sustainability

MDPI

Article

# Valuing Improved Power Supply Reliability for Manufacturing Firms in South Korea: Results from a Choice Experiment Survey

**Doo-Chun Kim, Hyo-Jin Kim and Seung-Hoon Yoo ***

Department of Energy Policy, Graduate School of Energy & Environment, Seoul National University of Science & Technology, 232 Gongreung-Ro, Nowon-Gu, Seoul 01811, Korea; smartenergy@seoultech.ac.kr (D.-C.K.); hjinkim@seoultech.ac.kr (H.-J.K.)

* Correspondence: shyoo@seoultech.ac.kr

Received: 27 September 2018; Accepted: 26 November 2018; Published: 30 November 2018

**Abstract:** An outage of electricity may cause considerable economic damage to industrial sectors. Thus, South Korea electricity authorities demand information about the value of improved power supply reliability for the manufacturing sector to implement them in planning electricity supply. This article aims to measure the value using a specific case of South Korean manufacturing firms. The choice experiment (CE) approach is adopted for this purpose. A nationwide CE survey of 1148 manufacturing firms was undertaken. The firms revealed statistically significant willingness to pay for a decrease in the duration of interruption, avoiding interruption during daytime (9 a.m. to 6 p.m.) rather than off-daytime (6 p.m. to 9 a.m.), and preventing interruption during weekdays rather than weekend. For example, they accepted a 0.02% increase in the electricity bill for reducing one minute of interruption during electricity outage, a 2.98% increase in the electricity bill to avoid interruption during the daytime rather than off-daytime, and a 1.60% increase in electricity bill for preventing interruption during weekdays rather than weekends. However, they put no importance on the season of interruption. These results can be useful for policy-making and decision-making regarding improving electricity supply reliability.

**Keywords:** power supply reliability; electricity; manufacturing industry; choice experiment; willingness to pay

## 1. Introduction

In microeconomics, labor and capital are usually assumed as basic production factors. However, electricity is another important production factor in modern times. Even if labor and capital are plentiful, without electricity commodities cannot be produced because factories and various production facilities are operated using electricity. That is, electricity is an essential input to industrial production. In particular, the industrial sector may use more electricity as the industrial structure improves. For example, artificial intelligence, self-driving, and international data centers need a lot of power consumption. Thus, a stable power supply contributes to industrial production and further to economic development by increasing economic activities [1].

This is the case for South Korea [2–5]. As of 2017, 56.3% of the total power consumption was for industrial purposes. This percentage is the highest among OECD countries except Iceland. Steel, shipbuilding, semiconductor, automotive, and petrochemical industries, which mainly support the export-led South Korean economy, account for a significant portion of industrial electricity use. For example, a steel company consumes all of the electricity produced by a nuclear power plant with a capacity of 1 GW. If electricity is not supplied properly to these sectors, massive damage will shake the foundations of the national economy [6].

Even if a power outage occurs for just one minute, it can cause significant damage to the manufacturing firms without uninterrupted power supply (UPS). For example, in the case of a food factory, if the mechanical equipment is stopped for a short period of time, all products on the production line must be disposed of. In addition, a power outage in a semiconductor plant that requires ultraprecision microprocessing compared to other manufacturing operations can cause tremendous damage regardless of whether an UPS is installed or not.

South Korea experienced a nationwide rolling blackout in September 2011, with a sudden increase in power demand due to high temperatures and a decrease in power supply due to power plant maintenance. During the blackout, the industrial sector suffered great damage. Therefore, there is a consensus among the people that such a blackout should not occur again [7]. The Korea Electric Power Corporation (KEPCO), the only power distribution company in South Korea, and the South Korean government, which oversees KEPCO, are responsible for supplying electricity without any power outage. The government and KEPCO has made every effort to reliably supply electricity to the industrial sectors, making huge investments in power plants, transmission facilities, distribution facilities, and electricity storage systems. Not only the government and KEPCO but also the Korea Power Exchange (KPX) are responsible for reliably supplying electricity because KPX operates Korea power system.

The government is pushing for an energy transition policy to reduce the share of coal and nuclear power generation and increase the share of renewable energy generation from 2.2% in 2016 to 20.0% by 2030. Although public consensus has been formed on the promotion of the energy transition policy, there are also concerns about securing power supply stability due to the expansion of renewable energy. This is because electric power generation from renewable energy such as wind power and photovoltaic power has a nature of intermittency and uncertainty. Thus, a stable supply of electricity to the industrial sector will be the most important issue for the power authority, as renewable energy will be dramatically expanded in accordance with the government's energy transition policy. In particular, this is needed to secure additional backup power sources, such as gas-fired plants and pumping-up power plants, expand the installation of electricity storage devices, and drastically strengthen the power system. These require a large amount of investment. To justify the investment, the benefits of the investment must outweigh its costs.

Determining the optimal level of power supply reliability requires a function of cost needed to improve power supply reliability and a function of damage costs reduced by improving power supply reliability. The optimal level of power supply reliability is determined at a level that minimizes the sum of the two cost functions. In particular, the function of damage costs reduced due to improved power supply reliability is the same as the function of economic value resulting from improved power supply reliability. Therefore, it is necessary to develop a function that represents the economic value of improving the reliability of power supply.

