Improving drinking water quality in S. Korea: A choice experiment with hypothetical bias treatments

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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 S. Korea is drinking untreated tap water. The present study uses choice experiments and an extensive cost-benefit analysis (CBA) to investigate the feasibility of installing two advanced water treatments in Cheongju waterworks in S. 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 uses latent class attribute non-attendance models in a choice experiment setting in order to estimate the benefits of the two water treatments. Moreover, it explores strategies to mitigate potential hypothetical bias as this has been the strongest criticism brought to stated preference methods to date. Hypothetical bias is the difference between what people state in a survey that they would willing to pay and what they would actually pay in a real situation. The study employs cheap talk with a budget constraint reminder and honesty priming with the latter showing more evidence of reducing potential hypothetical bias. This is innovative and important as hypothetical bias impedes the reliability of survey results. 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 S. Korea. These lower bounds were found using bootstrapping and simulations. The CBA shows that one of the two treatments, granular activated carbon, is more robust to sensitivity analyses. Scenarios under which the instalment of the advanced water treatments is feasible are discussed together with environmental solutions in the long-run.

***Keywords*:** Drinking Water Quality, Water Pollution, Choice Experiments, Willingness to Pay, Random Parameter and Latent Class Logit, Cost-Benefit Analysis, Hypothetical Bias Treatments, Cheap Talk, Honesty Priming, Attribute Non-Attendance

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

Introduction

Water pollution has spread as a result of industrialization 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 worldwide.

The situation is especially worrying in S. 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 S. 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

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

experiences of an earthy smell and fishy taste when drinking tap water (Um et al., 2002). At the same time annual sales of bottle water increased by 96% between 2009 and 2014, and sales of in-line filters grew by 49% during the same period of time (Database of the Korean Statistical Information Service). Moreover, this dramatic increase in sales of bottled water leads to more disposal of water bottles and exacerbates the negative effects of perception of undrinkable tap water via increased marine litter.

The present study investigates the feasibility of installing two different advanced water treatment systems in S. Korea's Guem River Basin and in the waterworks for the purpose of providing drinking water (Cheongiu). The two treatments are: granular activated carbon (GAC), and ozone plus GAC treatment. GAC is usually added to the process of filtration, and ozone treatment is coupled with the system of chlorine disinfection as an additional method to remove fine particles and to create chemical reactions in the water. These two systems are seen as an intermediary solution in the short-run however, the present study also discusses the most appropriate environmental solutions for improving long-term potable water quality. Benefits are estimated using Choice Experiments (CE) and an comprehensive Cost-benefit analysis (CBA) is used to test the feasibility of installing two advanced water treatment systems under various scenarios. The choice experiment setting is using latent class models and accounts for attribute non-attendance. Most importantly however, two different methods are used in order to reduce potential hypothetical bias: Cheap Talk and Honesty Priming. This is something innovative and necessary as hypothetical bias impedes the reliability of survey results. If people overstate for example their willingness to pay for the project then, basing the political decision purely on stated values would lead to wrong decisions. Cheap Talk is making the consumers aware of the fact that people in general tend to overstate their true WTP when related to goods such as organic products. Studies have shown that if consumers are informed about this overstatement, this will be reduced or completely eliminated (Farrell and Rabin 1996, Cummings and Taylor 1999, Aadland and Caplan 2003, Brown, Ajzen and Hrubes 2003, Carlsson et al., 2005, Landry and List 2007, Champ, Moore and Bishop 2009, Jacquemet et al. 2011, Silva et al. 2011, Tonsor and Shupp 2011, Lagerqvist and Hess 2011, Gschwandtner and Burton 2020) even though evidence is mixed. Loomis (2014) for example found that in 3 out of 7 studies that used Cheap Talk the hypothetical bias was eliminated, in 3 it was reduced and in one study it had no effect (Loomis, 2014; Table 1 page 38). In the present setting the Cheap Talk script included also a budget constraint reminder which is something that seems to enhance its efficacy. Consumers were reminded that if they spend more on a product they have less money left for other goods.[2] This type of setting has proved to be especially efficient. Recently, Penn and Hu (2019) include significant evidence that Budget/Substitute Reminders enhance Cheap Talk (CT) effectiveness. They also show that this combination of CT with a Budget Reminder is more effective for public goods and choice experiments which is also the case in the present study.[3] Even more recently, Gschwandtner and Burton (2020) show that when this setting (CT with Budget Reminder) is complemented with a Honesty Priming treatment, the willingness to pay (WTP) for organic chicken is reduced up to 46% compared to a situation where no treatment is in place.

Honesty Priming is a method borrowed from social psychology which asks consumers to complete 10 statements, using missing words. These missing words could be chosen from 2 options, a correct ('true') one (such as 'The earth is round') and a wrong one (such as 'The earth is square').[4] By this, literature has shown consumers can be induced to answer truthfully in the following choice tasks (Maxwell et al. 1999, Chartland et al. 2008, De-Magistris et al. 2013). The main reason for choosing these two methods is the fact that they have been shown to be successful in some studies despite of their simplicity. In our implementation 3 different combinations of these two methods are used as will be described later. This is something innovative and necessary that to our knowledge has not been previously done in the context of water improvement in S. Korea. Um et al. (2002) use averting

[2] For simplicity, we will refer to this method just as 'Cheap Talk'.

[3] Penn and Hu (2019) compare their results with this treatment to a hypothetical baseline rather than to a 'real' willingness to pay. They call the difference between the results with this treatment (CT and Budget Reminder) and the hypothetical baseline 'Potential Hypothetical Bias' and they show that the treatment is quite effective in managing to reduce it (by 20%).

[4] The exact wording of both the Cheap Talk Script with Budget Constraint Reminder and Honesty Priming is given in the Supplementary Material in the Appendix.

behaviour (a revealed preference technique) to estimate the WTP for drinking water safety in Pusan, the second largest city in S. Korea. The study estimates a WTP between USD 4.2 - 6.1 per month to improve the tap water quality from the current pollution level to the 'drinkable without any treatment' level. Kwak (1994) is the first study to use a stated preference technique to evaluate the WTP for a specific attribute of tap water (safety) in Seoul, the largest city in S. Korea. The study estimates a mean WTP for an automatic monitoring system and complementary emergency reservoirs of USD 3.28 per month. Yoo and Yang (2001) use a double bounded dichotomous choice contingent valuation method (CVM) to estimate the WTP for improved tap water quality in Busan/S. Korea. The authors find an average monthly WTP of USD 3.60 (KRW 5,063). Park et al. (2007) estimate the WTP for good quality tap water in S. Korea using CVM questionnaires, estimating a WTP per household between USD 1.06 and 2.70. Kwak et al. (2013) measure WTP for tap water quality improvement in Pusan using CVM. The mean WTP was estimated to be 2.2 USD per month. The study that is most closely related to the present research is by Na (2013). She conducts an ex-post CBA of an advanced water treatment system installed in 2009 in An-San City/S. Korea concluding that the investment was valid. None of the studies mentioned above however, use Choice Experiments, arguably the most advanced method for eliciting stated preferences up to date and, none of them use treatments against hypothetical bias, arguably the strongest criticism brought to stated preference methods up to now (Cummings et al., 1986; Mitchell and Carson, 1989, Murphy et al. 2005, Carson and Groves 2007).[5] Nevertheless, these studies are useful in determining the attributes of drinking water that seem to be important: taste, odour, colour, softness and safety and to provide a range of indicative values to assess the validity of the estimates in the present research.

