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Willingness to Pay for Substituting Coal with Natural Gas-Based Combined Heat and Power in South Korea: A View from Air Pollutants Emissions Mitigation

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Received: 15 March 2018; Accepted: 9 May 2018; Published: 14 May 2018



Abstract: As of 2017, coal-fired generation is responsible for about half of electricity generation in South Korea. This causes a serious problem of emitting air pollutants such as particulate matters, sulfur oxides, and nitrogen oxides. Thus, the South Korean government is seeking to substitute a part of coal-fired generation with natural gas (NG)-based combined heat and power (CHP) generation for the purpose of mitigating air pollutants emissions. This article tries to assess the public willingness to pay (WTP) for the substitution adopting contingent valuation (CV). The data on the additional WTP for consuming 1 kWh of electricity produced from NG-based CHP generation over coal-fired generation were gathered from a CV survey of 1000 interviewees. The mean additional WTP estimate for the substitution is obtained as KRW 28.08 (USD 0.025) per kWh of electricity use. This is equivalent to 25.9% of the average price of electricity, KRW 108.50 (USD 0.098) per kWh in 2017. It is obvious that the South Korean public has a significant WTP for substituting coal with NG in electricity generation to mitigate air pollutants emissions. The government needs to gradually push for the substitution.

Keywords: coal; natural gas; air pollutants emissions; willingness to pay; contingent valuation

1. Introduction

About half of electricity generation in 2017 comes from coal-fired generation in South Korea [1]. This causes a severe problem of emitting air pollutants such as particulate matters, sulfur oxides (SO_x), and nitrogen oxides (NO_x) that are harmful to the human body. SO_x and NO_x are the main causes of acid rain, and they can enter the human body and cause respiratory problems. According to the Korean Ministry of Environment, the amount of air pollutants emissions emitted from coal-fired generations accounted for more than half of air pollutants emissions produced by industrial facilities for massive air pollutant discharge [2]. On the other hand, natural gas (NG) generation was responsible for about 20% of electricity generation in 2017. NG-based combined heat and power (CHP) plants can be a useful alternative to coal-fired plants in terms of mitigating air pollutants emissions. It is known that the amount of air pollutants emissions from coal-fired generation is about 17 times larger than that from NG-based CHP generation in South Korea [3].

The United States Environmental Protection Agency found that air pollutants such as SO_x and NO_x are the most significant factors affecting human health and environment [4]. SO_x and NO_x are mainly produced by coal-fired generations and other industrial facilities. SO_x are colorless, strong irritant gases that, when a certain dose is exceeded, are toxic to the respiratory tract and cause damage to plants with low resistance even at low concentrations. The reason why NO_x are becoming an essential problem in air pollution is that they can increase the amount of ozone in the atmosphere

by photolysis and can produce smog which harms humans and plants. NO_x penetrate deeper into the human body's respiratory system than SO_2 , irritate lungs, and cause pneumonia and bronchitis. Especially when combined with hemoglobin in blood, they disturb the transfer of oxygen in the tissues and cause anemia, to a much worse extent than carbon monoxide [5–7].

In South Korea, both NO_x (68%) and SO_x (29.5%) accounted for most of the air pollutants emissions [8]. Furthermore, SO_x and NO_x react chemically with other substances in the air and form $\text{PM}_{2.5}$. $\text{PM}_{2.5}$ is dangerous because it easily penetrates deep into the human body. $\text{PM}_{2.5}$ can reach the alveoli through the nose and airways during breathing, and it can infiltrate the blood vessels and cause inflammation. Currently, the proportion of $\text{PM}_{2.5}$ generated by SO_x and NO_x accounts for two-thirds of the total amount of $\text{PM}_{2.5}$ emissions produced in the metropolitan area in South Korea [9].

Thus, the South Korean government is seeking to substitute a part of coal-fired generation with NG-based CHP generation for the purpose of mitigating the air pollutants emissions. However, the substitution requires a higher production cost of electricity, meaning that the average price of electricity rises. Moreover, government officials are asking for information about the value that the enforcement of the substitution policy produces to the public, which is of great help to obtain implications concerning whether the substitution should be performed or not. For this purpose, this study strives to obtain the public willingness to pay (WTP) for consuming 1 kWh of electricity produced from NG-based CHP generation over coal-fired generation.

