Improving Drinking Water Quality in South Korea: A Choice Experiment

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Abstract:

Increased pollution leads to a constant decrease of drinking water quality worldwide. Due to safety concerns, unpleasant taste and odour only about 3% of the population in South Korea is drinking untreated tap water. The present study uses choice experiments and cost-benefit analysis to investigate the feasibility of installing advanced water treatments in Cheongju waterworks in South Korea. The waterworks is situated in the middle of the country and is providing more than half a million people with drinking water. The study shows that the lower bound of the median WTP for installing a new advanced water treatment system is about $ 2 US/month, which is similar to the average expenditures for bottled water per household in South Korea. Scenarios under which the instalment of the advanced water treatments is feasible are discussed together with environmental solutions in the long-run.

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JEL Codes: C83, D02

#238

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Abstract

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Keywords: Drinking Water Quality, Water Pollution, Choice Experiments, Willingness to Pay, Random Parameter and Latent Class Logit, Cost-Benefit Analysis

JEL Classifications: C19, C83, C90, D12, D61, Q25, Q51, Q53

Introduction

Water pollution has spread according to economic development across the world. Increased discharges of untreated sewage, combined with agricultural runoff and inadequately treated wastewater from industry, have resulted in the severe degradation of water quality worldwide. According to the UN World Water Development Report (2017) over 80% of the world's wastewater – and over 95% in some least developed countries – is released to the environment without treatment. This poses a severe threat to human health, ecosystems and the environment, and ultimately to economic activity and sustainable economic development.

The situation is especially worrying in South Korea, a developed country with historically polluted water supply. Several accidents of contamination in the water supply including detection of trihalomethanes in tap water in 1990, phenol in the river in 1991, heavy metal and harmful pesticides in tap water in 1994, and disease germs in tap water in 1993 and 1997, have made the average Korean concerned about the safety of the water supply, and very few citizens drink water directly from the tap (Um et al. 2002). A 2011 survey reported that only 3.2% of the population in South Korea drank untreated tap water, down from 4.1% in 2010.[1] This implies that most Koreans are dissatisfied with the quality of drinking water and distrust the organisations related to it. Many Koreans complain about unpleasant experiences of an earthy smell and fishy taste when drinking tap water (Um et al., 2002).

Annual sales of bottle water increased by 96% between 2009 and 2014, and sales of in-line filters increased by 49% during the same time (Database of the Korean Statistical Information Service).

The present study aims to understand the main causes of pollution in a specific target area in South Korea (Guem River Basin) and to investigate the feasibility of installing two different advanced water treatment systems in Cheongiu waterworks, the waterworks providing it with drinking water: granular activated carbon (GAC), and ozone plus GAC treatment. Granular activated carbon is usually added to the process of filtration, and ozone treatment is added to the system of chlorine disinfection as an additional method to remove fine particles and to create chemical reactions in the water. Ozone has greater oxidation potential to make iron, manganese and sulphur from insoluble metal oxides or elemental sulphur than other disinfection processes. It also eliminates organic particles and chemicals through coagulation or chemical oxidation (Langlais et al., 1991). These two water treatment systems are seen as an intermediary solution in the short-run however, the present study also discusses the most appropriate environmental solutions for improving potable water quality in the target area in the long-run. Cost-benefit analysis (CBA) is used to test the feasibility of installing two advanced water treatment systems. Three main steps are involved: measurement of the social benefits, cost estimation of the two

[1] Ministry of Environment, South Korea, 2013.

alternatives and the CBA. Choice experiments are chosen for measuring the benefits with three alternatives: the status quo, GAC, and GAC plus ozone.[2] From these choice experiments, marginal willingness to pay (MWP) is calculated and compared to the projected costs of the projects, estimated using data from eight former projects. Moreover, confidence intervals are constructed for the lower bound of the MWP. The economic feasibility is tested by comparing the costs and benefits of the two alternatives.

The results suggest that the GAC treatment provides the best outcome. This is tested against a number of different specifications including risk and uncertainty, rates of returns, and different construction and business life periods. To the best of our knowledge, no other study has assessed the feasibility of this highly necessary project before. Moreover, we do not know any other study for Korea combing choice experiments, arguably the most advanced stated preference method to date, with CBA to achieve a similar goal.

Methodology

The present study uses random parameter logit and latent class logit models in order to estimate the WTP of the respondent and ultimately the benefits of the advanced water treatments systems. Moreover, it estimates confidence intervals for the lower bound of the WTP. It then performs a cost-benefit analysis in order to assess the relationship of these benefits to the costs and to determine the feasibility of the project. In what follows, these methodological elements will be shortly described.

Random Utility Framework

The response to the choice between the three constructed choice alternatives (GAC, GAC plus ozone, and the status quo) can be modelled in a random utility framework. The overall utility (U) can be expressed as the sum of a systematic component, which is expressed as a function of the attributes presented (v_{in} for alternative i and individual n), and a random component (e_{in}):

$$U_{in} = v_{in} + e_{in} \qquad (1)$$

Alternative i is chosen over alternative j if $U_{in} > U_{jn}$. The probability of person n choosing alternative i is given by:

$$\pi_n(i) = \Pr(v_{in} + e_{in} \geq v_{jn} + e_{ij} \,; \forall\, j \in C_n) \qquad (2)$$

[2] Cho (2007) reported that Ozone treatment would not usually be installed alone because the system can work more efficiently together with GAC treatment.

where C_n is the choice set for individual *n*. If we consider V_{in} to be a conditional indirect utility function that has a linear form, we can write it as follows:

$$V_{in} = \beta_1 + \beta_2 x_{in2} + \beta_3 x_{in3} + \cdots + \beta_k x_{ink} + \alpha(Y - P_i) \qquad (3)$$

where x_{ink} are the attributes of the alternatives described above, *Y* is income, and P_i is the price of alternative *i*. Assuming that the error terms are Gumbel distributed with a scale parameter μ, the probability of choosing alternative *i* is given by:

$$\pi_n(i) = \frac{exp^{\mu V_{in}}}{\sum_{j \in C_n} exp^{\mu V_{jn}}} \qquad (4)$$

where the scale factor μ is usually assumed to be equal to 1.