The present results suggest that the carbon treatment (GAC) 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 analysed in an extensive CBA. Policy recommendations are given in the concluding section together with long-term solutions regarding the prevention of further water pollution in the target area. To the best of our knowledge, no other study has assessed the feasibility of such a highly necessary project before. Moreover, we do not know any other study for S. Korea combing choice experiments, arguably the most advanced stated preference method to date, with CBA to achieve a similar goal. Additionally, confidence intervals are constructed using bootstrapping and simulation in order to estimate the lower bound of the marginal willingness to pay. Most importantly however, this is the only study we know for S. Korea that uses treatments against hypothetical bias and therefore, we expect more accurate results for potential policy decisions. The issue of hypothetical bias (HB) isn't recent and several studies have document its prevalence even in the early HB correction literature (List and Gallet, 2001; Murphy et al., 2005). However, recent literature has shown that correcting for hypothetical bias in surveys is an absolute necessity (Penn and Hu, 2018; Gschwandtner and Burton 2020). The present study is, to our knowledge the first to provide WTP estimates for drinking water improvement in S. Korea aiming to correcting for hypothetical bias. It employs two mitigation strategies: cheap talk and honesty priming with the latter showing more evidence of reducing potential hypothetical bias.

Survey Design and Data Collection

The survey was conducted in July/August, 2015 in Cheongju/S.Korea by three professional companies.[6][7]

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[5] Another appropriate method would be a single dichotomous choice posed as a referendum. The appropriateness of the method is dictate by the research question and aspects of credibility. However, none of the studies mentioned above uses either a CE nor a referendum format.

[6] Focus Group and Pilot studies have preceded the survey following NOAA guidelines (https://coast.noaa.gov/data/digitalcoast/pdf/survey-design.pdf).

[7] Even though the survey was conducted 5 years ago, the methods applied are relevant today and for future studies. Moreover, the present project has served as a basis for the implementation of the treatments in S. Korea which is happening at this moment. We thank the anonymous referee that helped us to point this out.

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 4 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 S. 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 people per 10 million, whereas GAC and GAC + 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. Pollution (particularly in the form of blue-green algae) gives rise to unpleasant taste and odour in water. The proposed water treatment can influence this, and thus improve water taste and odour. Pirbazari et al. (1993), Ho et al. (2004) and Cho (2007) demonstrate that moving from the status quo to GAC reduces pollution and increases satisfaction with water from 10 % to 90 %; moving from GAC to GAC + Ozone increases satisfaction to 99.9%.

The colour of drinking water is linked to the concept of True Colour Unit (TCU)[8]. The current standard for the colour of drinking water in S. Korea is five TCU. Tap Water Public Relations Association, S. 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.

There have been no studies measuring the benefit of improving drinking water quality using choice experiments in S. Korea, so there are no indicative prices informing about the benefits from improved *attributes* of drinking water quality. However, there are some contingent valuation studies calculating the WTP for improvements in drinking water quality mentioned above (Um, et al. 2002; Park, et al. 2007; Kwak, et al. 2013 and Na 2013). We borrow our estimates for the levels of the price attribute from these. Accordingly, we set 6 levels of additional fees for the monthly water bill: 0 (Status Quo), USD 0.45 (KRW 500), USD 0.89 (KRW 1000), USD 1.79 (KRW 2000), USD 2.68 (KRW 3000) and USD 3.57 (KRW 4000). The way in which the price profiles were related to the alternatives is explained in detail in Appendix 2.

In this research, three options (status quo, GAC, GAC + Ozone) and four attributes (safety, taste & odour, colour, and cost) are considered. Three attributes have three levels, and cost has six levels. Therefore, the complete factorial design will be 162 ($3^3 \times 6^1$). Obviously it is impossible to confront the consumer with all these alternatives therefore, a subset was chosen *using a D-optimal design*, the most

[8] 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.

prevalent approach for measuring the efficiency of experimental design (Ferrini & Scarpa, 2007). The final design consists of 32 choice sets per product using the main effects design strategy. The final version of the choice sets is presented in Table A.2.3 in Appendix 2. The questionnaire (Appendix 1) presents 8 examples of a choice card/task implemented into the survey. As it is often done in the literature, we blocked the experiment into four sets of 8 choices for each product such that the pairwise correlations among attribute levels are balanced, improving the estimation of the variance-covariance matrix. We further used a between-subject design such that consumers were randomly assigned to one of the four treatments. Therefore, the respondents had to perform 'only' 8 randomly chosen choice tasks in the survey, which is a number typically used in the literature (see Adamowicz et al. 1994, Balcombe et al. 2016a, Burton et al. 2016). Each respondent received a set of instructions for completing the survey and the choice task together with background information about the project and a detailed description of the attributes. Two different methods against hypothetical bias were employed as will be described below. A rich set of socio-economic characteristics were elicited together with the choice tasks in the survey and will be described in more detail in the data section.

Hypothetical Bias

It is often the case that stated preference studies demonstrate significant differences between stated versus real values. The difference between the two is called hypothetical bias (Cummings and Taylor 1999, Penn and Hu 2018). As hypothetical bias is the strongest criticism brought to stated preferences techniques, the present choice experiment contained two different methods to reduce hypothetical bias as described in the introduction. The two methods were implemented using 3 different treatments: one where both cheap talk and honesty priming were used together, one where only cheap talk was used and one where only honesty priming was used. Consumers were randomly assigned to one of four blocks each one corresponding to different treatments: block 1 corresponded to the use of both cheap talk and honesty priming, block 2 corresponded to the use of cheap talk only, block three corresponded to the use of honesty priming only and block four contained no treatment (for reference).

In total, 573 questionnaires were collected with 68 cases in which the respondents replied incorrectly to the debriefing question.[9] 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 for the S. Korean population.[10]

The survey consisted of five parts. 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. Part (B) introduced the hypothetical bias treatments. Part (C) performed the choice experiment with the 8 choice cards presented to the respondents. 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

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[9] 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.

