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The Convenience Benefits of the District Heating System over Individual Heating Systems in Korean Households

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Abstract: Koreans usually prefer the district heating system (DHS) to the individual heating system (IHS) because DHS can give them convenience and safety within their living environment. The Korean government thus plans to expand the DHS and requires information about the value that consumers place on the DHS over the IHS, which has not been dealt with in academic literature. This paper attempts to investigate Korean households' willingness to pay (WTP) for DHS over IHS, for residential heat (RH). To this end, the authors apply the dichotomous choice contingent valuation to assessing additional WTP for DHS using a survey of 1000 randomly selected households living in buildings with IHS. A mixture model is applied to deal with the zero WTP responses. The WTP distribution is specified as a mixture of two distributions, one with a point mass at zero and the other with full support on the positive half of the real line. The results show that the mean additional WTP for DHS-based RH over IHS-based RH is estimated to be KRW 5775 (USD 5.4) per Gcal. This value can be interpreted as the consumer's convenience benefits of DHS over IHS, and amounts to approximately 6.0% of the average price: KRW 96,510 (USD 90.4) per Gcal in 2013, for IHS-based RH. This information is useful for evaluating changes to the method used for supplying RH from IHS to DHS.

Keywords: district heating system; individual heating system; contingent valuation; willingness to pay; convenience benefit

1. Introduction

In the literature, the district heating system (DHS) is considered best for the supply of heat, a vital requirement of human life, in urban areas with high population density [1]. A number of studies have shown that DHS plants give better performance in energy efficiency and the abatement of air pollutant emissions, mitigate greenhouse gas emissions, and contribute greatly to the enhancement of public convenience and energy saving compared to individual heating systems (IHS) such as decentralized boilers [2–6]. The DHS has thus been provided in both existing apartments, replacing IHS, as well as in newly planned cities in Korea.

Korean residents prefer DHS to IHS because DHS provides convenience and safety in their living environment. The DHS does not demand an individual boiler, which can significantly increase consumer convenience and safety [7]. Consumers can utilize the space formerly taken up by a boiler as storage space, and so converting IHS into DHS can substantially expand living space. Consumers using IHS are sometimes confronted with trouble in their boilers, and particularly during the winter season, this can cause great inconvenience. A boiler usually requires operation and maintenance costs, as well as repair cost. Therefore, the IHS-based residential heat (RH) consumers pay both the costs and the fuel charges. However, the costs required in the DHS are included in the DHS bill, and thus the DHS-based RH consumers pay just the RH charges. Occasionally, individual boilers may explode. Over the period 2008–2012, for example, 16 people were killed and 110 people were wounded when individual boilers exploded. For these reasons, some 200,000 households have voluntarily changed their heating system from IHS to DHS, even though the change meant considerable cost.

The Korean government has been expanding, and plans to further expand the DHS. The number of households with access to DHS in 2003 was 1,251,000 and its proportion of Korean households was just 8.1%. However, they had increased to 2,306,000 and 12.5% in 2013. The average annual growth rate over that ten years was 6.3%. According to the Ministry of Trade, Industry, and Energy [8], the average annual growth rate during the period 2013–2018 will be 8.4%. To this end, KRW 8.3 trillion (USD 7.8 billion) will be invested.

In summary, it is expected that the DHS will be expanded in Korea to meet the increasing demand of residents and to implement the national plan of increasing the DHS. The Korean government thus requires information about the convenience benefits of DHS over IHS for consumers. It appears that the measurement of convenience benefits of DHS-based RH use is not an important research topic in most countries, because to the best of the authors' knowledge the issue has not been reported in the literature. In Korea, however, researchers need to supply usable and quantitative information for policymakers.

Our study attempts to value the convenience benefits to residents of the DHS over IHS in Korea. The results of a contingent valuation (CV) survey are thus reported here. The rest of the paper is structured as follows. Section 2 explains the methodology adopted here. A model for willingness to pay (WTP) is described in Section 3. The results are reported and discussed in Section 4. The final section concludes the paper.

