondents will prefer conversion (i.e., intersection of top three rows and last three columns of Case i)). On the other hand, when the hybrid conversion cost is KRW 2.5 million or higher (Case ii), iii), and iv)), the conversion probabilities do not reach 28.8%, and changes in other attributes do not influence the conversion probability substantially. This implies that hybrid conversion costs, fuel cost savings, and battery replacement costs should be balanced to satisfy general expectations of conversion, while improvement of other attributes does not have a significant impact when hybrid conversion costs go over a certain threshold.

5.2.2. Conversion probability and WTP as feasibility tests

One of the main purposes of this study is to verify the feasibility of the government-led R&D project to convert parcel delivery trucks to hybrid vehicles. The research team consisting of experts involved in this government project have initially proposed a goal

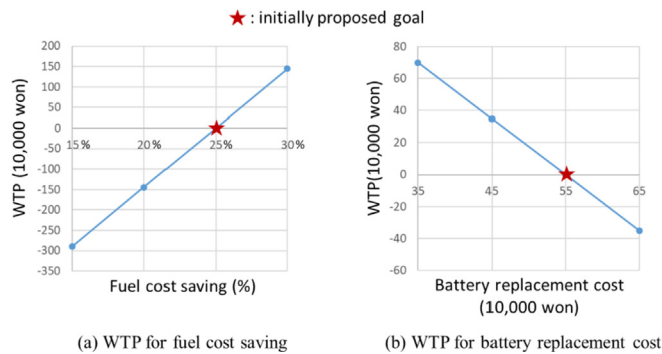


Fig. 10. Conversion Probability according to the Hybrid Conversion Cost
Note: KRW 10,000 was equal to approximately USD 8.85 as of 2017.

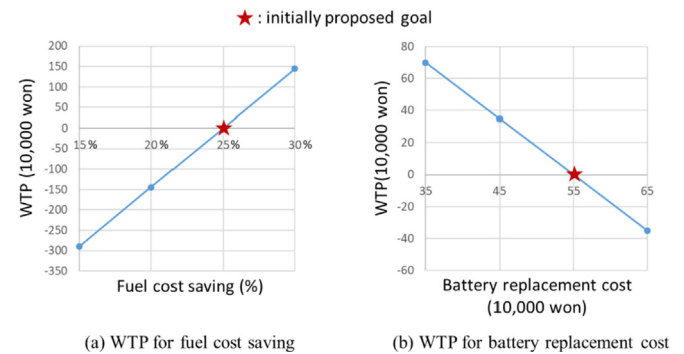


Fig. 11. WTP based on initially proposed goal.

of fuel cost savings of 25% and battery replacement cost of KRW 550,000. However, it is worth noting that although the current study began with these targets in mind and assessed the expected outcomes by looking at feasible ranges around them, the realized fuel cost savings and battery replacement costs in the end may differ from the initial target values.

Fig. 10 displays the median and mean values of the conversion probabilities by hybrid conversion costs when the other two attributes are set to initially proposed target values. This is simply a continuous, graphical version of Table 5 but by fixing the fuel cost savings to 25% and battery replacement cost to KRW 550,000, the target values. The figure shows the conversion costs to be incurred per vehicle for each level of conversion probability. This tradeoff relationship between conversion costs and conversion probability ought to be considered when policymakers make their final decision.

It is informative to use the conversion probability obtained from the survey results, which we previously referred to as the general preference for conversion, as the benchmark. Based on the mean values, Fig. 10 shows that the conversion probability is above 28.8%, the general preference for conversion, only when the hybrid conversion cost is KRW 3.2 million or less. Looking at the median values, the hybrid conversion cost should be KRW 1.31 million or less to reach the conversion probability of 28.8% or more. If the government attempts to maintain the initially proposed developmental targets, it appears that the government ought to secure a budget to cover some conversion costs in order to elicit conversion probability of 28.8% or more, and consider providing subsidies to achieve its goals.