[10] According to Thompson (1987): Equation (1) on page 43 of the paper defines the sample size n = $\max_{m} z^2(\frac{1}{m})(1-\frac{1}{m})/d^2$ where m=nr of categories, (choices)=3 in our case, d= allowed sampling error of 0,05, z= upper $(\alpha/2m) \times 100$th percentile of the standard normal distribution can be found in the tables for α=0.05 and Φ(z)= 0.99 being equal to 2.3. Therefore, n = $\frac{2.3^2(\frac{1}{3})(1-\frac{1}{3})}{0.05^2} \approx 470$.

above.[11] 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. A list of all socio-economic characteristics and the correlations among them can be found in tables A3.1 and A3.2 in the Appendix.

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). This might counteract the potential overestimation resulted from a better educated sample.

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 using bootstrapping and simulations. 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. Rather than discussing these methodological elements at length, they will be only shortly described here and discussed more together with the empirical results.

Random Utility Framework

The response to the choice between the three constructed choice alternatives (labelled as Status Quo, GAC, and GAC + Ozone) is modelled in a random utility framework using random parameter logit. RPL models are performant and are designed to overcome the limitations of a standard logit model by allowing for random taste variation, unrestricted substitution patterns and correlation in unobserved factors (Train and Weeks, 2005). RPL achieves this by allowing model parameters as well as constants to be random, by allowing multiple observations with persistent effects and by allowing a hierarchical structure for parameters. A simple form of the choice probability for alternative i in the case of RPL can be described as follows:

$$P_{n,t,ß_n}(i) = \frac{exp^{(\alpha_n + ß_n x_{nti})}}{\sum_{j \in C_{nT}} exp^{(\alpha_n + ß_n x_{ntj})}} \qquad (1)$$

where $ß_n$ include both random and non-random parameters specific to the individual n and that the constant α_n is also allowed to be random (t = 1,…,T is the choice situation when the individual is faced with multiple choice situations), C_n is the choice set for individual n and x_{nti} is a vector of observable independent variables that includes attributes of the alternatives, and socio-economic characteristics of the respondent. In order to estimate the coefficients of the RPL, it is necessary to maximise the likelihood $P_{n,t,ß_n}$from equation (1). To estimate the coefficient for representing a sample, a log-likelihood function is estimated through simulated methods, because (1) does not have a closed form.

Latent Class Model (LCM)

[11] 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.

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).

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). In the present analysis, the models with the lowest BIC were selected.

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. In the present study the parameters were set to zero if an attribute had a zero coefficient in LCM and therefore, in this way, we allow the data to decide on the attributes that are not attended and are not imposing a specific non-attendance structure on the model ex ante.

One of the main aims of the present study is to quantify the individual's willingness to pay (WTP) for each attribute within the choice set. The WTP is calculated as the ratio of each attribute's coefficient over the monetary value coefficient (Louriero and Umberger, 2007; Kerr and Sharp, 2009; Greene, 2012) and is interpreted as a change in value associated with an increase of the attribute by one unit.

This measure can then be used in order to estimate the levels of welfare associated with various products and their attribute combinations in order to decide which one is most valued by the consumer.[12]

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 historically 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 1 below.

Table 1. *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)	$\frac{B}{C}\ \text{ratio} = \sum_{t-0}^{T} {B_t}/{(1+r)^t} \Big/ \sum_{t=0}^{T} {C_t}/{(1+r)^t}$

[12] In the case of RPL simulation is used to calculate the ratio between the attribute coefficients and the price. One simulation method for the WTP is the Krinsky-Robb method. For this the Choleski factors of the estimated coefficients are calculated.

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.

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

The empirical specification for the RPL model can be written as follows:

$$U_j = \alpha_j + \beta_{jk} X_{jk} + \gamma_{jl} Z_{jl} + (\theta_m D_m) X_p + \varepsilon_j \quad (3)$$

where: U_j are the utilities derived from each alternative *j=1,..,3*; α_j are the alternative specific constants related to each alternative[13]; β_{jk} are the coefficients of the four attributes (safety, odour & taste, colour and price) summarized in the vector *X*, where *k=1,…,4*; γ_{jl} are the coefficients of the socio-economic characteristics summarized in the vector *Z*, where *l=1,…,L*; θ_m is the coefficient of the hypothetical bias treatment summarized in the vector *D*, where *m=1,..,3*; X_p is the price coefficient; ε_j is the error term. The index indicating the individual is skipped for simplicity.

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 assumes that the representative utility has a parameter vector that has its own distribution, and estimates 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.[14] 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 different ways: RPL1 uses them as alternative specific

[13] The alternative-specific constant of the status quo is set to zero for normalization.

[14] The number of initiations of the random draws is 1,000 (Bhat, 2001).

constants[15] and RPL2 uses them as interaction terms with the price.[16] 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 WTP will decrease and the hypothetical bias treatment can be considered to have been effective.

Table 2 shows the estimation results of the RPL1 and RPL2 models. In RPL1, the coefficients of the three attributes (safety, taste & 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.

The ASCs of the socio-economic factors are chosen when their coefficients are significant at least in one option at the 95% significance level. The ones that are significant are: 'elderly', 'bill' and 'environ'. '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.[17] The coefficients of the three dummies of hypothetical bias treatments (D_{both}, D_{cheap}, D_{honest}) 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 introduces the hypothetical bias dummies as interactions 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. Again 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 GAC + Ozone option. This result suggests that people who consume more drinking water are likely to prefer this option. The results of the two random parameter logit models are similar but RPL1 shows lower log-likelihood AIC, BIC, and a higher pseudo R^2 than the RPL2, suggesting a better fit.

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

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)

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

[16] The hypothetical bias dummies used are: D_{both} represents block 1 which uses both cheap talk and honesty priming for reducing the hypothetical bias; D_{cheap} stands for block 2 using cheap talk; and D_{honest} for block 3 using the honesty priming task. Block 4 works as the base group, as all dummy variables are zero.

[17] 'environ' 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.

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} ·x4	-	-0.2343 (0.0145)
D_{cheap} ·x4	-	-0.2730 (0.0027)
D_{honest} ·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 parentheses represent P-values, and S.D stands for Standard Deviation.

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). With the help of debriefing questions, the researcher elicits the attributes that were least attended by the respondents and tries to see how setting their coefficients to zero may influence the analysis. In response to the question 'Which of the following attributes did you ignore when completing the choice task?' 32.8% of respondents said colour, with all other attributes between 8.1 and 9.6 %.