2. Methodology

2.1. Methods: The CV Approach

According to microeconomic theory, an additional WTP for DHS over IHS can be used as a basis for valuing the convenience benefits of the DHS [9,10]. Because the residential DHS provides the consumer with RH, the authors consider the convenience benefits of RH use through DHS rather than IHS. The people's additional WTP for the consumption of RH through DHS rather than IHS can be gauged using stated preference techniques, a representative one of which is the CV technique. Arrow et al. [11] concluded that the CV technique is able to generate credible information that can be applied in relation to decisions regarding administration and jurisdiction. The CV approach is likely to be in accordance with the general notion of microeconomics [12–15]. It has often been employed in energy management issues [16–22], however, it has not been used when dealing with RH.

The authors conducted a pre-test on the survey questionnaire with a focus group made of one hundred persons to examine whether the questionnaire could be properly understood and to obtain the distribution of the WTP values. The pre-test results helped us to rectify the errors in the questionnaire and to refine the bids to be presented to the respondents. The final questionnaire consisted of (a) questions concerning the general perceptions of RH from the DHS; (b) explanations of the objectives of the survey; (c) questions about the additional WTP for the use of RH from the DHS rather than IHS; and (d) questions regarding household characteristics.

A professional survey company implemented a random sampling and field CV survey. During the CV survey, the interviewer asked the respondents to make a responsible decision about payment. To satisfy this condition, the survey firm selected and interviewed heads of households or home-keepers; the respondents' ages ranged from 20 to 65. The authors decided to use face-to-face interviews so that the respondents were provided with sufficient information on the objects to be valued. Based on the interviewers' comments, the interviewees supplied answers to the WTP questions without any particular difficulty. The trained interviewers carried out 1400 personal interviews at the interviewees' homes during October 2014.

The post-interview follow-up telephone check was done to reduce the number of skipped questions and to verify the results of the survey, both of which tend to increase the reliability of our data. Besides obtaining answers for the skipped variables, a total of 1400 observations verified that the CV survey was properly conducted. Whether the interviewer performed their job properly, whether the interviewers used the visual aids properly, and whether the respondents sufficiently understood the CV questions were asked by phone. The authors also checked the consistency of the respondent's answers by asking several questions again. Perhaps remarkably, respondents in Korea understood the CV questions easily with the help of the interviewer. In the process of verification, 400 observations from the original total of 1400 interviewed were removed from the sample. For some observations, no one by the given name at the telephone number given by the respondent could be found. For some questionnaires, the answers given over the phone were inconsistent with the answers given in the interview. For some survey results, there were skipped variables that cannot be made up over the phone. Some respondents frankly confessed that they did not pay attention to the CV survey. Some observations were evaluated to be of poor quality by the interviewers. Finally, 1000 useable observations were obtained.

2.2. Method of WTP Elicitation and Bid Amounts

According to Mitchell and Carson [23], open-ended questions can induce an overestimated WTP. Thus, they should be avoided in empirical CV studies. In accordance with the guidance of the National Oceanic and Atmospheric Administration on the CV approach [24–26], a dichotomous choice (DC) question method was employed. The use of a DC question indicates that interviewees are asked questions about whether they are willing to pay a specific amount for achieving a goods or not.

The DC question method is usually classified into a single-bounded (SB) DC format and a double-bounded (DB) DC format. The first demands the respondent to answer just one question. On the other hand, the second asks her or him to answer one and the other follow-up questions. As the answer to the additional question obviously gives us more information about the WTP, DB questions can produce more efficient output than SB ones [27]. However, many studies in the literature claim that some bias is captured when moving from an SB to a DB question [28–30]. Therefore, DB question is not used here because it increases the bias involved in WTP responses and it is thus not favored by Bateman et al. [29] and Carson and Groves [30].

2.3. Payment Vehicle

The interviewees could easily reveal their true WTP using the medium through which the amount would be paid. The medium is called the payment vehicle, and may be a tax, a fund, a donation, or an expenditure. Price of RH can be a good payment vehicle because it is well-known to most of the interviewees and is clearly related to their actual expenditure [30–32]. The costs and prices of RH delivered by DHS vary by location. However, the price of IHS-based RH does not vary according to the region in Korea, although the cost of supplying IHS-based RH varies from region to region. Thus, the authors used the payment vehicle for the CV survey as price of IHS-based RH.

The WTP question as described in Appendix A was posed in the following manner: "Given that residential heat in your household is supplied through an individual heating system and the price of residential heat is KRW 96,510 (USD 90.4) per Gcal in 2013, would your household be willing to pay a specified bid for carrying out the supply of heat by the district heating system, instead of the individual heating system through an increase in price of residential heat, supposing that residential district heating system would certainly be implemented?".