The costs of increasing power supply reliability can be measured without particular difficulties. However, estimating the benefits or economic value arising from the investment for improving power supply reliability is a very difficult task. This is because the outcome of the investment is improved supply reliability of electricity, and power supply reliability is not a commodity traded in the market. It is necessary to apply techniques to create a hypothetical market for trading power supply reliability so that the reliability of power supply can be assessed by the consumers. Moreover, power supply reliability has several attributes, each of which should be valued. There are various types and periods of power outages, such as when the outages occur, how long they last, when they happen during the week or on weekend, and in which season they take place. In other words, power supply reliability is a multi-attribute good [8]. For example, power supply reliability has multiple attributes such as Information/Notice Provided, Continuous/Uninterrupted Supply, Frequency, Duration, Number, and Time of week.

There are two kinds of techniques to evaluate the power supply reliability. The first technique is to utilize actually revealed data. For example, one may directly investigate the economic damage incurred when a real power outage occurs and view this value as the economic value of improving the power supply reliability. Alternatively, a replacement cost approach that uses the cost information needed to install and operate an emergent backup generator that can reliably supply electricity in the event of a power outage could be applied. The second technique is to ask consumers directly or indirectly about the value of power supply reliability and analyze the responses using economic and econometric theories. In doing so, the application of specially designed economic method is required to value a multi-attribute good.

A typical way to do this is choice experiment (CE). CE is the most prevalent methodology for a multi-attribute good and has almost always been applied in some previous economic studies that have dealt with the valuation of improved power supply reliability [9–13]. In this study, the CE is applied to valuing improved power supply reliability for manufacturing firms in South Korea. The four attributes of power supply reliability considered in this study are duration of power outage, the season of power outage, the time of day when power outage occurs, and the day of the week when power outage occurs. These were identified as factors of interest to the power authority as well as consumers in managing power supply reliability.

As will be explained in more detail below, this study randomly selected 1148 manufacturing firms from all over the country under the supervision of a professional survey company to gather data on value judgments about improved power supply reliability through a CE survey of them. The subsequent composition of this paper is as follows. Section 2 describes in detail the methodology and application procedures used in this study. Section 3 explains the economic and statistical models for analyzing data collected through the CE survey. Section 4 reports some implications after reporting the results. The final section is devoted to presenting conclusions.

## 2. Methodology

### 2.1. CE Approach

Two techniques that have been widely employed for nonmarket good valuation in the literature are CE and contingent valuation (CV) [14–17]. The CE method asks the respondents to evaluate value trade-offs among some attributes and indirectly derives their willingness to pay (WTP). Usually, the CV method is applied to a single-attribute good while the CE method is applied to a multi-attribute good. Therefore, the CE method is more suitable for valuing a multi-attribute good than the CV method. The CE approach is theoretically grounded in the random utility maximization model. The model implies that if an individual chooses one alternative among several alternatives, the utility arising from the alternative is always more than the utility arising from the other alternatives. Therefore, the application of the approach requires a survey of consumers. CE is a useful method for estimating the relative values for different attributes of an environmental and nonmarket good or new product.

In general, respondents are required to choose the most preferred alternative out of several alternatives, which include a current status alternative, presented to them in the CE survey. Each alternative comprises several attributes of concern, including the price attribute. CE is a useful method to estimate the relative importance of several attributes for a good or service. Marginal WTP (MWTP) for increasing or decreasing the level of each attribute can be obtained through analyzing the data on respondents' choices and then interpreting or utilizing the results.

### 2.2. Attributes

In designing a CE, the first important thing to do is to determine the appropriate attributes and define their levels. An extensive literature review and consultation with experts enabled us to identify a preliminary list of attributes of power supply reliability. Most previous studies reveal that duration of power supply interruption, season of power supply interruption, power supply interruption time of day, and power supply interruption day of the week [10,13,18–22] have important implications for the value of improved power supply reliability. We then reviewed and revised the preliminary list of attributes derived from extensive literature reviews through extensive interviews with policy analysts, researchers, and professors. As a result, the final set of attributes was chosen by discussing with experts such as policy-makers, stakeholders, and environmental activists.

As reported in Table 1, the finally determined attributes are Duration of interruption, Season of interruption, Time of day, Day of week, and Price. A focus group interview with 30 people in the manufacturing industry was implemented to check for whether the survey questionnaire is fully meaningful, understandable, and persuasive to the respondents. Their responses were affirmative. The descriptions and levels of them are also explained in Table 1. They are assumed to be orthogonal in terms of valuation function rather than production function. Furthermore, all other attributes of power supply reliability are assumed to be the same in the course of the value judgments required in the CE survey.