This result is expected because people cannot presumably detect the differences between 5 and 3 TCU, and this was also suggested by the RPL results. Around 10% of the respondent's answer that they ignore taste and odour. It may seem surprising that some people (8.4%) in the sample report to have ignored water bills when making their choices. However, given that the water bill is only a small proportion of monthly income (0.21%), this may be understandable. Safety appears to be the least ignored attribute which seems to be consistent with the RPL results.

Another question asked the respondents to rank the attributes according to their preference. Many respondents answered that they prefer safety first and taste & odour second; in total, 346 respondents choose safety as the first attribute and 277 taste and odour as the second attribute. In the case of colour and water bill, respondents answered that they are the less preferred two attributes, with 204 respondents preferring water bill to colour. Safety appears to be definitively the most and colour the least appreciated attribute.

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. Goodness of fit values for models from 2 to 9 classes are presented in Table A4.1 of Appendix 4, both for models using hypothetical bias (HB) treatments as ASCs and for using them as interaction terms with the price. As can be observed, the optimal number of classes for the model using HB as ASCs is 5 and 4 for the model using HB as interaction terms. After these number of classes the BIC-value starts rising.

Identifying the insignificant attributes in the FAA1 class models estimated without restriction, and then restricting these to zero gives the following model structure for ANA1:

$$U_{ij|1} = \alpha_{j|1} + \beta_{safe|1}X_{safe} + \beta_{t\&o|1}X_{t\&o} + \beta_{col|1}X_{col} + \beta_{p|1}X_p + \gamma_{lj|1}Z_l + \theta_{m|1} \cdot D_m + \varepsilon_{ij|1}$$
$$U_{ij|2} = \alpha_{j|2} + \beta_{safe|2}X_{safe} + 0 \cdot X_{t\&o} + 0 \cdot X_{col} + \beta_{p|2}X_p + \gamma_{lj|2}Z_l + \theta_{m|2} \cdot D_m + \varepsilon_{ij|2}$$
$$U_{ij|3} = \alpha_{j|3} + \beta_{safe|3}X_{safe} + 0 \cdot X_{t\&o} + 0 \cdot X_{col} + \beta_{p|3}X_p + \gamma_{lj|3}Z_l + \theta_{m|3} \cdot D_m + \varepsilon_{ij|3}$$
$$U_{ij|4} = \alpha_{j|4} + \beta_{safe|4}X_{safe} + \beta_{t\&o|4}X_{t\&o} + 0 \cdot X_{col} + \beta_{p|4}X_p + \gamma_{lj|4}Z_l + \theta_{m|4} \cdot D_m + \varepsilon_{ij|4}$$
$$U_{ij|5} = \alpha_{j|5} + \beta_{safe|5}X_{safe} + \beta_{t\&o|5}X_{t\&o} + 0 \cdot X_{col} + \beta_{p|5}X_p + \gamma_{lj|5}Z_l + \theta_{m|5} \cdot D_m + \varepsilon_{ij|5} \qquad (4)$$

Where 1-5 are the number of classes, '*safe, t&o, col, p*' are indexes for the four attributes, l is the index for the socio-economic characteristics Z, m is the index for the hypothetical bias treatments represented by the dummies D, and ε is the error term.[18] It can be observed that in FAA1, colour was the attribute ignored in most classes, as expected. Table 3 presents the results of the estimation.

Class 1 seems to ignore the safety attribute as its coefficient is insignificant; otherwise, in all other estimations of classes, providing this 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.[19] 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

[18] The index for the individual is skipped for simplicity.

[19] 75 = 406 x 0.185, where 0.185 is the class probability.

Class 1 (18.5% of the respondents), while the coefficient of the cost/price is negative and significant in all classes. This reinforces the results obtained from RPL and from debriefing questions. The discussion for ANA2 follows a similar pattern and can be found in the Appendix.

Table 3. *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)
Dboth	-3.6684 (0.0472)	-4.2468 (0.0000)	-8.6509 (0.9438)	-1.9746 (0.2125)	-1.6949 (0.0136)
Dcheap	4.3111 (0.9981)	-2.1275 (0.0303)	-8.3258 (0.9792)	-5.2732 (0.0014)	-1.0262 (0.1561)
Dhonest	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)
Dboth	-1.8130 (0.3076)	-3.5534 (0.0000)	-0.6633 (0.0817)	-1.7025 (0.2631)	-1.3913 (0.0233)
Dcheap	4.7046 (0.9979)	-2.2884 (0.0000)	-1.4024 (0.0000)	-5.6954 (0.0005)	-1.8048 (0.0091)
Dhonest	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-R2 ; 0.3071

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

Willingness to pay

In what follows the WTPs will be presented and discussed per attribute. When applying ANA, the WTP of each class is weighted by the individual specific probabilities of class membership in order to compute individual WTPs. The mean and median values of the individual WTPs, are then calculated. Table 4 presents these per attribute and model.

Table 4. *Estimation of the mean and median WTPs*

	Mean *WTP*				***Median*** *WTP*			
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 5, ANA2 shows the largest mean WTPs of all three attributes. The largest mean and median WTPs are for the safety attribute and the lowest for the colour attribute, as expected. Interestingly, the mean WTPs 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.

Confidence intervals for the median values have been constructed using simulation and bootstrapping. The exact way is explained in Appendix 5 (including the statistical code used). The results of both estimation methods can be used for sensitivity analysis. For example the range obtained with the simulation can be chosen for the safety attribute and the range from bootstrapping can be used for taste and odour, as they provide lower WTPs for the two attributes, respectively.

Estimation of Benefits

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:

$$\begin{aligned} WTP_{j,safe} &= \Delta x_{j,safe} \times MWTP_{safe} \\ WTP_{j,T\&O} &= \Delta x_{j,T\&O} \times MWTP_{T\&O} \\ WTP_{j,colour} &= \Delta x_{j,colour} \times MWTP_{colour} \end{aligned} \quad (6)$$

Lockwood et al. (1993) state that while the mean WTP is the correct measure to use from the standpoint of economic efficiency, the median WTP is probably the more appropriate measure to facilitate a democratic decision-making process. Therefore, in this research, the WTPs using the median WTPs are used. Table 5 shows examples of the WTP calculations per household for the two advanced treatment systems using the median WTP values of the ANA1 model as this provides the most conservative estimates.