The focus of this study is the substitution of the electricity produced from coal-based CHP plants as well as coal-fired thermal power plants with that from NG-based CHP plants. Technically, the substitution does not always mean the replacement of coal-fired plants with NG-based CHP plants. The substitution can be achieved by lowering the operation rate of coal-fired plants and increasing that of NG-based CHP plants. One more point to note is that most NG-based CHP plants can only produce electricity without producing heat. The usual CHP of South Korea has three operating systems: Mode 1, which produces heat and electricity simultaneously; Mode 3, which only produces electricity; and Mode 5, which can adjust the production ratio of heat and electricity. Thus, it is possible to operate NG-based CHP plants to produce electricity only adopting Mode 3 even if there is no demand for heat. The demand for heat in South Korea varies from season to season. There is a certain amount of heat demand in spring and fall and a lot of heat demand in winter. There is little demand for heat in summer. Usually, during summer, CHP operators adopt Mode 3 as the operating system of CHP and supply heat produced from peak load boilers.

This study can contribute to the literature on the additional WTP for electricity from NG-based CHP generation instead of coal-fired generation for the purpose of reducing air pollutants emissions. To the best of the authors' knowledge, there is no former research that has investigated the public WTP for consuming 1 kWh of electricity produced from NG-based CHP generation over coal-fired generation to mitigate air pollutants emissions in the literature. The cost of generating electricity from NG-based CHP plants is higher than that from coal-fired plants. Since the gap of the cost will be eventually covered by an increase in electricity bill levied on people, it is vital to gather public opinion regarding whether or not to pay for the substitution. This is because the substitution cannot be successful without public support for it. Thus, policy-makers ask for quantitative information about people's WTP for the substitution, which this study attempts to assess.

The remainder of this article consists of four sections. Section 2 describes the methodology that this article adopts: more specifically, the object to be evaluated, the method of CV, the sampling and survey instrument, and the elicitation of WTP are explained. Modeling of the WTP data is dealt with in Section 3. The fourth section provides the results and a discussion of them. The final section presents conclusions.

2. Methodology

2.1. Object to Be Evaluated

As addressed above, increasing air pollutants emissions in South Korea has become a critical problem, and effective and rigorous policies should be put in place to reduce air pollutants emissions. Thus, the government seeks to substitute a part of coal-fired generation with NG-based CHP generation. According to data released by the South Korean Ministry of Trade, Industry and Energy, when the same amount of electricity is produced, the amount of air pollutants emitted from a long-installed power plant is 31.1 times greater than that from a NG-based CHP plant, and that from a recently installed coal-fired power plant is 3.2 times larger than that a NG-based CHP plant [3]. Coal-fired power plants emit more air pollutants such as NO_x and SO_x than NG-based CHP plants, even if they are equipped with modern desulfurizing and denitrifying facilities.

In addition, the government is seeking to substitute a part of coal-fired generation with NG-based CHP generation for the purpose of reducing air pollutants emissions. The main policy instrument, which was conveyed and explained to the respondents through the use of newspaper articles, color pictures, and well-made presentation materials during the CV survey, is to consume 1 kWh of electricity produced from NG-CHP generation over coal-fired generation. Thus, the government requires quantitative information about the public WTP for the substitution. This article attempts to evaluate the additional WTP for substituting coal-fired generation with NG-based CHP generation with a view to reducing the air pollutants emissions.

2.2. Method: CV

From the literature review, it has been found that stated preference (SP) methods have been usually applied to carrying out the measurement of the public WTP. The SP methods usually ask people to state their WTP for consuming the goods or services concerned. Two representative approaches belonging to SP methods are the CV approach and CE approach [10–16]. The former elicits the WTP response directly, while the latter derives the WTP responses indirectly. This study will employ the CV approach instead of the CE approach because the first is much simpler to apply than the second, and the attributes required in using the CE approach are not well defined in this study.

Our research can be compared with previous research in four points. First, studies that assessed people's additional WTP for electricity generated from NG-based CHP plant over coal-fired plant to mitigate air pollutants emissions remain scarce. Most of the related research has tackled public value for reducing the air pollutions or improving the air quality [17–23].

Second, our application of the CV technique coincides with the practice adopted in the former studies dealing with this kind of research topic. Moreover, the CV technique is based on microeconomics and is thus theoretically sound [24]. Since the findings obtained in this article can be used in policy making and analysis, it is crucial to use a reasonable and sound methodology. The CV technique is not only practically useful but also theoretically robust.