Latent Class Model (LCM)

The Latent Class Model is a semi-parametric extension of the Multinomial Logit Model which allows the investigation of heterogeneity on a class (segment) level and relaxes the assumptions regarding the parameter distribution across individuals (Greene and Hensher, 2009). This approach has individuals endogenously grouped into classes of homogenous preferences (Scarpa and Thiene, 2005, Hammitt and Herrera-Araujo 2017) and estimates their probability of membership to their designated class depending on their socio-economic characteristics (Kikulwe et al., 2011). As a result, the class membership likelihood function is as follows (adapted from Boxall and Adamowicz, 2002):

$$M_{ns} = \lambda_s Z_n + \xi_{ns} \qquad (5)$$

Where Z_n denotes the observed characteristics, λ_s denotes the parameters of the specific segment and the error terms are assumed to be IID with a Gumbel distribution. Therefore, the probability of an individual, *n*, belonging to a specific class, *s*, is (adapted from Kikulwe et al., 2011):

$$Prob(s) = \frac{\exp(\lambda_s Z_n)}{\sum_{k \in S}(\lambda_k Z_n)} \qquad (6)$$

Where *k* denotes the number of classes. Given it is a probability function, the sum of all segment probabilities equals one. This additional information assists in constructing a function that both reveals the probability of an individual, *n*, selecting alternative *i* over *j* and accounts for heterogeneity (Boxall and Adamowicz, 2002). Hence the model can be represented similarly to equation (4), (adapted from Kikulwe et al., 2011):

$$Prob(\mathrm{i}|\mathrm{C},\mathrm{S}) = \frac{exp(\beta s X_{\mathrm{in}})}{\sum_{j \in C}\exp(\beta s X_{\mathrm{jn}})} \times \frac{\exp(\lambda_s Z_n)}{\sum_{k \in S}(\lambda_k Z_n)} \qquad (7)$$

When examining the number of segments, the literature does not indicate a definite approach in selecting the correct number (Scarpa and Thiene, 2005; Greene, 2012). The standard specification tests used for maximum likelihood models appear to be inadequate (Greene, 2012) and therefore, other information criteria, such as the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC*)*, are suggested as well as the judgement of the researcher on the interpretation of the findings (Scarpa and Thiene, 2005).

Attribute Non-Attendance (ANA)

Hensher et al. (2005) discuss that respondents may not always use all attributes when making their decision in choosing an alternative; some may, intentionally or not, be ignored. According to Mariel et al. (2013) respondents do not use all attributes when making their decision and if this information is not taken into account the estimate of their willingness to pay could be influenced. Campbell et al. (2008) explain that by using de-briefing questions this 'Attribute Non-Attendance' can be identified and this was also done in the present study.

Cost-Benefit Analysis (CBA)

A variety of methods exist for studying the feasibility of investments in public sectors such as public roads, airports and water/air quality. Among these methods, cost-benefit analysis has played the most prominent role. In the present study three discounted cash flow rules are used; Net Present Value (NPV), Internal Rate of Return (IRR), and B/C ratio (B/C) as shown in Table 4 below.

Table 4. *Decision rules for CBA*

Net Present Value (NPV)	$\mathrm{NPV} = \sum_{t=1}^{T} \frac{E(NB_t)}{(1+r)^t} - I_0$ $NB_t = B_t - C_t$ (the flow of net benefits in time t period)
B/C ratio (B/C)	$\frac{B}{C}\ \mathrm{ratio} = \sum_{t-0}^{T} B_t/(1+r)^t \Big/ \sum_{t=0}^{T} C_t/(1+r)^t$
Internal Rate of Return (IRR)	$\sum_{t=0}^{T} \frac{B_t}{(1+IRR)^t} = \sum_{t=0}^{T} \frac{C_t}{(1+IRR)^t}$

Note. r; discount rate, T; life-cycle of the project, I_0; initial investment cost.

To calculate the discounted cash flow, it is necessary to have information on the future costs (C_t) and benefits (B_t). Estimates of business incomes and costs over the project life are used as substitute variables in private business. If the NPV is greater than zero for the project, then the project can be accepted. IRR is the discount rate that makes NPV equal to zero and evaluates the feasibility of a project by calculating the minimum required rate of return in terms of opportunity cost. If the IRR of a project is greater than the opportunity cost, the project can be accepted. Finally, the B/C ratio is the reaction of total discounted benefits to costs. To account for risk and uncertainty, various sensitivity analysis are performed in the present study. Different life cycles of the project, various discount rates and cost increase scenarios are considered in order to assess the robustness of the results.

Survey Design and Data Collection

Choice Experiment Design

We develop choice sets described by bundles of attribute values associated with drinking water quality. The basic three alternatives that the consumers are faced with are the two advanced filtering systems (GAC and Ozone) and the Status Quo. Rapid sand filtration waterworks is the main process for purifying water in S. Korea (74.2 % of water processing: Ministry of Environment of Korea, 2014), and will be considered as the Status Quo option in what follows. It is synonymous to the 'no option' alternative in other surveys.

Before designing the choice sets, a set of attributes found in the literature to affect the choice of drinking water was developed. The list of the 5 attributes (safety, taste, odour, colour and price) and the levels chosen for the analysis are presented in the Appendix (part A of the survey) as they were communicated to the consumer. The attributes were also chosen based on a survey performed by the Ministry of Environment for South Korea in 2013 on the main reasons why Korean people are not satisfied with drinking water quality. Cho (2007) remarks that one risk factor (among others) is that chlorine disinfection is unable to remove are trihalomethanes. As a high concentration of trihalomethanes is related to cancer risk (Mitchell & Carson, 1986, Eom, 2008). Cho (2007) analysed the relationship between the three types of treatment systems and the levels of trihalomethanes and found that status quo (of 0.1 mg/l) is associated with a cancer risk of 40 per ten million, whereas GAC and GAC plus ozone is associated with a risk of six and one per ten million respectively.