Table 5. *Benefits using the median WTPs of the ANA1 model*

KRW 1000		Safety	Taste and odour	Colour	Sum
Median of WTP (m)		0.04676	0.00630	0	
GAC	change of attribute (Δx_i)	34 (40 to 6)	80 (10 to 90)	9 (90 to 99)	
	Benefit (m×Δx_i)	1.590	0.504	0	**2.094**
Ozone +	change of attribute (Δx_i)	39 (40 to 1)	89.9 (10 to 99.9)	9.9 (90 to 99.9)	
	Benefit (m×Δx_i)	1.824	0.567	0	**2.391**

Table 6 shows the comparison of the benefits from the WTP estimates from the 4 different models.

Table 6 *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 6, all benefits using the median WTPs are lower than those obtained for the mean WTPs. The median WTPs 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.

Total 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, S. 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.

The total benefits are calculated by multiplying the number of households served by the waterworks (196,712) with the WTPs per household obtained in Table 6. Table 7 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.

Table 7. *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	447	412	547	5,823	5,368	4,944	6,565

	(412)	(380)	(350)	(465)	(5,026)	(4,558)	(4,199)	(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 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 WTPs 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 S. 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 S. 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. The construction period was set to 4 years (48 months) based on the estimates from eight similar previous projects which installed the GAC + Ozone in S. Korea.[20] All the projects were completed in less than five years. Further details on project life, discount rate, design costs, construction, supervision and operating costs are given in the Appendix 7.

Table 8 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.

Table 8. 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 (USD)	1,605 (1,369)	3,776 (3,220)	11,479 (9,790)	11,479 (9,790)	11,930 (10,175)	451 (385)	451 (385)	451 (385)
Ozone (USD)	466 (397)	1,096 (935)	3,332 (2,842)	3,332 (2,842)	3,332 (2,842)	41 (35)	41 (35)	41 (35)

Note. The price unit is KRW million. The exchange rate is based on 31/12/2015.

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)

[20] Ministry of Environment, South Korea, 2009

The assumptions made for the CBA are summarized in Table 9. In addition to these assumptions, we consider the extent to which people will benefit from improved 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. In our case, we have estimated the number of people that have negative ASCs for the two alternatives and have found that the highest percentage is 15.5 (63 people) in the case of ANA2. To mitigate the effect of this group who is unwilling to pay, 15.5% of people will be excluded.

Table 9. *Summary of basic assumptions for CBA*

Factor		Range
Business life (years)		10 – **20**
Social discount rate (%/year)		**1** – 10
Benefit	WTP of safety (KRW 1000)	0.0365, 0.0465 – **0.0468**
	WTP 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 10 summarizes the total monthly benefit for the two methods for improving drinking water quality within the target area estimated using ANA1.

Table 10. *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 WTPs.

Another point to discuss is when and how much of the social benefit should be applied to the cash flows. In this research, the first supply year is the fifth year after starting construction of the advanced water treatment systems; however, after five years, the social benefits might be changed by any change in the real purchasing power of money. The survey was conducted in 2015 so the benefit is estimated on the basis of the price in 2015.

Table 11. *Cash Flows of the GAC and GAC plus ozone alternatives (summarizing cost and benefit flows)*

	GAC		GAC plus ozone	
	Net value	Present value	Net value	Present value
2015	-1,605	-1,605	-2,071	-2,071
2016	-3,776	-3,579	-4,872	-4,662
2017	-11,479	-10,313	-14,811	-13,563
2018	-11,479	-9,776	-14,811	-12,979
2019	-6,987	-5,859	-9,618	-8,065
2020	4,492	3,605	5,152	4,134
…	…	…	…	…
2038	4,492	1,632	5,152	1,872
	50,022	15,788	51,706	13,067

Note. Values are in KRW million. USD 1 = KRW 1177.5, based on the exchange rate of 31/12/2015. The project starts to yield benefits just in the last year of construction (2019).

In the last row of Table 11, the NPV of the GAC alternative is estimated as KRW 15,788 million (USD 13 million) and for the GAC plus ozone 13, 067 million (USD 11 million). The three discount cash flow methods allow a more exact analysis of which alternative is more effective. Table 12 shows the results of CBA of the two alternatives when using the whole data set to calculate the social benefits.

Table 12. *Cost-Benefit Analysis of the two alternatives*

KRW million	Present Cost	Present Benefit	NPV	B/C ratio	IRR
GAC (USD thousand)	40,556 (34,589)	56,344 (48,055)	15,788 (13,465)	1.389	8.97 %
Ozone + GAC (USD thousand)	51,269 (43,726)	64,336 (54,871)	13,067 (11,145)	1.255	7.46 %

Note. USD 1 = KRW 1172.5, based on the exchange rate of 31/12/2015.

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 to address these risks and uncertainties. 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 by 20%, which is the percentage from comparing the largest unit construction cost among previous projects with the unit cost of the standard. The last category contains several scenarios that manipulate the benefits.

Risk Premium Approach

At a social discount rate of 1% the NPV (B/C ration) for the GAC and GAC + Ozone alternatives are 39,907 KRW million (1.855) and 40,254 (1.687) respectively; similarly, at social discount rates of 10% these figures are -2,257 KRW million (0.933) and -7,002 (0.838). From Table 12, we know that an NPV of zero is associated with a discount factor of 8.97% and 7.46% respectively.

Reduction of Business Life

In the case of ozone treatment, the business life is reported to be between 15 and 20 years, and the physical service life of the GAC treatment is reported to be between 40 and 50 years. We consider sensitivity analysis when the business lives of the two alternatives vary from 10 to 20 years. At a business life of ten years, both projects become infeasible with negative NPVs. A business life of 12 and 14 years, respectively, makes the GAC and GAC plus ozone alternative feasible (holding all other assumptions fixes).

Decrease in Benefits

Several situations are examined for decreases in benefits. The first case assumes the benefits decrease to zero over 20 years, using a method similar to straight-line depreciation in accounting. As a result, the total social benefits are reduced by KRW 260 million for the GAC alternative, and KRW 297 million for the ozone plus GAC alternative every year, so they will be zero at the end of the period. Under this assumption, both projects become unfeasible, with a NPV of -8,099 KRW million and -14,208 for the GAC and GAC plus ozone alternatives respectively.

The second case assumes no benefit after the twelfth year of operation. Following the logic derived from the changes in business life, the GAC project is still feasible (with an NPV of 479 KRW million) but he GAC plus ozone project now has a negative net contribution.

Third, we consider the results with a lower estimate of the benefits, using the lower bound in the 95% confidence interval of simulating the median values of the WTPs of the ANA1 model. In this case, the annual social benefit of the GAC decreases by KRW 854 million (17.3%) and the one of the ozone plus GAC decreases by KRW 981 (20.5%). Under this scenario, both projects are still feasible with positive NPVs and IRRs of 6.32% and 4.95% for the GAC and GAC + Ozone alternatives, respectively. When using the lower bound in the 95% confidence interval of the *bootstrapping* method, similar results prevail, with IRRs of 8.74% and 7.24%.