Third, we tried to follow several guidelines recommended for applying the CV approach in the literature. They include the use of a dichotomous choice (DC) question, a minimum sample size of 1000, the announcement of the possible presence of substitutes for the goods to be investigated in the CV survey, and so on. More details will be presented in the next subsections.

Fourth, when eliciting the WTP responses, this study paid attention to not only mitigating the response bias but also augmenting the statistical efficiency. The respondents are asked just one question in the single-bounded (SB) DC method. Hence, it may suffer from low statistical efficiency. The double-bounded (DB) DC method, which requires two WTP questions, may suffer from the response bias. Cooper et al. [25] contrived a one-and-one-half-bounded (OOHB) DC method to alleviate the bias. It can produce a more efficient result than the SB DC method and cause less response bias than the DB DC method. Furthermore, the spike model proposed by Kriström [26] is combined with the OOHB DC method in order to model the WTP data with zero observations.

2.3. Sampling and Survey Instrument

As mentioned above, the government is seeking to substitute a part of coal-fired generation with NG-based CHP generation for the purpose of reducing air pollutants emissions. Concerning an appropriate sample size, the blue-ribbon panel of Arrow et al. [27] recommended the use of 1000 observations. Moreover, South Korea Ministry of Strategy and Finance has established a guideline to use 1000 observations in applying the CV technique. Therefore, the authors secured a sufficient budget for the CV survey, and commissioned a professional polling firm to sample 1000 interviewees nationwide based on the demographic characteristics reported by Statistics Korea [28]. In this regard, our sampling method was stratified random sampling. The entire process of sampling and carrying out the survey was administered by the firm during November 2017. The firm sought to make sure that the sample characteristics represents the population characteristics well. An experienced specialist at the firm ran the whole process.

A pretest using a focus group of 30 persons was implemented with an earlier version of the survey instrument to examine whether the survey questionnaire was understandable and clear enough for the interviewees to finish filling in or not. The outcomes of the in-depth interviews with the focus group have been utilized to correct the questionnaires fully for use in the main survey. The finally modified version of the survey questionnaire is made up of four parts. The first part presents the background and objective of the survey. The second part includes several questions ascertaining the interviewees' opinions and judgment regarding the substitution of the electricity produced from coal-based CHP plants as well as coal-fired thermal power plants with that from NG-based CHP plants. The third part deals with the questions concerning the additional WTP for consuming 1 kWh of electricity produced from NG-based CHP plant over coal-fired plant. Some questions about respondents' characteristics are given in the final part.

2.4. Elicitation of WTP

As explained above, this article adopted an OOHB DC question with a view to eliciting the WTP responses. The DC question was originally recommended for the use in the field CV survey by a number of studies. The main reason for the recommendation is that it can reduce the respondents' burden of answering the WTP question and derive an incentive-compatible response from interviewees [29]. The DC question is quite simple. The only work for a respondent to do is to state "yes" or "no" to a given bid amount. The respondent will report "yes" if her/his additional WTP for consuming 1 kWh of electricity produced from NG-based CHP generation over coal-fired generation is more than or equal to an offered bid and "no" otherwise. On the other hand, an open-ended question of directly asking the WTP value is not preferred to the DC question in the literature because the former can induce a number of protest WTP responses [24,30,31]. The OOHB DC format has a merit of taking only the preferential features of the SB and DB DC formats.

One complication involved in applying the CV is that it puts people in a hypothetical situation and thus the respondents can have difficulties in stating their true WTP. An appropriate payment can help the respondents confronted with the hypothetical situation to report their WTP, making them feel as if they were in the real world. Some examples of the payment vehicle include a tax such as income tax or property tax, a donation, a fund, a usage fee, and so on. The payment vehicle should be directly related to the object to be evaluated and be familiar to people. We decided that the payment vehicle meeting the two conditions is electricity bills. Thus, the WTP question presented to the respondents was "Would you accept an amount of increase in electricity bills for substituting coal-fired generation with NG-based CHP plant to reduce air pollutants emissions?"