In this analysis, cancer risk is used for depicting the three levels of the safety attribute. The first level is 40 people per 10 million.

As previously discussed, pollution (particularly in the form of blue-green algae) gives rise to unpleasant taste and odour in water. The propose water treatement can influence this, and thus improve water taste and odour. Pirbazari et al. (1993), Ho et al. (2004), Cho (2007) and Korea-Water (2015) demonstrate that moving from the status quo to GAC reduces pollution and increases satisfaction with water from 10 % to 90 % happiness; moving from GAC to GAC plus ozone increases satisfaction to 99.9%.

The colour of drinking water is linked to the concept of True Colour Unit (TCU)[3]. The current standard for the colour of drinking water in S. Korea is five TCU. Tap Water Public Relations Association, S.

[3] One TCU corresponds to the amount of colour exhibited under the specified test conditions by a standard solution containing one milligram of platinum per litre.

Korea (2013) reported that 7 % of people complained about the colour of drinking water in S. Korea. Thus, it could be conservatively assumed that 10 % of people were likely unsatisfied with the colour of drinking water. It is also reported that the GAC can reduce the colour of drinking water to less than 4 TCU and the GAC + Ozone can usually remove the colour of drinking water to less than 3 TCU (Choi, 2007). Bean (1962) reported that the 3 TCU level of drinking water colour is the human detection limit. Therefore, it is assumed that the GAC + Ozone is linked to a cautious satisfaction level of 99.9 %. In the case of the level of 4 TCU, it was assumed that 99 % of people would be satisfied with the colour because its level is very close to the human detection limit.

Data / Survey Instrument

The survey was conducted in July/August, 2015 in Cheongju/S.Korea by three professional companies using both 'face-to-face-interviews' and 'online surveys'.[4] As hypothetical bias is the strongest criticism brought to stated preferences techniques, the present choice experiment contained three different hypothetical bias treatments: Cheap Talk, Budget Constraint Reminder and Honesty Priming.

In total, 573 questionnaires were obtained with 68 cases in which the respondents replied incorrectly to the debriefing question.[5] A further 98 cases were excluded because they chose the same alternatives in the eight choice cards and therefore it is deemed that sufficient attention may not have been given. Another case was excluded because it was an outlier with respect to the average monthly water bill: KRW 150,000 compared to the sample average of KRW 11,570. Therefore, 406 responses were used in the further analysis. This number of observations should be approximatively representative according to Thompson (1987).

The survey consisted of five parts. The first part (A) described the hypothetical scenario, the choice experiment, the attributes and their levels and gave an example of a choice card with explanations of the options available. The second part (B) introduced the hypothetical bias treatments. The third part (C) performed the choice experiment with the 8 choice cards presented to the respondents. The fourth part (D) included three types of debriefing questions and one scale consisting of seven questions related to attitudes towards improvement of drinking water quality. The answers were ranked on a Likert type scale from 1 ('Strongly Disagree') to 7 ('Strongly Agree'). The first type of debriefing questions asked the respondents about which attributes they might have ignored while making their choices. The second type of debriefing questions asked the respondents to rank the attributes according to their importance. The third type of debriefing questions aimed at determining the validity of the choices as described

[4] Unfortunately, it wasn't possible to analyse the impact of the survey method on hypothetical bias due to collinearity between the survey methods with the hypothetical bias dummies.

[5] Debriefing questions asked respondents to choose the pictures that they cannot see among the 10 pictures on the choice cards. If respondents chose pictures that were on the choice cards, they were deemed to not be concentrating enough on the choice experiment and were eliminated from the sample.

above.[6] The fifth and last part (E) of the questionnaire included the usual questions about socio-economic characteristics but also questions regarding alternatives to tap water, monthly water consumption and water bill. The socio-economic characteristics were used in order to determine the representativeness of the sample.

Demographic information demonstrates that the sample was in line with that of the population with respect to the proportion of male participants (0.518 compared with 0.515 in the population), age (40.4 compared with 41.0), household income (4.4 KRW million compared with 4.3) and water bill (11,820 KRV compared with 11,429); the sample was slightly better educated with 14.7 years of schooling compared with 13.3 in the population. Further, the average family size is 3.46, which is larger than the average family size of the population, 2.51. The family size of the sample might cause a bias of underestimation because many empirical studies have reported that family size negatively influences the stated willingness to pay (Ahlheim et al. 2004, Chambers et al. 1998).

Empirical Results

Benefits

As described in the methodology section, the data will be analysed using random parameter logit and latent class attribute non-attendance models.

RPL

Four issues related to the RPL estimations need to be mentioned: first, utility functions can use alternative specific constants (ASCs) to reflect the average effect on utility of all factors not included in the model. We will report ASCs related to each alternative. Second, when using RPL models, it is necessary to specify the distributions of the coefficients of the attributes. In this analysis we use the normal distribution for safety, taste & odour and colour and keep the coefficient of the cost variable as a fixed parameter for convenience of simulation and interpretation of the results (King et al., 2016; Meijer and Rouwendal, 2006; Revelt and Train, 1998). Third, when analysing RPL models, it is important to look into the significance of the standard deviation of the random parameters. As discussed in the methodology section, RPL assume that the representative utility has a parameter vector that has its own distribution and estimate the mean parameters and their density by maximising the probability function. By this, RPLs can provide an individual parameter for each respondent and can accommodate the assumption that each individual has a different preference.[7] If the standard deviation is significantly different from zero, the random parameters have significant variations which means that the respondents have different marginal utilities for the attributes. Fourth, we include hypothetical bias dummies in two

[6] A homogeneity test (Greene 2012) showed that the homogeneity between the 68 respondents that answered wrongly the debriefing questions and the rest of the sample could be rejected at 1% level of significance.
[7] The number of initiations of the random draws is 1,000 (Bhat, 2001).

different ways: RPL1 uses them as alternative specific constants[8] and RPL2 uses them as interaction terms with the price. The hypothetical bias dummies used are: D_{both} represents block 1 which uses both cheap talk with budget constraint reminder and honesty priming for reducing the hypothetical bias; D_{cheap} stands for block 2 using cheap talk and budget constraints reminder; and D_{honest} for block 3 using the honesty priming task. Block 4 works as the base group, as all dummy variables are zero. If people have a hypothetical bias of overstatement and the treatments for mitigating hypothetical bias are effective, the coefficients of the dummy variables will be negative. If the coefficients of dummies are negative and significant, the size of the cost coefficient as a denominator will increase so the MWTP will decrease and the hypothetical bias treatment can be considered to have been effective.