**Table 1.** Descriptions and levels of four chosen attributes and price attribute used in this study.

| Attributes | Descriptions | Levels |
|---|---|---|
| Duration of interruption | Duration of industrial electricity supply interruption | Level 1: 5 h # <br> Level 2: 1 h <br> Level 3: 20 min |
| Season of interruption | Season when industrial electricity supply interruption takes place | Level 1: Summer or winter # <br> Level 2: Spring or fall |
| Time of day | Time when industrial electricity supply interruption occurs | Level 1: Day time # (9 a.m. to 6 p.m.) <br> Level 2: Off-daytime (6 p.m. to 9 a.m.) |
| Day of week | Day when industrial electricity supply interruption happens | Level 1: Weekday # <br> Level 2: Weekend |
| Price | Percentage of an additional payment for industrial electricity use (unit: %) | Level 1: 0 # <br> Level 2: 1% <br> Level 3: 5% <br> Level 4: 10% <br> Level 5: 20% |

Note: # indicates the status quo of each attribute. Status quo is a Latin phrase meaning the current state.

The power supply reliability decreases when industrial electricity supply interruption occurs in summer or winter, daytime, and weekdays. Moreover, the longer the duration of the industrial electricity supply interruption the lower the power supply reliability. The status quo of Duration of interruption, Season of interruption, Time of day, and Day of week means the level with the most negative situation. In other words, the power supply interruption lasts for 5 h during the summer or winter, weekday, and daytime is assumed to be the current state, and the state that is improved in the current state is set to the level of each attribute. The level of the attribute for Price is explained as the percentage of an additional payment for industrial electricity use. Although there is no actual payment, we explained to the respondents that the power supply reliability for manufacturing firms could be improved by increasing the industrial electricity bill. The status quo of this attribute means that there is no additional payment in the most negative situation.

Since a number of alternatives can be created from Table 1, several alternatives from possible combinations of attributes should be derived. To this end, the orthogonal main effects design was employed and 16 alternatives were obtained. The orthogonal main effects design is effective in terms of isolating the effects of individual attributes on the choice. The ability to 'design in' this orthogonality is an important advantage over the revealed preference random utility models, in which attributes are often found to be highly correlated with one another [23]. The orthogonal main effect design was implemented using the SPSS 12.0 package. From these, eight choice sets were generated. Each choice set is made up of two alternatives and the current status alternative. Each interviewee was presented with eight choice sets and reported eight responses to the provided questions that indicated which alternatives were the most preferred among the three alternatives in each choice set.

### *2.3. Survey Instrument and Method*

There are three parts to the survey instrument. Several questions about the power outage make up the first part to check respondents' perceptions before the CE survey on power supply reliability begins in earnest. To facilitate the respondents' understanding, a description of the features and effects of power supply reliability is provided, along with color photographs, shown in this section. Such work not only relieves respondents of the burden of a fully-fledged survey but also provides significant statistical data in itself. Explanations about the attributes and questions concerning the value trade-off work, which are conventionally required in a CE survey, are presented in the second part. The third part contains questions about the manufacturing firms' information. The main part of the survey questionnaire in this study is given in Appendix A. Figure A1 is an example of choice card we present to the respondents.

As in Makeen et al.'s [24] paper, supply reliability can be defined from an engineering perspective. However, since it may be difficult for interviewees affiliated with each firm to fully understand this in the CE survey, the authors attempted to define and explain the supply reliability in easier terms in the CE questionnaire. The power supply reliability was defined as the extent that the power system can reliably supply electric power to the consumer maintaining adequate voltage and frequency without interruption. In addition, it was targeted not only for certainty of quantitative supply of electricity but also for certainty of quality supply. These points were sufficiently conveyed to the respondents in the CE survey.

The number of observations to be analyzed in this study is 1148. Apparently, the sample size is small. However, accordingly to Statistics Korea [25], the population size of manufacturing industry of South Korea in 2016 was 64,885. Therefore, the sampling rate is approximately 1.77%. This figure is judged to be not small. This is because the Korea Ministry of Strategy and Finance and Korea Development Institute [26] recommended 1000 as a suitable sample size the total number of households in South Korea is about twenty million. Moreover, Arrow et al. (1993) recommended 1000 as an appropriate sample size of the United States households, although the United States has a much larger number of households than South Korea. Of course, budget constraints also affected the determination of the sample size. The cost of obtaining an observation through the survey was approximately USD 50. Therefore, more than $50,000 was invested to carry out the survey.

We have focused on sampling to ensure the representativeness of our sample in two aspects. First, a random sampling observed from an economy census by Statistics Korea, the Korean National Statistical Office. Our sample was classified by region and industry sector. Manufacturing can be divided into 25 sectors by Korean Standard Industrial Classification [27] and each section is denoted in Appendix A. Q1. Second, a field CE survey was done by interview experts from a professional polling firm during June and July. Trained interviewers visited the sampled manufacturing firms and, carried out total 1148 face-to-face interviews which require significantly higher costs than mail or telephone interviews. The interviews were conducted with randomly selected manufacturing firms to maximize the scope for detailed questions and answers.