3. WTP Model

3.1. OOHB DC Model

Cooper et al. [25] proposed an approach to model the OOHB DC CV data. A_j is defined as a bid presented to respondent j . Before implementing the field CV survey, we need to determine several sets of two bids, A_j^L and A_j^U ($A_j^L < A_j^U$). A set is randomly selected from the several sets and presented to each interviewee. Each set is composed of A_j^L and A_j^U . About half of respondents in a group who receive the same set are asked to state “yes” or “no” to the payment of A_j^L . If the response is “yes”, an additional question about whether they are willing to pay A_j^U or not is asked. If the response to the payment of A_j^L is “no,” the additional question is needless. The other half of the respondents are confronted with a question about the payment of A_j^U . If the response is “no”, a follow-up question about whether they are willing to pay A_j^L or not is asked. If the response to the payment of A_j^U is “yes,” the follow-up question is not required.

Let Y_j be the interviewee’s WTP. Three responses, “yes–yes” ($Y_j > A_j^U$), “yes–no” ($A_j^L < Y_j < A_j^U$), and “no” ($Y_j < A_j^L$), can emerge from the situation where A_j^L is offered at first. One of three responses, “yes” ($Y_j > A_j^U$), “no–yes” ($A_j^L < Y_j < A_j^U$), and “no–no” ($Y_j < A_j^L$), can occur in the case that A_j^U is provided at first. Therefore, there can be six kinds of responses. Let I_j^{YY} , I_j^{YN} , I_j^N , I_j^Y , I_j^{NY} , and I_j^{NN} be binary variables which correspond to the six kinds of responses. For instance, I_j^{YY} is one if j th interviewee reports “yes–yes” and zero otherwise.

3.2. Combination of OOHB DC Question and Spike Model

An additional question, “Would your household agree to pay anything?”, was given to the respondents who reported a “no” response to the lower bid or a “no–no” response to the upper bid. Their WTP is less than the lower bid and more than zero if the answer is “yes.” Their WTP is zero if the answer is “no.” One more binary variable, I_j^{TY} , is defined as one if the answer is “yes” and zero otherwise. Thus, there are eight outcomes:

- “yes–yes” ($Y_j > A_j^U$),
- “yes–no” ($A_j^L < Y_j < A_j^U$),
- “no–yes” ($0 < Y_j < A_j^L$),
- “no–no” ($Y_j = 0$),
- “yes” ($Y_j > A_j^U$),
- “no–yes” ($A_j^L < Y_j < A_j^U$),
- “no–no–yes” ($0 < Y_j < A_j^L$), and
- “no–no–no” ($Y_j = 0$).

where the first four outcomes are achieved when A_j^L is offered at first and the latter four outcomes are obtained when A_j^U is supplied at first.

As will be explained below, out of the 1000 respondents, 452 said they had no intention of paying a penny. Thus, the spike model can be usefully employed to deal with the WTP data. Considering that the most-frequently used distribution in analyzing the DC CV data is logistic distribution, we specify the WTP distribution function, $F_Y(\cdot)$, as:

$$F_Y(A; \gamma_0, \gamma_1) = \begin{cases} [1 + \exp(\gamma_0 - \gamma_1 A)]^{-1} & \text{if } A > 0 \\ [1 + \exp(\gamma_0)]^{-1} & \text{if } A = 0 \\ 0 & \text{if } A < 0 \end{cases} \quad (1)$$

where γ_0 and γ_1 are the parameters of $F_Y(\cdot)$.

The log-likelihood function we deal with is:

$$\begin{aligned} \ln L = & \sum_{j=1}^S \{ (I_j^Y + I_j^{YY}) \ln[1 - F_Y(A_j^U; \gamma_0, \gamma_1)] \\ & + (I_j^{YN} + I_j^{NY}) \ln[F_Y(A_j^U; \gamma_0, \gamma_1) - F_Y(A_j^L; \gamma_0, \gamma_1)] \\ & + I_j^{TY} (I_j^N + I_j^{NN}) \ln[F_Y(A_j^L; \gamma_0, \gamma_1) - F_Y(0; \gamma_0, \gamma_1)] \\ & + (1 - I_j^{TY})(I_j^N + I_j^{NN}) \ln F_Y(0; \gamma_0, \gamma_1) \} \end{aligned} \tag{2}$$

where S is the sample size.