3. Modeling of WTP Responses

3.1. Basic WTP Model

There are two approaches to modeling of WTP responses gathered from a DC CV survey: the utility difference approach suggested by Hanemann [33] and the WTP function approach proposed by Cameron and James [34]. The first specifies utility difference using a random utility maximization model, and the second specifies the WTP responses directly. As pointed out by McConnell [35], a choice of one over the other is not an issue of right and wrong, but that of a researcher's preference, because the two approaches are dual in an economic sense. The literature shows that the first has been more frequently applied than the second, and thus the utility difference approach is adopted in our study. The ratio of "yes" responses to each given bid is the basic input required for the application of the approach.

3.2. Model of Dealing with Zero WTP Responses: Mixture Model

Some people are greatly interested in the residential DHS, but others are totally indifferent to, or place no value on, the residential DHS. In this case, the portion of zero WTP responses in the CV survey may be high. Researchers should pay closer attention to dealing with the WTP responses with zero observations. For this purpose, a mixture model suggested by Werner [36] is applied. The following model is theoretically based on Werner's [36] mixture model, where the mixture of two distributions is modeled for zero and positive WTP responses. One distribution is the point mass at zero, and the other distribution is for positive interval WTP data.

The mixture model enables us to analyze both zero point and positive interval WTP data in a univariate setting. Let the random variable for the level of WTP, and the probability density function (pdf) and the cumulative distribution function (cdf) of the positive WTP be Z, $h(Z;\omega)$ and $H(Z;\omega)$, respectively, where ω is a vector of parameters and $H(0;\omega) = 0$. Let the probability of WTP's being zero be σ. The pdf and cdf of Z are denoted as $f(Z;\omega)$ and $F(Z;\omega)$, respectively. Thus, the form of $f(Z;\omega)$ is:

$$f(Z;\omega) = \begin{cases} 0, & \text{if } Z < 0 \\ \sigma, & \text{if } Z = 0 \\ (1-\sigma)h(Z;\omega), & \text{if } Z > 0 \end{cases}. \tag{1}$$

$F(Z;\omega)$ has the following functional form:

$$F(Z;\omega) = \sigma + (1-\sigma)H(Z;\omega), \text{ for } \quad Z \geq 0. \tag{2}$$

Since point mass is usually zero, a strategy of adopting a mixture of two distributions is required in order to reflect the probability at zero in the model. Equation (2) is a convex combination of two distributions where weights are σ and $1-\sigma$. In other words, the probability of zero WTP is σ and positive WTP is drawn from $H(Z;\omega)$ with probability $1-\sigma$. One more thing to consider is the fact that σ is a kind of probability and thus should range from zero to one. In order to explicitly consider this point, σ is specified as the logistic distribution function:

$$\sigma = \frac{\exp(\rho)}{1+\exp(\rho)} \tag{3}$$

where ρ is the parameter to be estimated. ρ is firstly estimated and then σ is computed using the estimate for ρ, instead of directly estimating σ. Because Equation (3) is a distribution function, the value for σ naturally lies between zero and one.

The next step is to assume the functional form of $H(Z;\omega)$ which satisfies $H(0;\omega) = 0$. Following the former practice in the literature, the positive WTP is assumed to be distributed as Weibull. Thus:

$$H(B;\omega) = H(B;\alpha,\beta) = 1 - \exp(-\beta B^{\alpha}), \text{ for } \quad B \geq 0 \tag{4}$$

where $\omega = (\alpha, \beta)$ is a parameter vector to be estimated and B is a given bid.

The mean of WTP can be computed as:

$$E(Z) = \int_0^{\infty} [1 - F(B; \sigma, \alpha, \beta)]dB - \int_{-\infty}^{0} F(B; \sigma, \alpha, \beta)dB = (1 - \sigma)\left(\frac{1}{\beta}\right)^{1/\alpha} \Gamma\left(1 + \frac{1}{\alpha}\right) \tag{5}$$

where $\Gamma(\cdot)$ is gamma function defined as:

$$\Gamma(t) = \int_0^{\infty} v^{t-1} \exp(-v)dv. \tag{6}$$

Some covariates, such as the respondent's household income, can be incorporated into the mixture model. There are two methods of modeling covariates. The first makes covariates penetrate ρ in Equation (3). That is, ρ is simply changed into $y'\theta$ where y is a vector of covariates and θ is a vector of corresponding parameters to be estimated. The second method lets covariates enter the β in Equation (4). In other words, β is substituted by $u'\lambda$, where u is a vector of covariates and λ is a vector of corresponding parameters to be estimated. There are three models with covariates: the model with $y'\theta$, the model with $u'\lambda$, and the model with both $y'\theta$ and $u'\lambda$.