Finally, the CBA is examined when some residents do not wish to pay to improve the quality of drinking tap water. As previously discussed 15.5% (63) people serviced by the waterworks can be excluded in measuring the social benefits because they have a negative sum of the coefficients of the ASC and socioeconomic variables for both alternatives. With this assumption, both projects are still feasible holding all other assumptions fixed; the projects have positive NPVs, and IRRs of 6.04% and 4.68% for the GAC and GAC plus ozone alternatives, respectively.

Increase in Costs

The assumption made is that there is a 20% increase in unit construction costs using the applying the upper bound of previous cases in S. Korea. In this scenario, both projects remain feasible with positive NPVs and IRRs of 6.64% and 5.26% for the GAC and GAC plus ozone alternatives, respectively. Assuming there is a one-year delay in construction, delaying the benefits, also results in the feasibility of both projects being maintained, holding all other assumptions fixed. Both the GAC and GAC plus ozone alternatives have positive NPVs and IRRs of 8.31% and 7.04% respectively.

Summary of Sensitivity Analysis

Table 13 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 assumptions have been conservative. [21]

Table 13. *Outline of the Sensitivity Analysis*

Scenario	B/C		NPV (KRW) (Unit: million)		IRR (%)	
	GAC	Ozone + GAC	GAC	Ozone + GAC	GAC	Ozone + GAC
Basic	1.389	1.255	15,788 (USD 13.5)	13,067 (USD 11.1)	8.97	7.46
Discount rate increases (4.5 -> 10 %)	1.286	1.159	11,176 (USD 9.5)	7,901 (USD 6.7)	8.97	7.46
Business life reduces (20 -> 10 years)	0.889	0.798	-4,268 (USD -3.6)	-9,937 (USD -8.5)	2.12	0.06
Benefits decline to zero	0.800	0.723	-8,099 (USD -6.9)	-14,208 (USD -12.1)	0.23	-1.11
Benefits during 10 years	1.012	0.909	479 (USD 0.4)	-4,493 (USD -3.87)	4.72	2.83
Benefit with lower bound WTPs	1.149	1.037	6,053 (USD 5.2)	1,886 (USD 1.6)	6.32	4.95
Exclusion of households without Benefits	1.126	1.014	5,100 (USD 4.4)	730 (USD 0.6)	6.04	4.68
Cost increase (20 %)	1.181	1.064	8,630 (USD 7.4)	3,852 (USD 3.3)	6.64	5.26
One year delay of construction	1.362	1.234	14,324 (USD 11.7)	11,666 (USD 10.0)	8.31	7.04

Note. USD 1 = KRW 1172.5, the exchange rate based on 31/12/2015.

Conclusions, Discussion 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 S. 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 in the target are of Cheongju City is feasible.

[21] It is important to note that in the present analysis the surveyed households are willing to pay in order to improve the tap water quality and hence it is assumed that they will start drinking water from the tap more frequently once the treatments are implemented. Hence the cultural factor appears not to be the biggest limiting factor in the present analysis but future analysis will show if the behavior of S. Koreas will change. We thank the anonymous referee for pointing this out.

The present study uses choice experiments in order to assess the benefits from installing two advanced water treatments systems in the target area and then performs an extensive cost-benefit analysis to assess the feasibility of the project under various scenarios. To our knowledge, no other study has performed this type of analysis for S. Korea, a developed country with historically polluted water supply. The study employs two different methods to mitigate hypothetical bias (cheap talk and honesty priming) and finds both are effective in reducing it with honesty priming being more successful than cheap talk. Honesty priming, had the largest coefficient and was significant in most cases, hence appears to work best for the S. Korean consumer as a method for dealing with hypothetical bias. We consider this an important contribution to the state of practice, as hypothetical bias is the strongest criticism brought to the elicitation of stated preferences and, results obtained without this correction might be misleading and not suited for policy recommendations. The estimation of the benefit is done using random parameter logit models and attribute non-attendance latent class models. By this, it 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 & 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 S. Koreans (Database of the Korean Statistical Information Service). For the cost-benefit analysis median values have been used as more conservative values. Moreover, confidence intervals for the lower bound of these median values have been estimated using bootstrapping and simulations. To our knowledge, this has not been done before in this context and we consider this another important contribution to the methodological discourse rendering more robust WTP estimates.

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 15.5%. 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 projects is rejected. However, as discussed, these situations are very unlikely to occur. 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. Therefore, if financial constraints shall exist, this alternative shall be preferred.

The present study is confronted with several limitations. Firstly, only a restricted number of attributes is considered. Further studies could consider additional attributes such as for example 'chlorine taste' and might also consider interaction effects between these attributes. Benefits are just estimated based on the households serviced by the waterworks, however restaurants and other commercial units that profit from the water treatments could also be considered in order to provide a more comprehensive measure.

Most importantly, 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 be the wider policy prospects for the future. As studies[22] have identified livestock sewage as the main cause for water pollution in the target area, measures aiming at reducing it should be pursued. Such measures could be: installing livestock sewage treatment facilities, building artificial

[22] Kim et al. (2013).

swamps and detention ponds to deter the inflow of polluted water into the catchment, growing aquatic plants which can resolve pollutants in the waterways, and building detention facilities of sewage treatment plants. The Committee of Managing the Geuem River Basin has developed additional projects for preventing pollutants to enter the basin among which the maintenance of the drainage systems, provision of eco-friendly agricultural materials, building buffers and afforestation.[23] Such measures need to become the priority of policy if the quality of drinking water shall not further deteriorate and clean potable water shall be possible to supply to S. Korean citizens in a sustainable way. The feasibility of such projects shall constitute the scope of future research and should be used as one criteria among other in a decision process involving several stakeholders.

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*written in Korean

Appendix 1. A sample of the questionnaire

I	D					

Questionnaire about drinking water quality

How do you do?

This questionnaire aims to find out how most citizens think about the improvement of drinking water quality. There is no correct answer to each question so you can suggest your own opinions.

Your opinion will be used for establishing a sound policy in the water field. It is certain that this survey is completely anonymous and confidential by the related laws.

Thanks for your participation.

As the main water supply sources like the the Gumgang River and the Nakdong River were contaminated, it has become difficult to remove harmful substances with current water treatment facilities. Besides, there have been several crucial accidents of drinking water caused by heavy metal, THM, phenol, benzene, and so on.

Sometimes, if there are odour-causing substances like 2-MIB and geosmin in the Gumgang River, it is likely to smell earthy or have a fungi flavour, and the problem of chlorination by-products and harmful organic substances like dioxin, antibiotic and so on might occur.