In addition to the conversion probability calculations, we also investigate the feasibility of the government project when the attribute levels are set to initial targets proposed by the government, i.e. fuel cost savings of 25% and battery replacement cost of KRW 550,000, by examining consumer WTP. Note again that the WTP can be translated as the willingness to pay higher conversion costs. We set WTP to zero when fuel cost savings and battery replacement costs meets the initially proposed target values. Fig. 11 displays the WTP for the ranges that are in vicinity to the target values of fuel cost savings and battery replacement cost savings.

Fig. 11(a) shows that if the actual fuel cost savings turn out to be 15%, which is 10 percentage points less than the initial target value of 25%, the conversion should cost 2.89 million won less than when fuel cost savings is 25%. On the other hand, if the fuel cost savings increase to 30%, it is estimated that consumers are willing to pay additional 1.45 million won for conversion. Fig. 11(b) shows that if battery replacement cost is 650,000 won, which is 100,000 won higher than the initial target of 550,000 won, the conversion should cost 350,000 won less relative to when the battery replacement

cost meets the target level. In contrast, if the battery replacement cost is only 350,000 won, consumers are willing to pay 700,000 won more.

The WTP analysis allows us to predict how much a government should cover, or subsidize, conversion costs based on technological attainment of attributes. Comparing Fig. 11(a) and (b) shows that the conversion cost is much more sensitive to ranges of fuel cost savings compared to savings in battery replacement costs. Therefore, it would be more feasible if future project development focuses on fuel cost savings even if the battery replacement cost falls slightly short of its target. In fact, after the early results of our paper were completed, the project has focused on maximizing fuel cost savings and reducing battery replacement cost to a lesser degree. A recent interim report indeed indicates that fuel cost savings in hybrid vehicles have increased significantly although improvements in battery replacement cost savings have been marginal.

5.2.3. Offering installment payments for hybrid conversion costs

One of the key insights regarding hybrid conversion costs is that consumers are sensitive to the fixed costs that they need to pay up front. Even if the savings in fuel costs will eventually exceed the payments paid for conversion in the long term, consumers tend to place more weight on current expenditures. This implies that there is a considerable psychological discount rate against future utility. On the preference for timing of payments of products, Patrick and Park (2006) reveals that consumers tend to prefer prepayments for purchases of nondurable goods that are especially associated with pleasure, or hedonic goods. On the other hand, consumers prefer to postpay for durable goods due to the time discounting that enables consumers to discount the cost of the good through its usage of it over time. Similarly, due to the benefits of hybrid vehicles that are reaped over time as a durable good and the existing uncertainties or risks involved regarding future maintenance costs of hybrid vehicles, consumers may prefer postpayment to prepayment. In fact, when asked why they would not consider hybrid conversion in the survey, the main factors that respondents mentioned were the possibility of technical failures and concerns on the power of hybrid vehicles. This problem can be addressed by government subsidies that would allow consumers to pay for hybrid conversion in installments instead of lump-sum prepayments. The introduction of such an installment plan will allow consumers to compare their installment payments with fuel cost savings each period, and is expected to reduce future uncertainties surrounding conversion.

In addition, Section 4.2.2 discussed the results regarding consumers' WTP for improving hybrid technology. The results showed that to reduce battery replacement costs by another KRW 10,000, consumers would be willing to pay an additional KRW 35,000 for conversion. Both battery replacement and hybrid conversion costs

are translated in monetary terms, but the former is generated every fourth year after conversion. Thus, consumers will discount the monetary value that will be spent in the future. Policymakers need to understand this tendency among consumers and thus formulate policies to allow them to divide such costs and make installment payments.