3.3. SB DC Mixture Model

As explained above, an SB DC model is used in this study. The following SB DC model is based on Hanemann's [33] suggestion. There are T observations to be analyzed. A bid, B_j, is given to the respondent j for $j = 1, ..., T$. There are two outcomes, "yes" ($Z \geq B_j$) and "no" ($Z < B_j$). Therefore, two binary variables for the two results, I_j^Y and I_j^N, can be introduced. That is, the value of each binary variable is one if the respondent's response corresponds with its superscript, and zero otherwise. For example, I_j^Y is one if the respondent j reports "yes" and zero otherwise.

In order to identify zero WTP observations, the authors asked the respondents who gave "no" responses to a presented bid, B_j, an additional follow-up question that can distinguish true zero WTP from positive WTP. One can thus formulate one more binary variable, I_j^{TZ} whose value is one if jth respondent's WTP is true zero, and zero otherwise. The log-likelihood function of the SB DC mixture model is:

$$\begin{aligned} \ln L = \sum_{j=1}^{T} \{ & I_j^{TZ} \ln \sigma + (1 - I_j^{TZ}) I_j^Y \ln[(1 - \sigma)(1 - F(B_j; \sigma, \alpha, \beta))] \\ & + (1 - I_j^{TZ}) I_j^N \ln[(1 - \sigma) F(B_j; \sigma, \alpha, \beta)] \} \end{aligned} \tag{7}$$

4. Results and Discussion

4.1. Data

A total of 1000 observations were collected from the CV survey of randomly chosen households over the entire nation. The respondents were restricted to those who were living in buildings with IHS. They have been asked about their previous experience or general knowledge about DHS. A pre-test on the survey questionnaire with a focus group (100 people) was conducted to obtain the distribution of the WTP values. They were asked to report their additional WTP for using the DHS-based RH rather than the IHS-based RH. The authors sorted the reported positive values in ascending order, trimmed ten percent of observations from both tails, and determined seven bids from the trimmed distribution in a manner of increasing interval. A list of seven bids used for this study is KRW 2000, 5000, 8000, 15,000, 25,000, 40,000, and 60,000 per Gcal of RH use through DHS rather than IHS. When the CV survey was conducted, the exchange rate was USD 1.0 to approximately KRW 1067.5.

The distribution of responses by each bid level is shown in Table 1. Note that the proportion of those stating "yes" to an offered bid decreases as the bid amount increases. Zero WTP results in a "no-no" response, and Table 1 indicates that 435 households (43.5%), a considerable portion of the respondents, reported zero WTP for the RH supply from the DHS rather than IHS. Thus, our strategy of adopting a mixture model in the analysis of the SB DC CV data appears to be appropriate.

Table 1. Distribution of responses by bid amount.

Bid Amount in Korean Won [a]	Number of Responses (%) [b]			Sample Size [b]
	"Yes"	"No-Yes"	"No-No"	
2000	62 (43.3)	29 (20.3)	52 (36.4)	143 (100.0)
5000	42 (29.6)	42 (29.6)	58 (40.8)	142 (100.0)
8000	20 (14.0)	58 (40.6)	65 (45.5)	143 (100.0)
15,000	13 (9.1)	73 (51.0)	57 (39.9)	143 (100.0)
25,000	12 (8.4)	67 (46.8)	64 (44.8)	143 (100.0)
40,000	3 (2.1)	73 (51.1)	67 (46.8)	143 (100.0)
60,000	3 (2.1)	68 (47.6)	72 (50.3)	143 (100.0)
Totals	155 (15.5)	410 (41.0)	435 (43.5)	1000 (100.0)

Notes: [a] The unit is Korean won and USD 1 was approximately equal to KRW 1067.5 at the time of the survey; [b] The numbers in parentheses beside the number of responses are the percentage of sample size.