Table 5 shows the estimation results of the RPL1 and RPL2 models. In RPL1, the coefficients of the three attributes (safety, taste and odour, cost) are significant at the 99% significance level but the coefficient of colour is insignificant. This result implies that colour is the attribute for which people's average preference is near zero. As expected, the signs for safety and cost are negative (safety is measured by the number of people associated with cancer risk and, the lower the number the higher the safety), and the one of taste and odour is positive. The three coefficients of the standard deviations are significant at the 99% significance level suggesting that each respondent has a different preference with respect to the three attributes.

Regarding the socio-economic factors, the ASCs are chosen when their coefficients are significant at least in one option at the 95% significance level. The coefficients of 'elderly', 'bill' and 'environ' are significant. 'Elderly' has a negative coefficient suggesting that respondent living with elderly people in the household prefer the status quo. The positive coefficients of 'bill' and 'environ' suggest that people that consume more water and have higher water bills and people that have a positive attitude towards environmental measures related to water quality, prefer the advanced water treatment systems as compared to the status quo.[9] The coefficients of the three dummies of hypothetical bias treatments ($D_{both} \cdot x4$, $D_{cheap} \cdot x4$, $D_{honest} \cdot x4$) are negative and significant at the 99% significance level in the two advanced options, suggesting that all treatments of hypothetical bias were successful in reducing hypothetical bias resulted from overestimation. RPL2 uses interaction terms of hypothetical bias treatments with the price. The coefficients of the four attribute variables show the expected direction and are significant at the 99% significance level, but the one for colour is insignificant, similarly to RPL1. All three random parameters show significant coefficients for standard deviations at the 99% significance level, which implies that the three random parameters have significant variations.

Table 5. *Estimations of RPL 1 and RPL 2*

[8] In which case $\theta_m D_m$ are not multiplied with X_p.

[9] 'envion' measures the sum of the scale values of the preference for water-environment friendly policy contained at the end of in part D of the survey.

Variable	RPL 1	RPL 2
x1 (safety; cancer risk)	-0.0563 (0.0000)	-0.0437 (0.0000)
S.D of coefficient of x1	0.0419 (0.0000)	0.0613 (0.0000)
x2 (Taste and odour)	0.0089 (0.0000)	0.0087 (0.0000)
S.D of coefficient of x2	0.0219 (0.0000)	0.0220 (0.0000)
x3 (Colour)	0.0174 (0.2118)	0.0058 (0.6541)
S.D of coefficient of x3	0.1675 (0.0000)	0.1667 (0.0000)
x4 (Cost/Price)	-1.0791 (0.0000)	-0.6511 (0.0000)
$D_{both} \cdot x4$	-	-0.2343 (0.0145)
$D_{cheap} \cdot x4$	-	-0.2730 (0.0027)
$D_{honest} \cdot x4$	-	-0.6582 (0.0000)
ASC Of Ozone	-1.1352 (0.1927)	-2.2388 (0.0092)
Elderly	-0.6303 (0.0224)	-0.6712 (0.0111)
Bill	0.0385 (0.0185)	0.0397 (0.0096)
Environ	0.6553 (0.0000)	0.6113 (0.0000)
Fulltime		-0.4936 (0.0488)
D_{both}	-2.1771 (0.0000)	-
D_{cheap}	-1.8695 (0.0000)	-
D_{honest}	-2.5258 (0.0000)	-
ASC Of GAC	1.7204 (0.0053)	0.5395 (0.3684)
Elderly	-0.5236 (0.0075)	-0.4764 (0.0112)
Bill	0.0137 (0.2999)	0.0138 (0.2414)
Environ	0.2205 (0.0292)	0.2241 (0.0277)
Fulltime	-	-0.4086 (0.0273)
D_{both}	-1.1580 (0.0000)	-
D_{cheap}	-2.2261 (0.0000)	-
D_{honest}	-1.6462 (0.0000)	-
Sample size	406	406
Log Likelihood	-2655.96	-2692.9
AIC	5353.9	5425.8
BIC	5438.1	5487.9
Pseudo R^2_{adj}	0.2533	0.2430

Note. The values in the parenthesis represent P-values, and S.D stands for Standard Deviation.

The coefficients of the interaction terms of the hypothetical bias treatments are negative and significant at the 99% significance level, which suggests that the hypothetical bias treatments reduce the willingness to pay for improvement of the attributes. Among them, the coefficient of $D_{honest} \cdot x4$ has the largest value suggesting that honesty priming has been most successful in reducing hypothetical bias.

RPL2 uses four socio-economic factors: ‘elderly’, ‘fulltime’, ‘bill’ and ‘environ’. The coefficient of ‘fulltime’ is significant at the 95% significance level and negative suggesting those respondents with a full-time jobs prefer the status quo. The coefficient of the water bill variable is significant at the 95% significance level and positive only for the Ozone plus GAC option. This result suggests that people who consume more drinking water are likely to prefer this option. RPL1 shows lower log-likelihood AIC, BIC, and a higher pseudo R^2 than the RPL2, suggesting a better fit.

LCM-ANA

As mentioned in the methodology section, we estimate the latent class models controlling for attributes that were not attended with the help of attribute non-attendance (ANA) estimation. ANA can be an issue in CE where consumers are faced with a large number of choices within a short period of time (Mariel et al., 2013).