We can get the estimates for γ_0 and γ_1 by finding the values for γ_0 and γ_1 maximizing Equation (2), that is, using the maximum likelihood estimation method. When using Equation (1) and the estimates for γ_0 and γ_1 , the average WTP can be obtained as:

$$E(Y) = \int_0^\infty [1 - F_Y(A; \gamma_0, \gamma_1)] dA - \int_{-\infty}^0 F_Y(A; \gamma_0, \gamma_1) dA = (1/\gamma_1) \ln[1 + \exp(\gamma_0)] \tag{3}$$

4. Results and Discussion

4.1. Data

When the survey was carried out, USD 1.0 was equivalent to KRW 1105. The list of sets of A_j^L and A_j^U used in the CV survey is KRW 10/30, 20/40, 30/60, 40/80, 60/100, 80/120, and 100/150. They were determined through the focus group interview of thirty individuals as follows: first, we asked the WTP for the enforcement and obtained a set of WTP values; second, we deleted zero WTP values and then sorted the remaining positive WTP values to look into empirical distribution; third, some bids were selected from the distribution. One of the seven sets of A_j^L and A_j^U was randomly offered to the interviewees.

Finally, 1000 useable observations were obtained from the CV survey. Table 1 reports a summary of the interviewees' responses to each set of bids. Overall, 57, 105, 119, 219, 77, 81, 109, and 233 interviewees gave "yes-yes", "yes-no", "no-yes", "no-no", "yes", "no-yes", "no-no-yes", and "no-no-no" responses, respectively. Out of the 1000 respondents, 452 said they had no intention of paying a penny ("no-no" and "no-no-no" responses).

Table 1. Summary of the interviewees' responses to each set of bids.

Bid Amount ^a	Lower Bid Is Offered at First (%) ^b				Upper Bid Is Offered at First (%) ^b				Sample Size
	"yes-yes"	"yes-no"	"no-yes"	"no-no"	"yes"	"no-yes"	"no-no-yes"	"no-no-no"	
10 30	20 (13.9)	27 (18.8)	4 (2.8)	22 (15.3)	23 (16.0)	22 (15.3)	0 (0.0)	26 (18.1)	144 (100.0)
20 40	11 (7.7)	21 (14.8)	6 (4.2)	32 (22.5)	17 (12.0)	20 (14.1)	3 (2.1)	32 (22.5)	142 (100.0)
30 60	11 (7.7)	19 (13.3)	9 (6.3)	32 (22.4)	12 (8.4)	13 (9.1)	12 (8.4)	35 (24.5)	143 (100.0)
40 80	4 (2.8)	16 (11.2)	18 (12.6)	34 (23.8)	11 (7.7)	17 (11.9)	11 (7.7)	32 (22.4)	143 (100.0)
60 100	6 (4.2)	12 (8.5)	20 (14.1)	33 (23.2)	5 (3.5)	4 (2.8)	27 (19.0)	35 (24.6)	142 (100.0)
80 120	3 (2.1)	9 (6.3)	28 (19.7)	31 (21.8)	3 (2.1)	3 (2.1)	29 (20.4)	36 (25.4)	142 (100.0)
100 150	2 (1.4)	1 (0.7)	34 (23.6)	35 (24.3)	6 (4.2)	2 (1.4)	27 (18.8)	37 (25.7)	144 (100.0)
Totals	57 (5.7)	105 (10.5)	119 (11.9)	219 (21.9)	77 (7.7)	81 (8.1)	109 (10.9)	233 (23.3)	1000 (100.0)

Notes: ^a The unit is Korean won (USD 1.0 = KRW 1105 at the time of the survey). ^b The percentage of sample size is given in parentheses beside the number of responses.

4.2. Estimation Results of the Model

Table 2 presents the estimation results of the model. The estimates for γ_0 and γ_1 are all statistically significant. In particular, the negative sign of the estimate for γ_1 means that a higher bid amount induces a lower likelihood of saying "yes" to an offered bid. From Equation (1), the spike is derived as $[1 + \exp(\gamma_0)]^{-1}$. The estimate for the spike is calculated as 0.4497 and is statistically significant. Because the spike implies the possibility of the interviewees having zero WTP, the estimated spike

should not be significantly different from the sample ratio of zero WTP (45.2%). This is the case with our study.

Table 2 also provides an estimate of average WTP calculated using Equation (3). The average WTP has the value of KRW 28.08 (USD 0.025) per 1 kWh statistical meaningfulness. It is desirable to calculate its confidence interval to explicitly take into account the uncertainty concerning the calculation of the point estimate. The 95% confidence interval computed adopting the bootstrapping technique presented in Krinsky and Robb [32] is KRW 25.52 to 31.06 (USD 0.023 to 0.028) per 1 kWh.