4.2. Estimation Results of the SB DC Mixture Model

Table 2 reports the results from estimating the SB DC mixture model. Judging from the *t*-values computed under the null hypothesis that each parameter estimate is zero, each parameter estimate is statistically significant at the 1% level. The Wald statistic calculated under the null hypothesis that all the parameter estimates are jointly zero also implies that the estimated equation is statistically meaningful at the 1% level. Thus, one can proceed to any interpretation of the estimated coefficients with statistical meaningfulness.

Table 2. Estimation results of the mixture model.

Parameters	Coefficient Estimates [d]
α	0.6307 (10.94) #
β	0.2872 (6.29) #
σ	0.4350 (27.75) #
Mean additional WTP [a]	KRW 5775 (USD 5.4)
t-value	8.93 #
95% confidence interval [b]	KRW 4811 to 7743 (USD 4.5 to 7.3)
99% confidence interval [b]	KRW 4529 to 8648 (USD 4.2 to 8.1)
Number of observations	1000
Log-likelihood	−943.65
Wald statistic (*p*-value) [c]	2093.20 (0.000) #

Notes: [a] The unit is 1000 Korean won and 1.0 USD was approximately equal to KRW 1067.5 at the time of the survey; [b] The confidence intervals are calculated using the Monte Carlo simulation technique of Krinsky & Robb [37], with 5000 replications; [c] The null hypothesis is that all the parameters are jointly zero, and the corresponding *p*-value is reported in parentheses beside the statistic; [d] The numbers in parentheses beside the coefficient estimates are the *t*-values, computed from the analytic second derivatives of the log-likelihood; # indicates statistical significance at the 1% level.

The estimator for σ of the mixture model is 0.4350, which is the same as the percentage of the sample having zero WTP, as shown in Table 1 (43.5%). This demonstrates that the mixture model applied in the study depicts the sample successfully. The mean of additional WTP for one Gcal of RH use from DHS rather than IHS is calculated to be KRW 5775 (USD 5.4). This value is statistically meaningful at the 1% level. For the purpose of accounting for the uncertainties pertaining to the computation of the estimates, the authors also report 95% and 99% confidence intervals. They are computed by the use of the parametric bootstrapping method proposed by Krinsky and Robb [37] with 5000 replications.

4.3. Estimation Results of the Model with Covariates

To examine the impact of a respondent's socio-economic characteristics on the probability of him or her answering "yes" to a given bid, it is necessary to deal with the SB DC mixture model with covariates. The socioeconomic variables used for the covariates and the sample statistics of them are described in Table 3. For example, forty-nine percent of the participants had lived in a metropolitan area, and the mean monthly household income was KRW 4.31 million (USD 4.03 thousand).

Table 3. Definitions and sample statistics of the variables.

Variables	Definitions	Mean	Standard Deviation
Area	Dummy for the respondent living in a metropolitan area (0 = no; 1 = yes)	0.49	0.50
Income	Monthly household income before tax deduction (unit: KRW 1 million = USD 936.8)	4.15	1.87

Note: USD 1.0 was approximately equal to KRW 1067.5 at the time of the survey.

Table 4 contains the results from estimating the SB DC mixture model with covariates. Some empirical findings from the estimation of the three versions of the models are presented in Table 4. In Models A, B, and C, three covariates (Constant, Area, and Income) are included for the parameter ω, the parameter β, and the parameters ω and β, respectively. In Models A and C, the statistically significantly positive sign of the coefficient estimate for Area implies that a person who lives in the metropolitan area is less likely to pay an additional amount for DHS-based RH use than others. The statistically significantly negative coefficient estimate for Income shows that household income has a negative correlation with the probability of having a zero WTP.

Table 4. Estimation results for the mixture models with covariates.

Parameters [a]	Model A [b]	Model B [b]	Model C [b]
α	0.6307 (10.94) #	0.6970 (10.91) #	0.6970 (10.91) #
β	0.2872 (6.29) #		
Constant		0.4043 (5.68) #	0.4043 (5.68) #
Area		−0.2199 (−4.84) #	−0.2199(−4.84) #
Income		−0.0040 (−0.66)	−0.0040 (−0.66)
σ		0.4350 (27.74) #	
Constant	−0.0530 (−0.33)		−0.0530 (−0.33)
Area	0.4372 (3.35) #		0.4372 (3.35) #
Income	−0.1074 (−3.18) #		−0.1074 (−3.18) #
Sample size	1000	1000	1000
Log-likelihood	−934.01	−920.35	−910.71

Notes: [a] The variables are defined in Table 3; [b] For the meanings of Models A, B, and C, see the text. *t*-values are reported in parentheses beside the parameter estimates; # indicates statistical significance at the 1% level.