## 3. Model

### *3.1. Utility Function*

We assume that the utility function has a linear functional form. Let the levels of Duration of interruption, Season of interruption, Time of day, Day of week, and Price be $X_t$, where $t = 1, 2, 3, 4, p$. In addition, an alternative-specific constant (ASC) is introduced to capture the effect of any other factors not contained in the model. $ASC$ represents a dummy for the respondent choosing the status quo option among three alternatives. $ASC$ is one if the respondent chooses the third alternative (current status), zero otherwise. Let $V_{jl}$ be the utility for interviewee $j$ who chooses alternative $l$. The utility function is formulated as

$$\begin{aligned} V_{jl} &= W_{jl}(X_{jl}, T_j) + \varepsilon_{jl} \\ &= ASC_j + \beta_1 X_{1,jl} + \beta_2 X_{2,jl} + \beta_3 X_{3,jl} + \beta_4 X_{4,jl} + \beta_p X_{p,jl} + \varepsilon_{jl} \end{aligned} \tag{1}$$

where $W_{jl}$ and $\varepsilon_{jl}$ are the deterministic and stochastic parts of the utility function, respectively. $X_{jl}$ is a vector containing the levels of the attributes for alternative $l$ given to respondent $j$. $T_j$ is respondent $j$'s characteristics, such as $ASC$. The $\beta$'s are the coefficients that correspond to each attribute.

Omitting $jl$ for simplicity, we can apply Roy's identity to Equation (1) and derive the $MWTP$ estimate, $MWTP_{X_t}$, as

$$MWTP_{X_t} = (\partial W/\partial X_t)/(\partial W/\partial X_p) = \beta_t/\beta_p \text{ for } t = 1, 2, 3, 4 \tag{2}$$

The *MWTP*s of each attribute represent the marginal rate of substitution between the price and each attribute.

### *3.2. How to Obtain the Utility Function*

CEs share a common theoretical framework with other valuation approaches. Thus, in this study, the random utility model is used to explain individual choices by specifying functions for the utility that is derived from the available alternatives. Estimating the utility function implies estimating $\beta$'s. This function can be estimated using the multinomial logit (MNL) model developed by McFadden [28]. Usually, MNL model has been most widely applied to obtain $\beta$ in the literature. However, the MNL model inevitably assumes independence from irrelevant alternatives. Although the assumption seems to be somewhat restrictive, it has the advantage of enabling us to specify the log-likelihood function as a closed form. Thus, if the assumption is met, we can easily tackle the CE data. Let $J$ be the number of interviewees and $I_{jl}$ be a dummy variable that is defined as one if interviewee $j$ selects alternative $l$; otherwise, $I_{jl}$ is zero. The log-likelihood function for our MNL model is

$$\ln L = \sum_{j=1}^{J} \ln \left[ \frac{\prod_{k=1}^{3} \left( \exp(W_{jk}) \right)^{I_{jk}}}{\sum_{n=1}^{3} \exp(W_{jn})} \right] \tag{3}$$

## 4. Results and Discussion

### *4.1. Data*

A nationwide CE survey of 1148 randomly chosen manufacturing firms was conducted by a professional polling firm through person-to-person interviews during June and July 2017. Each manufacturing company gave us eight observations. In other words, each interviewee was presented with eight choice sets and reported eight responses to the provided questions. Thus, we would get a data set size of 9184 (1148 respondents $\times$ 8 choice sets). Table 2 reports the definitions and sample statistics for some characteristics of the manufacturing firms. We selected three variables: Region, Size, and UPS. Since South Korea is classified into five mega-city regions (Seoul-Incheon-Gyunggi, Daejeon-Chungbuk-Chungnam, Gwangju-Jeonbuk-Jeonnam, and Pusan-Ulasn, Daegu-Gyungbuk-Gyungnam) and two special mega-city regions (Gangwon and Jeju), the variable Region identifies whether or not to locate in the five mega-city regions is introduced. Most manufacturing firms are located in the five mega-city regions. Size and UPS can also affect the outcomes of the CE. Figure 1 is a graph for samples classified by region.

**Table 2.** Definitions and sample statistics for some characteristics of the manufacturing firms.

| Variables | Definitions | Mean | Standard Deviation |
|---|---|---|---|
| Region | Dummy for the interviewee's living in the five mega-city regions (0 = no; 1 = yes) | 0.94 | 0.25 |
| Size | The size of the firms (0 = large enterprise; 1= small and medium-sized enterprise) | 0.94 | 0.22 |
| UPS | Dummy for installing uninterrupted power supply (UPS) (0 = no; 1 = yes) | 0.10 | 0.30 |