Table 2. Estimation results of the model.

Variables	Estimates ^d
Constant	0.2018 (3.22) [#]
Bid amount ^a	−0.0285 (−23.69) [#]
Spike	0.4497 (29.03) [#]
Mean additional WTP per kWh	KRW 28.08 (USD 0.025)
<i>t</i> -value	20.15 [#]
95% confidence interval ^b	KRW 25.52 to 31.06 (USD 0.023 to 0.028)
99% confidence interval ^b	KRW 24.73 to 32.13 (USD 0.023 to 0.029)
Sample size	1000
Log-likelihood	−1208.21
Wald statistic (<i>p</i> -value) ^c	406.19 (0.000)

Notes: ^a The unit is KRW 1000, and the exchange rate was USD 1.0 = KRW 1105 at the time of the survey. ^b It is calculated using the bootstrapping technique given in Krinsky and Robb [32]. ^c It is computed under the null hypothesis of all the parameters' being jointly zero. ^d The values reported in parentheses beside the estimates are *t*-values. [#] indicates statistical significance at the 1% level.

4.3. Reflection of Covariates

Covariates mean the factors that can have an effect on the possibility of reporting “yes” to a given bid. Usually, the interviewees' characteristics are used as covariates. Usually, the covariates are reflected in the model by inserting them into γ_0 in Equation (1). We consider four variables—family, age, education, and income—as shown in Table 3. Therefore, a positive sign of the coefficient for a variable indicates that the bigger the value of the variable the higher the possibility of reporting “yes” to a given bid.

Table 3. Description of the variables used for covariates.

Variables	Definitions	Mean	Standard Deviation
Family	The size of the respondent's household (unit: persons)	3.26	1.12
Age	The respondent's age	47.16	9.30
Education	The respondent's education level in years	14.02	2.25
Income	The household's monthly income before tax (unit: million Korean won)	4.70	3.77

Table 4 shows the estimation results of the models with covariates. In the table, Model A and Model B means the model including the age variable described in Table 3, and the model including two dummy variables concerning level of the respondent's age rather than age, respectively. The two dummy variables are Age2 and Age3, which denote the dummies for the respondent's age's being more than or equal to 25 and less than 59, and more than or equal to 59, respectively. The estimate for γ_1 is of an expected negative sign and being statistically meaningful. The coefficient estimates for other variables are all statistically meaningful. The respondent's education level is positively related to the likelihood of saying “yes” to a given bid. Similarly, wealthier interviewees are more inclined to accept the payment of an offered bid than less wealthy interviewees.

Table 4. Estimation results of the models with covariates.

Variables ^a	Model A ^b		Model B ^b	
	Estimates	t-Values	Estimates	t-Values
Constant	−1.7800	−2.85 #	−2.7401	−2.74 #
Bid amount ^c	−0.0303	−22.33 #	0.0301	22.29 #
Family	0.1134	1.94 *	0.1115	1.87 *
Age	−0.0221	−3.09 #		
Age2			−0.5123	−0.66
Age3			−0.4977	−0.63
Education	0.1653	5.43 #	0.2003	6.97 #
Income	0.7277	2.51 **	0.5992	1.98 **
Spike	0.4484	27.86 #	0.4490	28.02 #
Mean additional WTP per kWh	KRW 26.49 (USD0.024)		KRW 26.57 (USD0.0240)	
t-values	19.96 #		19.93 #	
95% confidence intervals ^d	KRW 24.05 to 29.22 (USD 0.021 to 0.025)		KRW 23.96 to 29.18 (USD 0.0217 to 0.0264)	
99% confidence intervals ^d	KRW 23.38 to 30.19 (USD 0.021 to 0.027)		KRW 23.14 to 30.00 (USD 0.0209 to 0.0271)	
Wald statistics (p-values) ^e	398.21 (0.000)		397.31 (0.000)	
Log-likelihood	−1162.89		−1167.56	
Number of observations	1000			

Notes: ^a Table 3 explains the variables. ^b Model A and Model B indicates the model including Age variable described in Table 3 and the model including Age2 and Age3 rather than Age, respectively. Age2 and Age3 denote the dummies for the respondent's age's being more than or equal to 25 and less than 59, and more than or equal to 59, respectively. ^c The unit is KRW 1000 (USD 1.0 = KRW 1105 at the time of the survey). ^d It is calculated using the bootstrapping technique given in Krinsky and Robb [32]. ^e It is computed under the null hypothesis of all the parameters' being jointly zero. *, **, and # imply statistical meaningfulness at the 10%, 5%, and 1% levels, respectively.