4.4. Discussion of the Results

In Korea, information about the convenience benefits of RH use from DHS rather than IHS is needed. Korea imports ninety-seven percent of energy consumed in the country from abroad. In other words, Korea is a representative energy-poor nation. Thus, Korea has enacted and enforced DHS Business Act to utilize energy more efficiently and in a manner of emitting less carbon dioxide. According to the law, the central or local government should adopt either DHS or IHS to supply RH when developing new cities or re-developing old cities. Consequently, uncovering the convenience benefit to consumers of RH use from DHS instead of IHS is meaningful for Korea.

Before one examines the convenience benefit of RH use from DHS rather than IHS, one should check that our sample is representative of the Korean population. The sample values for three variables can be compared with their population values. The population values for gender, the size of the household, and the household's monthly income are available from Statistics Korea. According to Statistics Korea, the ratio of male people, the average of household income, and the average of the household size are 50.3%, KRW 4.30 million, and 3.2 persons, respectively, at the time of survey. These values are quite close to the sample means (49.7%, KRW 4.15 million, and 3.4 persons). Our CV survey was implemented using in-person face-to-face interviewing; thus response rate was almost one hundred percent. Therefore, it seems that our sample is reasonably representative of the national population.

The results show that the mean additional WTP for RH use from DHS rather than IHS is calculated to be KRW 5775 (USD 5.4) per Gcal. Given that the average price of RH from IHS was KRW 96,510 (USD 90.4) per Gcal in 2013, the convenience benefits that ensue from DHS-based RH consumption instead of IHS amounts to 6.0% of the average price of RH from IHS. This suggests that Korean residents would be willing to pay a significant premium to consume RH from DHS instead of IHS. Interestingly, the average price of DHS-based RH was KRW 87,870 (USD 82.3) in 2013, which was much lower than that of IHS-based RH (KRW 96,510 or USD 90.4). This is because IHS uses only natural gas as a fuel, but DHS employs not only natural gas but also waste heats emitted from incinerators and fossil fuel-based power plants as a fuel. The DHS-based RH consumers do enjoy both more convenience benefits and lower price than the IHS-based RH consumers. The government policy of enhancing the conversion of IHS into DHS would thus be supported by the residents.

Korea has experienced a growth rate of 3.9% per year during the period 2000–2015. The rate of the access to DHS has increased from 8.5% in 2000 to 15.2% in 2015. The expansion of DHS was due to the governmental policy of developing new towns for improving residential environment and expanding housing supply. It was found that a number of households prefer DHS to IHS in terms of its convenience. However, for old residential areas converting IHS to DHS demands a lot of construction work and large investments, which causes serious financial burdens. The Korean government is keeping low levels of residential heating cost in order to stabilize prices, which twenty-five out of the thirty-five DHS companies has been suffering from chronic deficits.

Actually, DHS has various advantages over IHS. For example, a number of studies have shown that DHS plants give better performance in energy efficiency and the abatement of air pollutant emissions, mitigate greenhouse gas emissions, and contribute greatly to the enhancement of public convenience and energy saving compared to IHS [2–7,38,39]. In particular, DHS is known to be more efficient in terms of national energy consumption than IHS in urban areas with high population density. For example, United Nations Environment Programme [40] explained combined heat and power (CHP) plant for DHS can save energy consumption by 49%. United States Environmental Protection Agency [41] reported that the CHP for DHS can decrease the amount of total fuel used by 32%. Korea Ministry of Trade, Industry, and Energy [8] announced that DHS can reduce the total amount of energy consumption by 24% compared to IHS.

In short, Korean consumers want DHS and DHS has a number of advantages over IHS, but there are not enough funds for the DHS supply. In addition, the fuel used in DHS of Korea mostly relies on natural gas, and thus the use of renewable energies and/or fuel cell in DHS is widely demanded. Thus, some new actions should be taken for expanding the supply of DHS. They include fuel cell-based DHS that does not use a natural gas-based CHP plant, a combination of geothermal facility and heat pump, solid waste-based CHP plant, the fourth generation DHS based on renewable energies, and so on. However, some preliminary feasibility studies reveal that they are not yet economically profitable in Korea's situation. It appears that more technological innovations, more efforts to reduce the costs involved in the actions, and government's financial assistance for the actions are needed for the actions to be implemented.