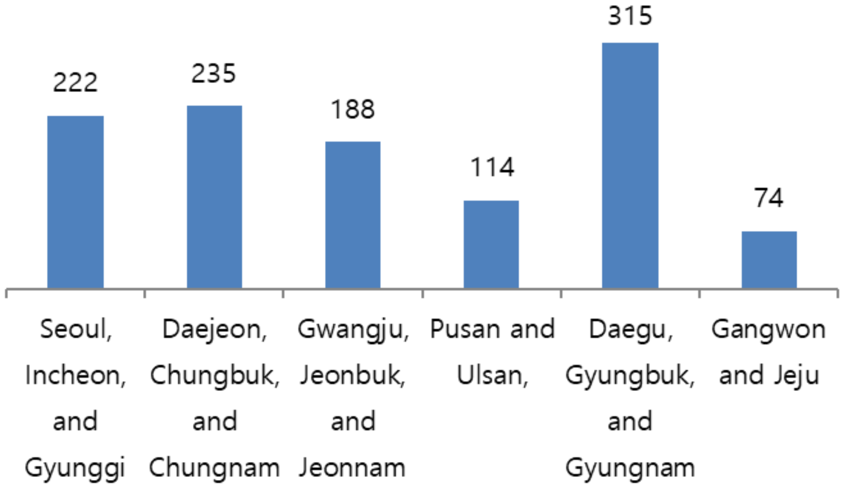


**Figure 1.** Samples classified by region.

### 4.2. Estimation Results

Table 3 reports the results of estimating the MNL model. All the coefficient estimates except for Season of interruption are statistically distinguishable from zero at the 1% level. The expected signs for coefficient estimates for the five attributes are all negative.

**Table 3.** Estimation results of the multinomial logit model.

| Variables [a] | Multinomial Logit Coefficient Estimates [c] | |
|---|---|---|
| *ASC* [b] | 0.6012 # | (8.27) |
| Duration of interruption | −0.0021 # | (−9.89) |
| Season of interruption | −0.0286 | (−0.80) |
| Time of day | −0.3190 # | (−9.23) |
| Day of week | −0.1710 # | (−4.78) |
| Price | −0.1071 # | (−25.59) |
| Number of observations | 9184 | |
| Wald-statistic ($p$-value) [d] | 1892.58 (0.000) | |
| Log-likelihood | −8812.59 | |

Notes: [a] The variables are defined in Table 1; [b] *ASC* refers to alternative-specific constants that represent dummies for the respondents choosing the status quo alternative; [c,#] indicates statistical significance at the 1% level, and $t$-values are reported in parentheses beside the estimates. $t$-value is the ratio of the departure of the estimated value of a parameter from its hypothesized value to its standard error; [d] The null hypothesis is that all the parameters are zero and the corresponding $p$-value is reported in parentheses beside the statistic.

The coefficient estimates for Duration of interruption, Time of day, and Day of week have negative signs. Thus, a one unit decrease in the level of Duration of interruption attribute increases the manufacturing firms' utility. Avoiding the status quo of Time of day and Day of week attributes also increases the utility. The coefficient for Price also has a negative sign. This implies that, as the price goes up the utility decreases. This result is quite reasonable, given that the price negatively contributes to the utility. The signs of all the estimated coefficients except for Season of interruption are consistent with our prior expectations.

### 4.3. MWTP Estimates for Each Attribute

Finally, the *MWTP* estimates for a decrease in the level of each attribute can be derived employing Equation (2). The results of estimating the *MWTP* values are provided in Table 4. The *MWTP* estimates for a one minute decrease in duration of interruption, avoiding interruption during daytime rather than off-daytime, and preventing interruption during weekdays rather than weekends are obtained as 0.02%, 2.98%, and 1.60%, respectively, of the electricity bill. These values are interpreted as the value of improved industrial electricity supply reliability in South Korea. Table 4 also presents the 95% confidence intervals for the *MWTP* estimates, which are computed using the procedures given in Krinsky and Robb [29].

**Table 4.** Estimation results of marginal willingness to pay (*MWTP*) values.

| | ***MWTP* per Manufacturing Firm per Month** | | |
|---|---|---|---|
| | **Estimates** | ***t*-Values** | **95% Confidence Intervals** |
| Duration of interruption | 0.02% # | 8.19 | 0.02% to 0.03% |
| Time of day | 2.98% # | 8.54 | 2.34% to 3.68% |
| Day of week | 1.60% # | 4.87 | 0.95% to 2.23% |

Notes: # indicates statistical significance at the 1% level. The confidence intervals are computed using the procedures given in Krinsky and Robb [29].

### 4.4. Discussion of the Results

As explained above, this study applied the MNL model. However, other models such as nested logit [30] model and mixed logit model [31] are also applicable. The estimation results of the two models are given in Table 5. Although specific estimation results vary from model to model, there is no difference in signs of the estimated coefficients. Since the MNL model is most widely used in empirical CE studies, this study tries to use the estimation results from the MNL model and derive the MWTP estimates.

**Table 5.** Estimation results of the nested logit and mixed logit models.

| **Variables** [a] | **Nested Logit Coefficient Estimates** [c] | | **Mixed Logit Coefficient Estimates** [c] | | |
|---|---|---|---|---|---|
| | **Estimates** | ***t*-Values** | **Assumed Distribution** | **Mean of the Coefficient Estimate** | **Variance of the Coefficient Estimate** |
| *ASC* [b] | −0.6548 # | 9.63 | Normal | −8.5119 # | −1.2917 # |
| Duration of interruption | −0.0020 # | −10.17 | Normal | −0.0524 # | −2.9011 # |
| Season of interruption | 0.0078 | 0.29 | Normal | 1.8101 # | 0.6878 # |
| Time of day | −0.2266 # | −7.39 | Normal | −18.2729 # | −5.1934 # |
| Day of week | −0.1792 # | −6.67 | Normal | −2.8403 # | −1.1643 # |
| Price | −0.0785 # | −12.34 | Normal | −1.3888 # | −5.7305# |
| Inclusive value | 0.6898 # | 13.86 | | | |
| Number of observations | | | 9184 | | |
| Log-likelihood | −8796.99 | | | −3751.88 | |

Notes: [a] The variables are defined in Table 1. [b] ASC refer to alternative-specific constants that represent dummies for the respondent's choosing status quo alternative. [c,#] indicates statistical significance at the 1% level.