In the present study we do not impose a specific attribute non-attendance structure. We estimate latent class models and then set the attributes that are ignored there equal to zero in the LCM-ANA specification. For this, full attribute attendance (FAA) latent class models were estimated first. As discussed in the methodology section, BIC values are used for choosing the optimal number of classes. The optimal number of classes for the model using HB as ASCs is 5 and 4 for the model using HB as interaction terms. Results for ANA1 are presented in Table 6.

Table 6. *Estimation of the coefficients of the ANA1 model*

variable	Class 1	Class 2	Class 3	Class 4	Class 5
x1 (safety)	-0.0115 (0.1685)	-0.0787 (0.0000)	-0.0315 (0.0000)	-0.0992 (0.0000)	-0.0659 (0.0000)
x2 (t&o)	0.0227 (0.0016)	0.0 (fixed)	0.0 (fixed)	0.0091 (0.0763)	0.0249 (0.0000)
x3 (colour)	0.1635 (0.0001)	0.0 (fixed)	0.0 (fixed)	0.0 (fixed)	0.0 (fixed)
X4 (cost)	-0.4385 (0.0162)	-1.6890 (0.0000)	-1.85815 (0.0000)	-0.4291 (0.0084)	-1.2237 (0.0000)
of Ozone, one	3.9368 (0.4143)	-10.3007 (0.0001)	-18.6362 (0.2240)	1.6704 (0.5182)	-2.4698 (0.0445)
Elderly	-1.5635 (0.1843)	-0.8538 (0.1485)	-5.6905 (0.9938)	8.1582 (0.9840)	-0.1390 (0.7508)
Bill	-0.0546 (0.3322)	-0.1164 (0.0432)	0.3009 (0.0442)	0.1269 (0.0093)	0.0249 (0.2348)
Environ	0.0982 (0.8803)	2.6911 (0.0000)	2.4889 (0.2331)	0.0109 (0.9686)	0.7965 (0.0003)
D_{both}	-3.6684 (0.0472)	-4.2468 (0.0000)	-8.6509 (0.9438)	-1.9746 (0.2125)	-1.6949 (0.0136)
D_{cheap}	4.3111 (0.9981)	-2.1275 (0.0303)	-8.3258 (0.9792)	-5.2732 (0.0014)	-1.0262 (0.1561)
D_{honest}	5.2144 (0.9988)	-4.4826 (0.0000)	0.0695 (0.9661)	-4.9345 (0.0023)	-2.6401 (0.0000)

of GAC, one	4.5498 (0.3429)	-0.9715 (0.5377)	2.6276 (0.0002)	2.5140 (0.3604)	-0.6299 (0.6164)
Elderly	-0.4004 (0.7747)	-1.4895 (0.0001)	-0.5352 (0.0751)	8.0302 (0.9842)	-0.5649 (0.0825)
Bill	-0.0086 (0.8787)	-0.1341 (0.0018)	0.1134 (0.0000)	0.1071 (0.0359)	-0.0386 (0.1066)
Environ	-0.2475 (0.7083)	1.1416 (0.0000)	-0.2641 (0.0455)	-0.0863 (0.7796)	0.8243 (0.0003)
D_{both}	-1.8130 (0.3076)	-3.5534 (0.0000)	-0.6633 (0.0817)	-1.7025 (0.2631)	-1.3913 (0.0233)
D_{cheap}	4.7046 (0.9979)	-2.2884 (0.0000)	-1.4024 (0.0000)	-5.6954 (0.0005)	-1.8048 (0.0091)
D_{honest}	6.8215 (0.9984)	-3.1666 (0.0000)	0.2009 (0.6191)	-4.5187 (0.0051)	-3.1014 (0.0000)
Class probability	0.185 (0.0000)	0.167 (0.0000)	0.220 (0.0000)	0.181 (0.0000)	0.247 (0.0000)
Sample size; 406, Log-likelihood; -2439.1, AIC; 5054.2, BIC; 5406.7, Pseudo-R^2 ; 0.3071					

Note: The values in the parenthesis represent P-values.

Class 1 seems to ignore the safety attribute as its coefficient is insignificant; otherwise, in all other estimations of classes, providing an attribute was deemed important, it was estimated to be statistically significantly so, with the expected sign. The sample size of Class 1 is estimated at 75.[10] Safety seems to be less important in Class 3 compared to Class 2 as the coefficient s only half as large. In Class 4 the of taste and odour is significant only at 10% suggesting that members of this class care less about this attribute than for safety and costs. Class 5 is the largest, consisting of 25% of the sample. With respect to the socio-economic variables, the estimates are in line with those from the RPL specification, with corresponding intuition.

To summarize, the coefficient of the safety attribute is significant in all classes except Class 1. This result implies that about 80% of the respondents would want to pay to improve the safety attribute in drinking water quality. The respondents included in Classes 1, 4 and 5 (60% of respondents) seem to have the willingness to pay (WTP) to improve the taste and odour attribute because the coefficient of this attribute is significant in their classes. The coefficient of the colour attribute is significant only in Class 1 (18.5% of the respondents), while the coefficient of the cost/price is negative and significant in all classes.

Results of using the interaction term between the HB dummies and the price coefficient (ANA2) are similar to the ones above and are presented in the Appendix in order to save space.

Willingness to pay

In what follows the WTPs will be presented and discussed per attribute. When applying ANA, the MWTP of each class is weighted by the individual specific probabilities of class membership in order

[10] 75 = 406 x 0.185, where 0.185 is the class probability.

to compute individual MWTPs. The mean and median values of the individual MWTPs, are then calculated. Table 7 presents these per attribute and model.

Table 7. *Estimation of the* ***mean and median*** *MWTPs*

	***Mean** MWTP*				***Median** MWTP*			
Model	RPL 1	RPL 2	ANA 1	ANA 2	RPL 1	RPL 2	ANA 1	ANA 2
Safety	0.0523	0.0491	0.0666	0.0974	0.0510	0.0434	0.0468	0.0396
Taste and odour	0.0082	0.0146	0.0146	0.0217	0.0090	0.0100	0.0063	0.0177
Colour	0.0171	0.0048	0.0690	0.0284	0.0017	0.0000	0.0000	0.0020

Note. Measured in KRW thousand.