5. Conclusions and Policy Implications

The DHS is widely accepted as an excellent alternative to IHS such as using individual boilers for the supply of RH in urban areas with high population density, enhancing public convenience and energy saving. The DHS is also a more effective measure to mitigate greenhouse gases and air polluting emissions than the IHS. The DHS has been and will be rapidly expanded owing to the governmental policy to increase it and the preferences of residents for it over IHS. The Korean government is planning to develop a new DHS project, for example, for gathering unused and/or discarded heat from thermal power plants and steel-making companies and distributing it to residents in metropolitan areas who need RH. Whether to supply RH from the project to residents who currently use IHS is a controversial issue, and policymakers thus need information about the convenience benefits of the DHS over IHS for decision-making about whether to implement the DHS project.

The convenience benefits of the DHS have rarely been estimated in the literature, although researchers are asked to supply usable and quantitative information with which policymakers can decide whether to introduce a new DHS for providing RH to replace IHS. Following the tenets of economic theory, the convenience benefits of using RH from the DHS rather than IHS are measured by the consumer′s additional WTP for such use. In particular, as the Korean government has regulated the unit price of current RH from the DHS under the cost of production, the price does not reflect convenience benefits generated from the supply of DHS-based RH instead of IHS-based RH.

To this end, this study applied the CV technique using a national survey of 1000 randomly chosen households. To mitigate the response effect in eliciting WTP and to augment the statistical efficiency involved in analyzing the WTP data, a Weibull distribution was used. The mean of the additional WTP for DHS-based RH over IHS-based RH was estimated to be KRW 5775 (USD 5.4) per Gcal. Considering that the average price of IHS-based RH per Gcal was KRW 96,510 (USD 90.4) in 2013, the convenience benefits of DHS-based RH use over IHS-based RH use amounted to 6.0% of the price of IHS-based RH.

This figure can be partially used to decide whether to invest in a new DHS to provide RH. Considering constrained budgets, correct and valid estimates of the economic benefits of the DHS for RH supply are required to make economically sound investment decisions. This information can be beneficially utilized in evaluating a new project to change the method of supplying RH from IHS to DHS. Economic evaluation is important because it helps ascertain whether the public favors a proposed DHS project for RH supply, as well as estimating the degree to which it is willing to pay for such a benefit.

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

Appendix A

The main part of the survey questionnaire employed in the study is as follows.

Questions about Willingness to Pay for District Heating System over Individual Heating System in Korea

Q1. Given that residential heat in your household is supplied through an individual heating system and the price of residential heat is KRW 96,510 (USD 90.4) per Gcal in 2013, would your household be willing to pay 2000 Korean won (first bid amount) for carrying out the supply of heat by the district heating system, instead of the individual heating system through an increase in price of residential heat, supposing that residential district heating system would certainly be implemented?

a. Yes—go to Q2.
b. No—go to Q3.

Q2. Given that residential heat in your household is supplied through an individual heating system and the price of residential heat is KRW 96,510 (USD 90.4) per Gcal in 2013, would your household be willing to pay 4000 Korean won ($2\times$ first bid amount) for carrying out the supply of heat by the district heating system, instead of the individual heating system through an increase in price of residential heat, supposing that residential district heating system would certainly be implemented?

a. Yes—Finish this survey
b. No—Finish this survey

Q3. Given that residential heat in your household is supplied through an individual heating system and the price of residential heat is KRW 96,510 (USD 90.4) per Gcal in 2013, would your household be willing to pay 1000 Korean won ($\frac{1}{2}\times$ first bid amount) for carrying out the supply of heat by the district heating system, instead of the individual heating system through an increase in price of residential heat, supposing that residential district heating system would certainly be implemented?

a. Yes—Finish this survey
b. No—go to Q4.

Q4. Then, is your household not willing to pay anything for carrying out the supply of heat by the district heating system, instead of the individual heating system?

a. Yes, our household is willing to pay something less than 1,000 Korean won.
b. No, our household is not willing to pay anything. In other words, our household's willingness to pay is zero.

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