Therefore, the government has plans to install advanced water treatment systems in order to improve the drinking water quality. However, it is necessary to invest an enormous budget for it. If the majority of citizens agree with the plan, it is possible to invest, if not, it is impossible to do. **If decided to invest, then your water bill would rise and your budget for other consumption should be reduced. Also, consider the fact; many studies have shown that many people say they are willing to pay more for the improvement of public goods or services than they actually will pay when it becomes available.**

In the case of installing the new system, it is thought that there are useful advanages in the three points like ① the safety, ② the taste and odour of tap water, ③ the clarity.

Part A. Survey description

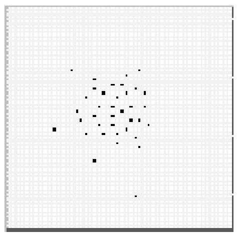
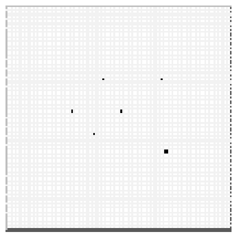
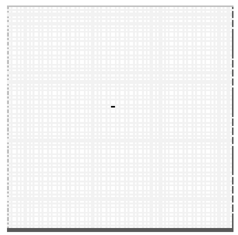
This survey presents you with each picture for describing the levels of

- the safety of drinking water
- the taste and odour
- the colour
- the additional water bill per month
- and pick the option you would choose as if it were in a real choice set.

The choices of option you will be asked to consider are about the waterworks purifying system for drinking water within your city region.

1. The safety

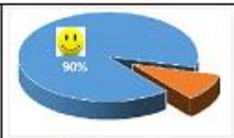
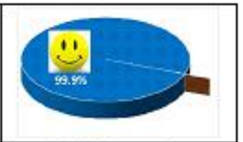
The safety of drinking water informs about the probability of how many people are diagnosed with cancer from drinking water all one's life according to the amount of THMs (Trihalomethanes). The current national criterion about THM is 0.1 mg/L meaning that cancer risk is probably 40 persons per 10 million. The levels are shown in the next Table.

		
40 persons / 10 million (≤ 0.1 mg/L of THM)	6 persons / 10 million (≤ 0.075 mg/L)	1 person / 10 million (≤ 0.05 mg/L)

※ Mitchell and Carson (1986), Cho, Woohyun (2007), Um, Y.S (2008)

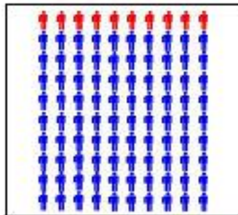
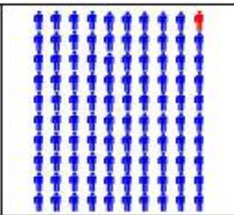
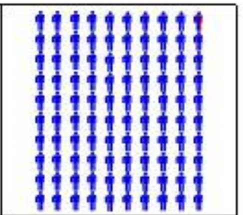
2. The taste and odour

The taste and odour inform about the levels of how many people are satisfied with the musty, earthy taste and odour in drinking water caused by Geosmin and 2-MIB. The current national criterion about Geosmin and 2-MIb is that less than 20 μg/L meaning that 10% people are satisfied with the taste and odour of tap water. The levels are shown in the next Table.

		
10% people (≤ 20 μg/L)	**90% people** (≤ 10 μg/L)	**99.9% people** (≤ 4 μg/L)

3. The colour

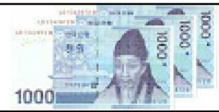
The colour informs about the levels of how many people are satisfied with the colour of drinking water. The current national criterion about the colour of tap water is less than 5 TCU meaning that 90% people are satisfied with the colour. The levels are shown in the next Table.

		
90% people (5 TCU)	**99% people** (4 TCU)	**99.9% people** (1 TCU)

※ 1 TCU (True Colour Unit) corresponds to the amount of colour exhibited under the specified test conditions by a standard solution containing 1 mg of platinum per litre. You can see the samples of a few levels of TCU in the right picture.

4. The additional water bill a month

For any specific option, the additional water bills presented is based on some amounts of KRW (1GBP=1,670KRW) suggested in the next table.

-		
KRW 0	KRW 2,000	KRW 3,000

Choosing one among the Options, **you should consider that the additional water bill a month will be charged to each household, therefore, please, choose the option in terms of water bill on the behalf of your home.**

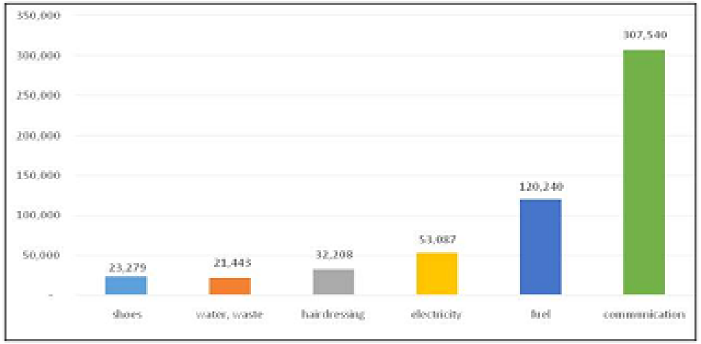
For your information, it is shown the average bill of 1 ㎥ water of some countries over the world in the next table.

The average drinking water bill per 1,000L (㎥) (KRW, 2013)

Nation	S, Korea	Japan	The U.S	The U.K	Germany	France
bill	619.3	1,646	1,446	2,357	3,236	2,491

Also, next Table shows some average monthly consumers' costs of a household in South Korea.

(KRW, 2013)



An example of Choice Card

Option	Option A (Status Quo)	Option B (GAC)	Option C (GAC+Ozone)
Safety Life time cancer risk due to Trihalomethanes in drinking water	40 / 10 million	6 / 10 million	1 / 10 million
Taste and Odour The proportion of people satisfied with the taste and odour in drinking water?	10%	90%	99.9%
Colour The proportion of people satisfied with the clarity of drinking water	90%	99%	99.9%
Water bill Additional water bill per month (KRW per month)	0	2,000	3,000
Choice Which option would you choose for drinking water in your home? (√ only one)	A ☐	B ☐	C ☐
Which proportions do you think other people choose among option A, B, and C? (the sum of 3three proportions must be 100%)	A (%)	B (%)	C (%)

You will be asked to select among Option A, B, and C under the assumption that you had to choose one of them. In the last row of choice card 1, 3, and 5, you are asked to write down which proportions do you think other people choose the options.
Option A (Status Quo) means that there is no investment for improving drinking water quality in your city.