As shown in Table 3, the standard deviation of the income variable is relatively large compared with the standard deviations of other variables. There is great variation in terms of income in our data. Thus, information about mean additional WTP for different income levels needs to be derived. Table 5 presents the mean additional WTP estimates by level of income. In this estimation, the values of other variables were taken as the sample averages of them. The table vividly portrays that people with higher income are willing to pay more money than people with a relatively lower income. Table 6 presents information of mean additional WTP estimates for different age groups. The mean additional WTP for young group, working class group, and retired group are estimated to be KRW 36.89 (USD 0.0334), KRW 26.49 (USD 0.0240), and KRW 26.76 (USD 0.0242) per kWh, respectively.

Table 5. Mean additional willingness to pay (WTP) estimates by level of income.

Level of Income ^a (unit: million Korean won)	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Mean Additional WTP per kWh (unit: Korean won) (t-Values) ^b	21.89 (10.55 #)	23.08 (13.00 #)	24.31 (16.06 #)	25.58 (19.00 #)	26.90 (19.92 #)	28.58 (18.13 #)	29.66 (15.33 #)	31.11 (12.83 #)	32.59 (10.89 #)	34.12 (9.43 #)

Notes: ^a The unit is KRW 1.0 million (USD 1.0 = KRW 1105 at the time of the survey). ^b It is computed under the null hypothesis of all the parameters' being jointly zero. # implies statistical meaningfulness at the 1% level.

Table 6. Mean additional willingness to pay (WTP) estimates by level of age.

Level of Age	Young group ^b	Working class group ^b	Retired group ^b
Mean Additional WTP per kWh ^a (t-values) ^c	KRW 36.89 (USD 0.033) (1.76 *)	KRW 26.49 (USD 0.024) (18.85 #)	KRW 26.76 (USD 0.024) (7.88 #)

Notes: ^a The unit is KRW 1,000 (USD 1.0 = KRW 1105 at the time of the survey). ^b Young group, working class group, and retired group indicate the groups of the respondent's age's being less than 25, more than or equal to 25 and less than 59, and more than or equal to 59, respectively. ^c It is computed under the null hypothesis of all the parameters' being jointly zero. * and # imply statistical meaningfulness at the 10% and 1% levels, respectively.

4.4. Discussion of the Results

To look into public preference for substituting coal-fired generation with NG-based CHP generation with a view to mitigating air pollutants emissions, we estimated a mean additional WTP for consuming 1 kWh of electricity produced from NG-based CHP plant over coal-fired plant. The most important issue in the estimation process is whether the sample represents the population. Thus, whether some variables for the sample are similar to those for the population or not should be examined. In this regard, the ratio of female respondents and the household's monthly income are looked into here. The sample averages for the variables were 50.0% and KRW 4.80 million, respectively. The population averages were 50.0%, KRW 4.70 million when the survey was conducted [28]. Interestingly, it seems that there are no significant gaps between the two values for each variable. This finding makes the representativeness of our sample even stronger.

How to select covariates may have an effect on the mean additional WTP estimate. Therefore, the mean additional WTP used in this article comes from the model with no covariates. The mean additional WTP for the substitution is KRW 28.08 (USD 0.025) per 1 kWh. This corresponds to 25.9% of the average price of electricity, KRW 108.50 (USD 0.098) per kWh in 2017. The 95% and the 99% confidence intervals for the mean additional WTP for the substitution are KRW 25.52 to 31.06 (USD 0.023 to 0.028) and KRW 24.73 to 32.13 (USD 0.023 to 0.029) per 1 kWh, respectively. In this regard, it can be concluded that the public in South Korea place a significant additional WTP for the substitution.

The additional WTP reflects the present values of the public future cost savings related to reduction of the air pollutants emissions. If the additional cost involved in electricity generated from NG-based CHP generation that can significantly mitigate air pollutants emissions by replacing coal-fired generation is less than the additional WTP plus the environmental benefits concerning the reduction of air pollutants emissions, substituting a part of the coal-fired generation with NG-based CHP generation can be successfully implemented.