5.3. Target consumer segmentation

5.3.1. Strategy of focusing on target consumer segments

This study shows the need to identify consumer segment targets for hybrid truck conversion and to primarily focus marketing resources on them. The findings of the research confirm that consumers have heterogeneous preferences regarding the conversion of trucks to hybrid vehicles. There are a few takeaways from the results. (1) According to the consumer classification of attribute importance in Fig. 8 and 129 consumers (68%) who prioritize conversion costs and 27 consumers (14%) who stress fuel cost savings are distributed at the two extremes. Consumers with conversion intentions are more likely to consider fuel cost savings to be more important, thus it is important to target this consumer segment in order to promote hybrid conversion. (2) In Section 4.3.2, the examination of demographic characteristics showed that those who place priority on fuel cost savings tend to be representatives of companies rather than self-employed. This result seems to have been observed because company representatives are relatively less sensitive to hybrid conversion costs relative to the self-employed, and are more likely to consider overall profits obtained through fuel cost savings. In addition, those with higher annual income regard hybrid conversion costs to be less important and place more emphasis on fuel cost savings. (3) The respondents were found to be more sensitive to conversion costs when they had purchased a second-hand truck because they were less willing to make additional investments in the vehicle. (4) Those with vehicles with relatively light average load weight and low fuel economy considered fuel cost savings to be important. It can be assumed that those with vehicles with high average load weight should have negative views about conversion given the low power expected of hybrid vehicles, as many respondents noted “low power” as a disadvantage of hybrid conversion. On the other hand, those who recently started working in the parcel delivery service industry tended to be more positive about hybrid conversion and the fuel cost savings that it can bring. In conclusion, strategies to focus on a pool of target consumers are necessary, after which the policy can then reach out to a wider range of consumers.

6. Conclusion and policy implications

The Korean government is planning an R&D project to convert the existing diesel trucks to diesel-electric hybrid vehicles in order to reduce PM and greenhouse gas emissions from parcel delivery trucks. This study examined the marketability and economic feasibility of hybrid conversion as part of the planning stages of a larger R&D project by modeling preferences of diesel truck owners. To this end, HB choice-based conjoint analysis was used to conduct the following tasks: calculate the importance of conversion attributes, forecast the conversion probabilities by attribute levels, calculate consumers' WTP, cluster consumers by attribute importance, and analyze demographic factors influencing each attribute importance.

The analysis results provided a range of insights into the R&D project for decision makers. First, consumers have heterogeneous preferences and are particularly sensitive to hybrid conversion costs, thus it is necessary to set an optimal conversion cost by considering both the technological feasibility and returns to

government investment through the demand forecasting model. In addition, policies that allow consumers to pay in installments for the conversion so that they can compare the gains from fuel cost savings each period must be formulated, instead of having them pay for the full cost in a lump sum. Finally, it is necessary to first focus on the consumer segment target that prioritizes fuel cost savings before gradually expanding to a larger consumer base.

Although the reliability of data may decrease when respondents lack concentration during the survey and when consumer preferences regarding conversion are too heterogeneous to be represented by a mean or median value, the study is meaningful in that it is one of the first few papers to examine consumer preferences on vehicle conversion. The current analysis considered consumer preferences only, but forthcoming research should integrate government budget and material costs required by attribute enhancements to offer a more balanced approach for setting development goals and devising subsidy policies to achieve maximum conversion probability and returns on investment (Kang et al., 2016). Moreover, analyses should be conducted to consider the relationship between consumer preferences and technical feasibility while evaluating engineering performance (Kang et al., 2015, 2017a). These types of analyses would provide a more holistic insight on project development.

Declarations of interest

None.