As shown in Table 7, ANA2 shows the largest mean MWTPs of all three attributes. The largest mean and median MWTPs are for the safety attribute and the lowest for the colour attribute, as expected. Interestingly, the mean MWTPs for taste and odour are smaller than those for colour in RPL1, ANA1 and ANA2. However, the median values are always the smallest for the colour attribute. Median values are always smaller than mean values.

Estimation of Benefit

Willingness to Pay per Household

The WTP per household can be calculated for each attribute and each alternative *j*, by multiplying the improvement of each attributes with the willingness to pay for a one unit improvement. Table 8 shows the comparison of the benefits from the MWTP estimates from the 4 different models.

Table 8. *Benefits from the four models*

KRW		RPL 1	RPL 2	ANA 1	ANA 2
GAC	Mean	3.206	3.270	4.056	5.370
	Median	2.467	2.274	**2.094**	2.781
Ozone + GAC	Mean	3.633	3.703	4.596	6.035
	Median	2.813	2.589	**2.391**	3.156

As shown in Table 8, all benefits using the median MWTPs are lower than those obtained for the mean MWTPs. The median MWTPs of the ANA1 model are always lower than for the other models. Therefore, the ANA1 model can be used as a lower bound. Furthermore, the benefits of all models can be used for sensitivity analysis.

Social Benefits

In order to estimate the total benefit of improving drinking water quality, it is necessary to know the population and the number of households served by the waterworks. In 2009, the number of people served by the waterworks was reported as 511,451 (Ministry of Environment, South Korea, 2010). Unfortunately, there are no recent numbers about the people served; however, given the fact that the population has constantly increased while the consumption per capita has remained relatively constant, it is reasonable to assume that 511,451 constitutes a lower bound for benefits estimation. The average family size per household is reported as 2.6 (Cheongju City, 2015). Therefore, the number of households served is estimated to be 196,712 (511,451/2.6).

The social benefits are calculated by multiplying the number of households served by the waterworks (196,712) with the WTPs per household. Table 9 shows the monthly and annual benefits for the two alternatives (GAC and Ozone +GAC) from the four models. The numbers in parentheses are the benefits expressed in US thousand Dollars based on the exchange rate of 1177.5 from 31/12/2015.

Table 9. *Monthly and Annual Social Benefits*

	Monthly				Annual			
KRW million (USD thousand)	RPL 1	RPL 2	ANA 1	ANA 2	RPL 1	RPL 2	ANA 1	ANA 2
GAC	485 (412)	447 (380)	412 (350)	547 (465)	5,823 (5,026)	5,368 (4,558)	4,944 (4,199)	6,565 (5,575)
Ozone + GAC	553 (470)	509 (433)	470 (399)	621 (527)	6,744 (5,724)	6,111 (5,190)	5,643 (4,793)	7,451 (6,327)

Note. USD 1 = KRW 1177.5, based on the exchange rate of 31/12/2015.

The monthly benefits from the GAC option are estimated to be between USD 350 and 465 thousand (KRW 412 - 547 million), and from the Ozone plus GAC option between USD 399 and 527 thousand (KRW 470 – 621). The total annual benefits from the GAC method are estimated to be between USD 4,199 and 5,575 thousand (KRW 4,944 - 6,565 million), and the one from the Ozone plus GAC treatment from USD 4,793-6,327 thousand (KRW 5,643 - 7,451 million) using the median MWTPs of the four models.

Cost Estimation

Several stages are involved in launching a new water treatment system including investigating, designing, contracting, building, and then maintenance and operation. In South Korea, all waterworks are owned and operated by the national or local governments. Therefore, projects on the waterworks often follow a public process. The cost of designing a project must be used in the bidding process. Usually, the cost of designing is set as an upper bound of the contract process. Every bidder has to bid the lowest price possible for competition. Therefore, most bids by governments in South Korea usually succeed with a lower price than the designed cost proposed by the governments. Design requires a significant expenditure. Legal investigation of the feasibility for a public project is usually implemented in the stage of basic design. Usually, the bidder suggesting the lowest price wins the contract. The remaining phases are construction and operation. As a result, it is not necessary to actually spend costs for design drawing until the feasibility has been demonstrated. Therefore, a preliminary cost is used to investigate the feasibility in this research.

Construction Period

Table 10. *Summary of three projects installing Ozone plus GAC treatment systems*

Waterworks	Project term (month)	Capacity (m^3/day)	Project cost (KRW million)
Seongnam	02/2008 – 12/2011 (47)	630,000	52,723
Deokso	07/2012 – 05/2015 (35)	450,000	25,800
Goyang	06/2005 – 06/2009 (38)	210,000	17,951

Note. The source is from Korea-Water.

The three projects showed in Table 10 above are similar to the present one and show project terms between 35 and 47 months. It is reasonable to assume the project term of four years (48 months). This estimate is close to that of the Seongnam waterworks, for which we use to allocate the distribution of costs across the four years; therefore, it is assumed that the construction costs are spent at the rate of 10 % in year 2 and 30 % from year 3 through 5 (in line with the Seongam facility). Designing the project is assumed to be conducted in Year 1. Improved water is assumed to be provided to customers in the last year of construction, because a trial test usually is run in that year. Therefore, the operating period start in the fifth year, after the construction. It is also necessary to estimate the time and cost for design drawing in practice. In this research, the length of design drawing is set at up to one year, and the cost of design drawing is estimated according to the standard cost of business engineering of the Korean government (Ministry of Land, Infrastructure, and Transport, 2013). A one-year delay in construction is a more cautious approach for sensitivity analysis although those cases hardly ever occur.

Project Service Life

Each project has a business life, a significant factor in assessing its feasibility. Most business projects require large initial expenditure, and the returns follow later. As a result, the amount of the return usually increases according to the business life. The project service life of advanced water treatment systems is typically set at 20 years according to the Enforcement Regulation of Local Public Enterprises Act, 2014 of South Korea. This period can be used as an institutional business life of the water treatment systems.