If not, further action is needed for successful substitution. As of 2017, coal-fired generation is responsible for about half of electricity generation in South Korea. Because coal is cheaper than NG, it is hard to operate an NG-based CHP plant instead of coal-fired plant. In addition, it is also a problem that the tax on NG, which emits fewer air pollutants, is much higher than coal. Thus, the government needs to charge a tax differentially on the energy sources to substitute a part of the coal-fired generation with NG-based CHP generation.

5. Conclusions

In South Korea, as the damage caused by air pollutants such as NO_x and SO_x emitted from coal-fired generation has increased recently, there is concern about health problems and $\text{PM}_{2.5}$ generated from air pollutants. According to the South Korean Ministry of Environment, coal-fired generations ranked in the top five among industrial facilities that emit the most massive air pollutants [2]. For the purpose of abating air pollutants emissions, the South Korean government has made a plan to substitute a part of coal-fired generation with NG-based CHP generation that emits fewer air pollutants.

As of 2016, the shares of coal, nuclear power, LNG, and new and renewable energies in the total power generation were 39.6%, 30.0%, 22.4%, and 4.8%, respectively. Of these, power generation from coal and nuclear power accounted for about 70% of the total. According to the government, the proportions of coal, nuclear power, LNG, and new and renewable energies will be 36.1%, 23.9%, 18.8%, and 20.0%, respectively, in 2030. Thus, coal and nuclear power sources will be still responsible for about 60.0% of power generation in 2030. The governmental plan is not to remove all coal-fired and nuclear power plants but to gradually substitute the electricity produced from coal-fired and nuclear power plants with that from LNG and renewable energies. What the government is seeking is the balanced development among power generation sources through diversifying power generation sources. How much electricity produced from coal-fired power plants should be substituted with that

from NG-based CHP is not yet determined. It is expected that the future demand for electricity will determine the degree of the substitution.

This study applied a CV technique to assessing the interviewees' additional WTP for substituting 1 kWh of electricity produced from coal-fired generation with that from NG-based CHP generation. The estimate for the mean additional WTP for the substitution was KRW 28.08 (USD 0.025) per kWh. This has statistical significance. Moreover, our sample represented the population well. Considering that the average price of electricity was KRW 108.50 per kWh in 2017, interviewees were willing to pay 25.9% more to consume 1 kWh of electricity produced from NG-based CHP generation over coal-fired generation.

As of 2016, the costs of electricity generation through coal-fired power plants and NG-based CHP plants were KRW 78.05 and KRW 100.13 per kWh, respectively. The gap between the two generation costs was KRW 22.08 per kWh, and this value is smaller than the mean additional WTP, which was KRW 28.08 (USD 0.025) per kWh. This means that interviewees are willing to pay more money than the actual additional generation costs of NG-based CHP over coal. Thus, it is obvious that the governmental policy of substituting coal with NG-based CHP for power generation to reduce the air pollutants emission is supported by the public, and the substitution should be made gradually.

An important observation emerged from the study results. The government and industry should be aware of how interviewees perceive the additional WTP for substituting coal-fired generation with NG-based CHP generation. For example, it is encouraged to substitute a part of coal-fired generation with NG-based CHP plant because the interviewees gave a higher value to electricity produced from NG-based CHP generation over coal-fired generation. This article added a contribution to the current literature by deriving the additional WTP for substituting coal-fired generation with NG-based CHP generation to mitigate air pollutants emissions. This study provided empirical evidence that the CV approach theoretically grounded in microeconomics could be successfully utilized in measuring the additional WTP.

The authors think that the framework of the study can be extended in future studies in several ways. For example, we need to examine how the value varies as time passes by conducting the CV survey every year for some years, and analyzing the CV data. Investigating how much the value changes across the regions and identifying other geographic factors which affect the value are also a good research topic. Comparing the findings from this study with those from other studies for foreign countries and analyzing the gap between the two enable us to obtain a new insight into the WTP estimate. These works can provide us with a new point of view concerning additional WTP.

Author Contributions: All the authors made significant contributions to this paper. G.-E.K. proposed the key ideas and quantitatively analyzed the survey data; H.-J.L. conducted a literature review and prepared about half of the paper; and S.-H.Y. made the survey questionnaire, formulated the WTP model, and derived the implications of the study results.

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. 20164030201060).

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

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