Acknowledgements

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References

- Álvarez-Farizo, B., Hanley, N., 2002. Using conjoint analysis to quantify public preferences over the environmental impacts of wind farms. An example from Spain. *Energy Policy* 30 (2), 107–116.
- Axsen, J., Kurani, K.S., 2010. Anticipating plug-in hybrid vehicle energy impacts in California: constructing consumer-informed recharge profiles. *Transport. Res. Transport Environ.* 15 (4), 212–219.
- Bolduc, D., Boucher, N., Alvarez-Daziano, R., 2008. Hybrid choice modeling of new technologies for car choice in Canada. *Transport. Res. Rec.* 2082 (1), 63–71.
- Brownstone, D., Bunch, D.S., Train, K., 2000. Joint mixed logit models of stated and revealed preferences for alternative-fuel vehicles. *Transp. Res. Part B Methodol.* 34 (5), 315–338.
- Dagsvik, J.K., Wennemo, T., Wetterwald, D.G., Aaberge, R., 2002. Potential demand for alternative fuel vehicles. *Transp. Res. Part B Methodol.* 36 (4), 361–384.
- Diamond, D., 2009. The impact of government incentives for hybrid-electric vehicles: evidence from US states. *Energy Policy* 37 (3), 972–983.
- Gao, S., Smits, M., Wang, C., 2016. A conjoint analysis of corporate preferences for the sectoral crediting mechanism: a case study of Shanxi Province in China. *J. Clean. Prod.* 131, 259–269.
- Green, P.E., Krieger, A.M., 1996. Individualized hybrid models for conjoint analysis. *Manag. Sci.* 42 (6), 850–867.
- Greene, D., Hossain, A., Hofmann, J., Helfand, G., Beach, R., 2018. Consumer willingness to pay for vehicle attributes: what do we know? *Transport. Res. Part A* 118, 258–279.
- He, H., Fan, J., Li, Y., Li, J., 2017. When to switch to a hybrid electric vehicle: a replacement optimisation decision. *J. Clean. Prod.* 148, 295–303.
- Helveston, J.P., Liu, Y., Feit, E.M., Fuchs, E., Klampfl, E., Michalek, J.J., 2015. Will subsidies drive electric vehicle adoption? Measuring consumer preferences in the US and China. *Transport. Res. Pol. Pract.* 73, 96–112.
- Heywood, J.B., Weiss, M.A., Schafer, A., Bassene, S.A., Natarajan, V.K., 2004. The Performance of Future ICE and Fuel Cell Powered Vehicles and Their Potential Fleet Impact (No. 2004-01-1011 (SAE Technical Paper)).
- Kang, N., 2014. Multidomain Demand Modeling in Design for Market Systems. PhD Thesis. University of Michigan.
- Kang, N., Feinberg, E.M., Papalambros, P.Y., 2015. Integrated decision making in