The service life of ozonization equipment is between 15 and 20 years, and that of a reinforced concrete structure is from 40 to 50 years. Thus, setting for the project service life at 20 years is an acceptable approach for assessing the feasibility of the advanced systems.

Design Cost

The Korean government suggests standards for the cost of business engineering. This ranges from 5.42% to 5.93% of total construction cost, depending on the size of the project, and this is itemised for the costs of basic design (between 1.38% and 1.51%), working design (2.76% and 3.01%) and construction supervision (1.28% and 1.141%).

When conducting the basic design in South Korea, the feasibility of public projects is usually investigated. Thus, the investigating costs can be included in the cost of the basic design.

Construction Costs

In 2008, the Office of Waterworks of Seoul Metropolitan Government examined the unit cost of constructing two advanced treatment systems in South Korea and published the data for reference and precedent. Table 11 shows the unit cost.

Table 11. *Unit cost of constructing two advanced treatment systems*

Capacity (thousand m^3/d)	100	200	400	700	1000
Granular Activated Carbon (KRW thousand)	117.4	109.0	93.7	89.0	80.6
Ozone (KRW thousand)	32.7	30.5	27.2	25.1	21.8

Note. Seoul Metropolitan Government (2008) with authors' adjustment to represents figures in 2015 prices.

As the capacity of Cheongju Waterworks is 403,000 m^3 per day, the total construction costs for the two advanced treatment systems are calculated by applying the unit cost to the capacity of 400 thousand m^3 per day; KRW 93.7 thousand for GAC and KRW 27.2 thousand for Ozone. The sum of the costs of the two methods is KRW 48,722,700 thousand[11], therefore, the ratio of basic design costs is 1.41%, the ratio of working design cost is 2.84% and the ratio of construction supervision is 1.33% as per the Korean government (discussed above). Table 12 shows the total costs including the estimation of design costs and construction supervision costs.

Table 12. *Estimation of costs of design and construction supervision*

[11] 27.2+93.7=120.9, 120.9*403=48,722.7

KRW thousand	Sum	Basic design	Working design	Construction supervision	Construction
GAC	39,868,162	532,432	1,072,415	502,223	37,761,100
Ozone	11,573,257	154,559	311,309	145,789	10,961,600
Sum	51,441,419	686,991	1,383,724	648,012	48,722,700

Operating Costs

Similar to the case of construction costs, operating costs are estimated using the unit cost of operating the two advanced treatment systems. Lee et al. (2008) report the unit operating cost per m^3 of the two advanced treatment systems according to five waterworks capacities in 2008. In addition, the actual unit costs of operating ozonization and GAC facilities of two waterworks of Korea-Water are explored. Table 13 shows the unit operating costs of operating the two advanced treatment systems in seven waterworks in South Korea.

Table 13. *Unit costs of operating two advanced treatment systems*

Supply of water (thousand m^3 per day)	30	100	210*	243*	300	600	800
GAC (KRW thousand/ m^3)	5.9	5.9	2.6	5.0	5.9	5.9	5.9
Ozone (KRW thousand/ m^3)	2.1	1.9	1.4	1.7	1.7	1.6	1.5

Note. Lee, K-H et al., (2008) and * means the estimation of the unit costs of two waterworks of Korea-Water.

We use the upper bound from Table 34, which when converted in 2015 prices provides a unit cost of 6.42 and 1.852 for GAC and ozone respectively; at estimated annual usage, total costs are therefore 451,464 (KRV thousand) and 40,982 (KRV thousand), respectively.

Cost Flows

Table 14 shows the cost flows including several types of costs such as investigating, designing, construction, supervision, and operating and maintenance for the two advanced water treatment systems. For the costs between years 2 and 5, we allocated the total construction cost according to the Seongnam project, as discussed above.

Table 14. *Cost flows for the two advanced water treatment systems*

System	year 1	year 2	year 3	year 4	year 5	year 6	⋯	year 24

GAC	1,605	3,776	11,479	11,479	11,930	451	451	451
Ozone	466	1,096	3,332	3,332	3,332	41	41	41

Note. The price unit is KRW million.

If the project service is set to 10 years, the operating period would be counted between year 5 and year 14. As a result, the benefit of improved drinking tap water can be calculated over the same period of the project service length because the drinking tap water treated by the newly installed ozone and (or) GAC systems will be supplied between the fifth year and the last year (i.e. 14th or 24th year). These types of assumptions for the period play important roles in sensitivity analysis.

Cost-Benefit Analysis (CBA)

CBA is defined as a procedure for aggregating the monetary values of the gains and losses for individuals and expressing them as a net social gain or loss (Pearce, 1983). The assumptions made are summarized in Table 15, all of which are discussed above.

In addition to these assumptions, we consider the extent to which people will benefit from improve water quality. Jo et al. (2015) investigated the proportion of people who will change their source of drinking water, for example, from bottled water, in-line filter, and spring to drinking tap water in S .Korea. They report that 84.3% of their respondents answered positively to the question: "Will you drink tap water when the quality of drinking tap water is improved?" Thus, 15.7% of people answered that they would not change their behaviours regarding drinking tap water even if the quality of drinking tap water is improved. In this case, the respondents would have zero willingness to pay to improve the quality of drinking tap water. To mitigate the effect of this group who is unwilling to pay, 15.7% of people will be excluded in measuring the social benefits of improving drinking water quality.

Table 15. *Summary of basic assumptions for CBA*

Factor		Range
Business life (years)		10 – **20**
Social discount rate (%/year)		**1** – 10
Benefit	MWTP of safety (KRW 1000)	0.0365, 0.0465 – **0.0468**
	MWTP of taste and odour (KRW 1000)	0.0063, 0.0060 – **0.0066**
	Advantaged household	165,828 - **196,712**
Construction period (years)		4-**6**
Construction cost (KRW per m^3/day)		**127,645** – 153,425

Note. The bold figures provide the upper bounds of the CBA values; B/C, NPV, IRR.

Present Values of the Cash Flows

To implement CBA, it is necessary to establish the cash flows for the costs and benefits of improving the drinking water quality. Next, the three types of decision rules are calculated to test the feasibility.