Using the results presented in Table 4, we can estimate the value of improved power supply reliability, which is a combination of these attributes using the *MWTP* estimates for a decrease in the attributes. In other words, multiplying the figures reported in Table 4 by the levels of attributes gives us the value of the alternative for the hypothetical state of the industrial electricity supply interruption. As an illustration, the results of calculating the value of improved power supply reliability at which manufacturing firms assess several alternatives for the hypothetical state of the industrial electricity supply interruption are shown in Table 6. For example, the value of the third alternative, which means the hypothetical state in off-daytime and weekend, with a 280 min decrease in duration of interruption from the status quo, is computed as 10.18% of the electricity bill.

**Table 6.** The value of alternatives for hypothetical state of the industrial electricity supply interruption.

| | Scenario A | Scenario B | Scenario C |
|---|---|---|---|
| Duration of interruption | 5 h | 1 h | 20 min |
| Season of interruption | Summer or winter | Summer or winter | Summer or winter |
| Time of day | Off-daytime | Daytime | Off-daytime |
| Day of week | Weekend | Weekend | Weekend |
| The value of improved power supply reliability | 4.58% | 6.40% | 10.18% |

The analysis results presented in Table 6 have a variety of potential uses. First, by using these findings, one can identify which attributes manufacturing firms value. According to the estimated utility function, the absolute value of the coefficient estimate for Time of day among the four attributes was the greatest. On the other hand, the absolute value of the coefficient estimate for Duration of interruption was the smallest. Therefore, if the cost of improving the power supply reliability is the same, it would be better to concentrate on avoiding interruption during daytime rather than off-daytime to reduce interruption during electricity outage. Of course, the cost of improving system reliability may vary with the power system conditions. More specifically, operating reserve costs are highly dependent on the generation scheduling and demand status of facilities in the power system (i.e., outage of transmission lines or generators). Usually, the price for reserve might be higher during daytime than off-daytime. Using Tables 4 and 6 we cannot only calculate the value of improved power supply reliability for a variety of alternatives, but also make alternatives that result in specific value of power supply reliability. Alternatives may be proposed that satisfy the levels of acceptable value of power supply reliability within the scope of total costs not exceeding the total benefits.

The estimation results of improved power supply reliability may vary depending on the times in which a value judgment is made because the economic technique used in this study is a stated preference approach, which analyzes the data that is asked about the entity's preference. For example, when the economy is booming, the value of improved power supply reliability can be measured as being higher, whereas when the economy is in a recession, the value can be estimated as lower. In addition, the value of improved power supply reliability could be lowered if electricity-intensive firms are reduced as the industrial structure changes and more companies are using relatively little electricity. On the other hand, an increase in electricity-intensive companies could increase the value. In other words, the value of improved power supply reliability depends on the economic situation, industrial structure, social atmosphere, and power supply situation, so it is difficult to maintain the specific value. Therefore, it is necessary to conduct a study at regular intervals on the value of power supply reliability. It is possible to grasp the trajectory whose value changes with the lapse of time, and it is also possible to predict the future value with the results.

Additionally, this article seems to contribute to the literature from a research perspective. First, the article utilized a CE technique to look into the value of the attributes of improved power supply reliability and found that the application was successful, because the estimation results were statistically meaningful and the respondents actively participated in the CE survey. Improved power supply reliability is not just a problem for South Korea but an important issue for the worldwide, especially for developing countries [32–34]. Thus, comparison of the results from our work with those from future works that will be applied in other countries will yield new implications.

Our finding can be compared with a finding of London Economics [8]. The value of lost load for electricity in Great Britain (Final report for OFGEM and DECC) of London Economics [8] is a representative example for estimating the economic value of electricity use mainly by applying CE and CV. As a result of evaluating the economic value of industrial power using CE, the WTP estimates for the various choice scenarios for small and medium sized businesses range from around 2% to 4%

of the annual electricity bill. Under the same scenarios as the London Economics [8], the value of the industrial electricity supply interruption ranges from approximately 1.2% to 5.78% of the annual electricity bill in our study. Interestingly, the range of the results of both studies is similar.

However, the sample size used in this study is small compared to the population size. Thus, it is necessary to collect and analyze a larger number of observations through securing sufficient budget for the survey in the future. This work would also enable the derivation of industry-specific implications. Analysis of data classified by industry will enable us to derive industry-specific implications.