- electric vehicle and charging station location network design. *J. Mech. Des.* 137 (6), 061402.
- Kang, N., Ren, Y., Feinberg, F.M., Papalambros, P.Y., 2016. Public investment and electric vehicle design: a model-based market analysis framework with application to a USA–China comparison study. *Design Sci.* 2.
- Kang, N., Feinberg, F.M., Papalambros, P.Y., 2017a. Autonomous electric vehicle sharing system design. *J. Mech. Des.* 139 (1), 011402.
- Kang, N., Burnap, A., Kim, K.H., Reed, M.P., Papalambros, P.Y., 2017b. Influence of automobile seat form and comfort rating on willingness-to-pay. *Int. J. Veh. Des.* 75 (1–4), 75–90.
- Kang, N., Bayrak, A.E., Papalambros, P.Y., 2018. Robustness and real options for vehicle design and investment decisions under gas price and regulatory uncertainties. *J. Mech. Des.* 140 (10), 101404.
- Kaufmann, S., Künzel, K., Loock, M., 2013. Customer value of smart metering: explorative evidence from a choice-based conjoint study in Switzerland. *Energy Policy* 53, 229–239.
- Lee, D.H., Park, S.Y., Kim, J.W., Lee, S.K., 2013. Analysis on the feedback effect for the diffusion of innovative technologies focusing on the green car. *Technol. Forecast. Soc. Change* 80 (3), 498–509.
- Lee, J., Cho, Y., 2009. Demand forecasting of diesel passenger car considering consumer preference and government regulation in South Korea. *Transport. Res. Pol. Pract.* 43 (4), 420–429.
- Lee, U., Kang, N., Lee, I., 2019. Selection of optimal target reliability in RBDO through reliability-based design for market systems (RBDMS) and application to electric vehicle design. *Struct. Multidiscip. Optim.* 1–15.
- Lenk, P.J., DeSarbo, W.S., Green, P.E., Young, M.R., 1996. Hierarchical Bayes conjoint analysis: recovery of partworth heterogeneity from reduced experimental designs. *Mark. Sci.* 15 (2), 173–191.
- Lieder, M., Asif, F.M., Rashid, A., Mihelić, A., Kotnik, S., 2018. A conjoint analysis of circular economy value propositions for consumers: using “washing machines in Stockholm” as a case study. *J. Clean. Prod.* 172, 264–273.
- Lüthi, S., Prässler, T., 2011. Analyzing policy support instruments and regulatory risk factors for wind energy deployment—a developers’ perspective. *Energy Policy* 39 (9), 4876–4892.
- Maritime Press of Korea, 2018. Parcel Delivery Volume Increased 13.3% Last Year. <http://m.maritimepress.co.kr/news/articleView.html?idxno=116878>.
- Metrix, 2017. Metrix corporation. <http://metrix.co.kr/>.
- Meyerding, S.G., Merz, N., 2018. Consumer preferences for organic labels in Germany using the example of apples—Combining choice-based conjoint analysis and eye-tracking measurements. *J. Clean. Prod.* 181, 772–783.
- MOLIT (Ministry of Land, Infrastructure and Transport), 2016. Report on Domestic and International Development Status of Eco-Friendly Hybrid Diesel-Electric Trucks Optimized for Parcel Delivery Service. Korea Agency for Infrastructure Technology Advancement, KAIA.
- Olson, E.L., 2013. It's not easy being green: the effects of attribute tradeoffs on green product preference and choice. *J. Acad. Mark. Sci.* 41 (2), 171–184.
- Olson, E.L., 2018. Lead market learning in the development and diffusion of electric vehicles. *J. Clean. Prod.* 172, 3279–3288.
- Orme, B., 2009. The CBC/HB System for Hierarchical Bayes Estimation Version 5.0. Technical Paper, Technical Paper Series. Sawtooth Software, Sequim, WA.
- Patrick, V.M., Park, C.W., 2006. Paying before consuming: examining the robustness of consumers’ preference for prepayment. *J. Retail.* 82 (3), 165–175.
- Peterson, M., Feldman, D., 2018. Citizen preferences for possible energy policies at the national and state levels. *Energy Policy* 121, 80–91.
- Rossi, P.E., Allenby, G.M., 2003. Bayesian statistics and marketing. *Mark. Sci.* 22 (3), 304–328.
- Rossi, P., Allenby, G., McCulloch, R., 2005. Bayesian Statistics and Marketing. Wiley, Hoboken, NJ.
- Shin, J., Hwang, W.S., 2017. Consumer preference and willingness to pay for a renewable fuel standard (RFS) policy: focusing on ex-ante market analysis and segmentation. *Energy Policy* 106, 32–40.
- Struben, J., Sterman, J.D., 2008. Transition challenges for alternative fuel vehicle and transportation systems. *Environ. Plan. Plan. Des.* 35 (6), 1070–1097.
- Toubia, O., Evgeniou, T., Hauser, J., 2007. Optimization-based and Machine-Learning Methods for Conjoint Analysis: Estimation and Question Design. *Conjoint Meas.: Methods Appl.*, pp. 231–258.
- Train, K., 2003. Discrete Choice Methods with Simulation. Cambridge University Press.
- Yin, R.K., 2003. Case Study Research: Design and Methods. Sage Publications.
- Zaunbrecher, B.S., Linzenich, A., Ziefle, M., 2017. A mast is a mast is a mast...? Comparison of preferences for location-scenarios of electricity pylons and wind power plants using conjoint analysis. *Energy Policy* 105, 429–439.
- Zhang, X., Bai, X., Shang, J., 2018. Is subsidized electric vehicles adoption sustainable: consumers’ perceptions and motivation toward incentive policies, environmental benefits, and risks. *J. Clean. Prod.* 192, 71–79.