Benefit Flow

Table 16 summarizes the total monthly benefit for the two methods for improving drinking water quality within the target area estimated using ANA1.

Table 16. *Social Benefits of improving drinking tap water quality*

KRW million (USD thousand)	GAC	Ozone plus GAC
Monthly Social Benefit	412 (350)	470 (399)
Annual Social Benefit	4,943 (4,198)	5,644 (4,793)

Note. USD 1 = KRW 1177.5, based on the exchange rate of 31/12/2015. 4,943=412 x 12.

The total annual social benefit from the GAC method for improving drinking water quality is estimated as KRW 4,943 million, and the annual social benefit from the ozone plus GAC treatment is KRW 5,644 million, using the median MWTPs.

Table 17 shows the results of CBA of the two alternatives when using the whole data set to calculate the social benefits.

Table 17. *Cost-Benefit Analysis of the two alternatives*

KRW million	Present Cost	Present Benefit	NPV	B/C ratio	IRR
GAC	40,556	56,344	15,788	1.389	8.97 %
Ozone + GAC	51,269	64,336	13,067	1.225	7.46 %

The NPVs of the two alternatives are larger than zero, but this is a necessary and not sufficient condition of investment. . If a discount rate of 8.97% and 7.46% applies to the GAC and GAC plus ozone alternative respectively, then its NPV would be zero and the B/C ratio would be one. The B/C ratio is recommended as the best decision-making tool (Pearce, 1983); by this measure, GAC (1.389) is preferred to GAC plus ozone (1.225).

Sensitivity Analysis

There is risk and uncertainty in forecasting future figures. Four categories of scenarios will be used. The first is related to the risk premium approach, which adds a premium to the chosen social discount rate of 4.5%. The second concerns the business life, which drops from 20 years to 10. The third increases construction costs increase by 20%, which is the percentage from comparing the largest unit construction cost among the previous eight projects with the unit cost of the standard. The last category contains several scenarios that manipulate the benefits.

Summary of Sensitivity Analysis

Table 18 summarises the various sensitivity analysis scenarios. Increasing the social discount factor to 10%, decreasing the useful life of the project, and significantly cutting the estimated benefits can make the alternative investments unfeasible; however, as outlined above, these are all extreme outliers. Further, where possible benchmark assumption have been conservative.

Table 18. *Outline of the Sensitivity Analysis*

Scenario	B/C		NPV (KRW million)		IRR (%)	
	GAC	Ozone + GAC	GAC	Ozone + GAC	GAC	Ozone + GAC
Basic	1.389	1.225	15,788	13,067	8.97	7.46
Discount rate increases (4.5 -> 10 %)	0.933	0.838	-2,257	-7,002	8.97	7.46
Business life reduces (20 -> 10 years)	0.889	0.798	-4,268	-9,937	2.12	0.06
Benefits decline to zero	0.800	0.723	-8,099	-14,208	0.23	-1.11
Benefits during 10 years	1.012	0.909	479	-4,493	4.72	2.83
Benefit with lower bound MWTPs	1.149	1.037	6,053	1,886	6.32	4.95
Exclusion of household without Benefit	1.171	1.058	6,942	2,966	6.57	5.21
Cost increase (20 %)	1.181	1.064	8,630	3,852	6.64	5.26
One year delay of construction	1.362	1.234	14,324	11,666	8.31	7.04

Conclusions and Policy Recommendations

This study was triggered by the fact that many Koreans are dissatisfied with drinking water quality. Most rivers as the main water resources, have been polluted since the fast industrialization in South Korea. As a result, most waterworks at present have not handled problems like unpleasant taste and odour of drinking tap water. The Korean government has planned to improve water quality to resolve the issue. Installing advanced water treatment systems has been a primary solution. This research focuses on testing how far an investment in a chosen advanced water treatment system is feasible.

The present study uses choice experiments in order to assess the benefits from installing the two advanced water treatments systems in the target area and then performs a cost-benefit analysis to assess the feasibility of the project. To our knowledge, no other study has performed this type of analysis for South Korea, a developed country with historically polluted water supply. The study employs three different treatments against hypothetical bias (cheap talk, budget constraint reminder and honesty priming) and finds that these are effective in reducing hypothetical bias. The estimation of the benefit is done using random parameter logit models and attribute non-attendance latent class models. This allows for random taste variation among the individuals and that some attributes of drinking water are ignored. Moreover, it allows to group individuals in latent classes and to determine which attributes are most valued by specific groups of respondents. The most important attribute to consumers was water safety, whereas colour was not an issue for respondents; 50-60% of respondents are willing to pay in order to improve the taste and the odour of potable water. The average WTP for installing the granular activated carbon treatment is between USD 1.78 and 4.56 and for additionally installing an ozone purification system is USD 2.03-5.13 per month. These values are comparable with results obtained in previous studies and with the average amount spend for bottled water per month by South Koreans. For the cost-benefit analysis median values have been used as more conservative values.

Under the conservative assumptions of a construction period of 5 years, a social discount rate of 4.5% and a business life between 15-20 years the feasibility of the project is given and the investments in both alternatives appear to be beneficial to the residents of Cheongju. The feasibility is maintained if the construction period is increased by one year, the social discount rate increases to 7%, a premium of 20% is added to the costs, and if the number of people benefitting from the improvement is reduced by 15.7%. If the business life falls below 12 years, the discount rate increases above 7.4%, the costs by more than 44% and the benefits gradually decrease to zero during the business life, the feasibility of the project is rejected. Throughout the various sensitivity analyses the granular activated carbon (GAC) was the more robust treatment showing higher benefit/cost ratios, net present values and internal rate of returns.

The analyses in this study focused on a short-term solution. Installing more advanced water treatment systems is dealing with the effects of pollution and not its causes. If these shall not be addressed, eventually, the water quality would worsen to a point, where it is not possible to treat it anymore. Improving raw water quality in the catchment, and preventing water pollution in the basin should therefore be the priority of policy prospects for the future.

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