**Author Contributions:** All the authors participated in writing this paper. D.-C.K. collected and compiled the necessary background data for the study and prepared the CE questionnaire, which was essential for the data collection; H.-J.K. wrote a large part of the paper and educated the interviewers; and S.-H.Y. performed statistical analysis and supervised the entire process of writing the paper.

**Acknowledgments:** This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. 20184030202230). In addition, the authors acknowledge that this research was financially supported by Korea Power Exchange (Grant Number: 2017-02).

**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A Main Part of the Survey Questionnaire

### *A.1. Questions About the Characteristics of the Manufacturing Firms*

The interviewee was asked to respond to the characteristics of the company they are working with: Sale revenue, the number of employees, average salary, operation cost, and inventory value. Questions were all open-ended questions, and the question about the type of manufacturing firms was as follows:

Q1. Please check √ the type of manufacturing firms of your company.

① Manufacture of food products
② Manufacture of beverages
③ Manufacture of tobacco products
④ Manufacture of textiles, except apparel
⑤ Manufacture of wearing apparel, clothing accessories and fur articles
⑥ Manufacture of leather, luggage and footwear
⑦ Manufacture of wood and of products of wood and cork; except furniture
⑧ Manufacture of pulp, paper and paper products, printing and reproduction of recorded media
⑨ Printing and reproduction of recorded media
⑩ Manufacture of coke, briquettes and refined petroleum products
⑪ Manufacture of chemicals and chemical products; except pharmaceuticals and medicinal chemicals
⑫ Manufacture of pharmaceuticals, medicinal chemical and botanical products
⑬ Manufacture of rubber and plastics products
⑭ Manufacture of other non-metallic mineral products
⑮ Manufacture of basic metals
⑯ Manufacture of fabricated metal products, except machinery and furniture
⑰ Manufacture of electronic components, computer; visual, sounding and communication equipment
⑱ Manufacture of medical, precision and optical instruments, watches and clocks
⑲ Manufacture of electrical equipment
⑳ Manufacture of other machinery and equipment
㉑ Manufacture of motor vehicles, trailers and semitrailers
㉒ Manufacture of other transport equipment
㉓ Manufacture of furniture

㉔ Other manufacturing

㉕ Maintenance and repair services of industrial machinery and equipment

*A.2. Questions About Marginal Willingness to Pay*

Type A. Q1. Check with √ the only available alternative that you prefer among Alternative A, B, or the status quo.

| | Alternative A | Alternative B | Alternative C |
|---|---|---|---|
| Duration of interruption | 20 min | 20 min | 5 h |
| Season of interruption | Summer or winter | Spring or fall | Summer or winter |
| Time of day | Off-daytime (6 p.m. to 9 a.m.) | Off-daytime (6 p.m. to 9 a.m.) | Day time (9 a.m. to 6 p.m.) |
| Day of week | Weekend | Weekday | Weekday |
| Price | 5% | 1% | 0% |
| | ☐ Alternative A | ☐ Alternative B | ☐ Status quo |

**Figure A1.** A sample choice set used in this study.

## References


1. Ferguson, R.; Wilkinson, W.; Hill, R. Electricity use and economic development. *Energy Policy* **2000**, *28*, 923–934. [CrossRef]
2. Yoo, S.H. Electricity consumption and economic growth: Evidence from Korea. *Energy Policy* **2005**, *33*, 1627–1632. [CrossRef]
3. Yoo, S.H.; Lee, J.S. Electricity consumption and economic growth: A cross-country analysis. *Energy Policy* **2010**, *38*, 622–625. [CrossRef]
4. Ju, H.C.; Yoo, S.H.; Kwak, S.J. The electricity shortage cost in Korea: An input-output analysis. *Energy Sources Part B Econ. Plan. Policy* **2016**, *11*, 58–64. [CrossRef]
5. Lim, K.M.; Yoo, S.H. Economic value of electricity in the Korean manufacturing industry. *Energy Sources Part B Econ. Plan. Policy* **2016**, *11*, 542–546. [CrossRef]
6. Ghosh, R.; Goyal, Y.; Rommel, J.; Sagebiel, J. Are small firms willing to pay for improved power supply? Evidence from a contingent valuation study in India. *Energy Policy* **2017**, *109*, 659–665. [CrossRef]
7. Kim, K.; Cho, Y. Estimation of power outage costs in the industrial sector of South Korea. *Energy Policy* **2017**, *101*, 236–245. [CrossRef]
8. London Economics. The Value of Lost Load for Electricity in Great Britain. Final Report for OFGEM and DECC. 2013. Available online: https://www.ofgem.gov.uk/ofgem-publications/82293/london-economics-value-lost-load-electricity-gbpdf (accessed on 19 April 2018).
9. Hensher, D.A.; Greene, W.H. The mixed logit model: The state of practice. *Transportation* **2003**, *30*, 133–176. [CrossRef]
10. Carlsson, F.; Martinsson, P. Does it matter when a power outage occurs? A choice experiment study on the willingness to pay to avoid power outages. *Energy Econ.* **2008**, *30*, 1232–1245. [CrossRef]

11. Abdullah, S.; Mariel, P. Choice experiment study on the willingness to pay to improve electricity services. *Energy Policy* **2010**, *38*, 4570–4581. [CrossRef]
12. Hensher, D.A.; Shore, N.; Train, K. Willingness to pay for residential electricity supply quality and reliability. *Appl. Energy* **2014**, *115*, 280–292. [CrossRef]
13. Ozbafli, A.; Jenkins, G.P. Estimating the willingness to pay for reliable electricity supply: A choice experiment study. *Energy Econ.* **2016**, *56*, 443–452. [CrossRef]
14. Min, S.H.; Lim, S.Y.; Yoo, S.H. Consumer's willingness to pay a premium for eco-labeled LED TVs in Korea: A contingent valuation study. *Sustainability* **2017**, *9*, 814.
15. Lim, S.Y.; Kim, H.Y.; Yoo, S.H. Public willingness to pay for transforming Jogyesa Buddhist temple in Seoul, Korea into a cultural tourism resource. *Sustainability* **2016**, *8*, 900. [CrossRef]
16. Wang, J.; Ge, J.; Ma, Y. Urban Chinese consumers' willingness to pay for pork with certified labels: A discrete choice experiment. *Sustainability* **2018**, *10*, 603. [CrossRef]
17. Vanstockem, J.; Vranken, L.; Bleys, B.; Somers, B.; Hermy, M. Do looks matter? A case study on extensive green roofs using discrete choice experiments. *Sustainability* **2018**, *10*, 309. [CrossRef]
18. Moeltner, K.; Layton, D.F. A censored random coefficients model for pooled survey data with application to the estimation of power outage costs. *Rev. Econ. Stat.* **2002**, *84*, 552–561. [CrossRef]
19. Hensher, D.A.; Rose, J.; Greene, W.H. The implications on willingness to pay of respondents ignoring specific attributes. *Transportation* **2005**, *32*, 203–222. [CrossRef]
20. Morrison, M.; Nalder, C. Willingness to pay for improved quality of electricity supply across business type and location. *Energy J.* **2009**, *30*, 117–133. [CrossRef]
21. Meles, T.H. *Power outages, Increasing Block Tariffs and Billing Knowledge*; University of Gothenburg: Gothenburg, Sweden, 2017.
22. Oseni, M.O. Self-generation and households' willingness to pay for reliable electricity service in Nigeria. *Energy J.* **2017**, *38*, 165–194. [CrossRef]
23. Hanley, N.; Wright, R.E.; Adamowicz, V. Using choice experiments to value the environment. *Environ. Resour. Econ.* **1998**, *11*, 413–428. [CrossRef]
24. Makeen, P.; Swief, R.A.; Abdel-Salam, T.S.; El-Amary, N.H. Smart hybrid micro-grid integration for optimal power sharing-based water cycle optimization technique. *Energies* **2018**, *11*, 1083. [CrossRef]
25. Korea Ministry of Strategy and Finance and Korea Development Institute. *Overview of Preliminary Feasibility Evaluation System and Methodology*; Korea Ministry of Strategy and Finance and Korea Development Institute: Sejong, Korea, 2018. (In Korean)
26. Arrow, K.; Solow, R.; Portney, P.R.; Leamer, E.E.; Radner, R.; Schuman, H. Report of the NOAA panel on contingent valuation. *Fed. Regist.* **1993**, *58*, 4601–4614.
27. Korean Standard Statistical Classification. Korean Standard Industrial Classification. 2017. Available online: http://kssc.kostat.go.kr (accessed on 20 August 2018).
28. McFadden, D. Conditional logit analysis of qualitative choice behaviour in frontiers in econometrics. In *Frontiers in Econometrics*; Zarembka, P., Ed.; Academic Press: New York, NY, USA, 1973; pp. 105–142.
29. Krinsky, I.; Robb, A.L. On approximating the statistical properties of elasticities. *Rev. Econ. Stat.* **1986**, *68*, 715–719. [CrossRef]
30. Lim, S.Y.; Lim, K.M.; Yoo, S.H. External benefits of waste-to-energy in Korea: A choice experiment study. *Renew. Sustain. Energy Rev.* **2014**, *34*, 588–595. [CrossRef]
31. Lim, S.Y.; Kim, H.J.; Yoo, S.H. Assessing the external benefits of contaminated soil remediation in Korea: A choice experiment study. *Environ. Sci. Pollut. Res.* **2018**, *25*, 17216–17222. [CrossRef] [PubMed]
32. Sagebiel, J. Preference heterogeneity in energy discrete choice experiments: A review on methods for model selection. *Renew. Sustain. Energy Rev.* **2017**, *69*, 804–811. [CrossRef]
33. Reinders, A. Perceived and Reported Reliability of the Electricity Supply at Three Urban Locations in Indonesia. *Energies* **2018**, *11*, 140.
34. Jimenez, R.; Serebrisky, T.; Mercado, J. What does "better" mean? Perceptions of electricity and water services in Santo Domingo. *Utilities Policy* **2016**, *41*, 15–21. [CrossRef]