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Part B. A warm up Task

Before doing the choice tasks, for each sentence below insert one of two words to make a grammatically correct sentence,

For example:

Seoul is the ( ) of South Korea. (Insert either **capital** or **centre**)

You might answer

Seoul is the (**capital**) of South Korea.

Now have a go at the following sentences:

1. This a ( ) story. (Insert either **true** or **bald**)
2. The earth is ( ). (Insert either **round** or **flat**)
3. You must always tell the ( ). (Insert either **truth** or **lie**)
4. The wallet is made of ( ) leather. (Insert either **fake** or **genuine**)
5. Whales live in the ( ). (Insert either **oceans** or **rivers**)
6. She has a ( ) interest in learning. (Insert either **genuine** or **little**)
7. I ( ) football. (Insert either **kick** or **like**)
8. I met a ( ) person this week. (Insert either **famous** or **fair**)
9. This is a ( ) explanation. (Insert either **silly** or **sensible**)
10. Your opinions seem to be ( ). (Insert either **genuine** or **individual**)

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Part C. Eight Choice Cards

In this part, you are asked to choose only one option among 3 Options of 8 choice cards. In 3 choice cards (1, 3, 6), you need not to write down the proportion.

Choice Card 1

Option	Option A (Status Quo)	Option B (GAC)	Option C (GAC+Ozone)
Safety Life time cancer risk due to Trihalomethanes in drinking water	40 / 10 million	6 / 10 million	1 / 10 million
Taste and Odour The proportion of people satisfied with the taste and odour in drinking water?	10%	not changed	90%
Colour The proportion of people satisfied with the clarity of drinking water	90%	not changed	99%
Water bill Additional water bill per month (KRW per month)	0	3,000	4,000
Choice Which option would you choose for drinking water in your home? (√ only one)	A ☐	B ☐	C ☐
Which proportion do you think other people choose among option A, B, and C? (the sum of 3three proportions must be 100%)	A (%)	B (%)	C (%)

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Choice Card 2

Option	Option A (Status Quo)	Option B (GAC)	Option C (GAC+Ozone)
Safety Life time cancer risk due to Trihalomethanes in drinking water	40 / 10 million	not changed	not changed
Taste and Odour The proportion of people satisfied with the taste and odour in drinking water?	10%	90%	90%
Colour The proportion of people satisfied with the clarity of drinking water	90%	not changed	99.9%
Water bill Additional water bill per month (KRW per month)	0	3,000	4,000
Choice Which option would you choose for drinking water in your home? (√ only one)	A ☐	B ☐	C ☐

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Choice Card 3

Option	Option A (Status Quo)	Option B (GAC)	Option C (GAC+Ozone)
Safety Life time cancer risk due to Trihalomethanes in drinking water	40 / 10 million	not changed	6/10 million
Taste and Odour The proportion of people satisfied with the taste and odour in drinking water?	10%	99.9%	99.9%
Colour The proportion of people satisfied with the clarity of drinking water	90%	99%	99.9%
Water bill Additional water bill per month (KRW per month)	0	1,000	3,000
Choice Which option would you choose for drinking water in your home? (√ only one)	A ☐	B ☐	C ☐
Which proportions do you think other people choose among option A, B, and C? (the sum of 3three proportions must be 100%)	A (%)	B (%)	C (%)

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Choice Card 4

Option	Option A (Status Quo)	Option B (GAC)	Option C (GAC+Ozone)
Safety Life time cancer risk due to Trihalomethanes in drinking water	40 / 10 million	6 / 10 million	6 / 10 million
Taste and Odour The proportion of people satisfied with the taste and odour in drinking water?	10%	not changed	90%
Colour The proportion of people satisfied with the clarity of drinking water	90%	99%	99%
Water bill Additional water bill per month (KRW per month)	0	1,000	2,000
Choice Which option would you choose for drinking water in your home? (√ only one)	A ☐	B ☐	C ☐

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Choice Card 5

Option	Option A (Status Quo)	Option B (GAC)	Option C (GAC+Ozone)
Safety Life time cancer risk due to Trihalomethanes in drinking water	40 / 10 million	not changed	1 / 10 million
Taste and Odour The proportion of people satisfied with the taste and odour in drinking water?	10%	not changed	not changed
Colour The proportion of people satisfied with the clarity of drinking water	90%	99%	99.9%
Water bill Additional water bill per month (KRW per month)	0	500	3,000
Choice Which option would you choose for drinking water in your home? (√ only one)	A ☐	B ☐	C ☐

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Choice Card 6

Option	Option A (Status Quo)	Option B (GAC)	Option C (GAC+Ozone)
Safety Life time cancer risk due to Trihalomethanes in drinking water	40 / 10 million	not changed	6 / 10 million
Taste and Odour The proportion of people satisfied with the taste and odour in drinking water?	10%	90%	99.9%
Colour The proportion of people satisfied with the clarity of drinking water	90%	not changed	99%
Water bill Additional water bill per month (KRW per month)	0	500	4,000
Choice Which option would you choose for drinking water in your home? (√ only one)	A ☐	B ☐	C ☐
Which proportions do you think other people choose among option A, B, and C? (the sum of 3three proportions must be 100%)	A (%)	B (%)	C (%)

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Choice Card 7

Option	Option A (Status Quo)	Option B (GAC)	Option C (GAC+Ozone)
Safety Life time cancer risk due to Trihalomethanes in drinking water	40 / 10 million	6 / 10 million	6 / 10 million
Taste and Odour The proportion of people satisfied with the taste and odour in drinking water?	10%	90%	99.9%
Colour The proportion of people satisfied with the clarity of drinking water	90%	not changed	not changed
Water bill Additional water bill per month (KRW per month)	0	2,000	3,000
Choice Which option would you choose for drinking water in your home? (√ only one)	A ☐	B ☐	C ☐

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Choice Card 8

Option	Option A (Status Quo)	Option B (GAC)	Option C (GAC+Ozone)
Safety Life time cancer risk due to Trihalomethanes in drinking water	40 / 10 million	6 / 10 million	1 / 10 million
Taste and Odour The proportion of people satisfied with the taste and odour in drinking water?	10%	90%	99.9%
Colour The proportion of people satisfied with the clarity of drinking water	90%	99.9%	99.9%
Water bill Additional water bill per month (KRW per month)	0	500	2,000
Choice Which option would you choose for drinking water in your home? (√ only one)	A ☐	B ☐	C ☐

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Part D. Debriefing Questions

We would like to understand how you made your choices.

Q 1. Which of the following attributes did you ignore when completing the choice task?

(You can tick none or as many as required.)

① Safety ☐

② Taste and Odour ☐

③ Colour ☐

④ Price ☐

Q 2. Please rank which of the attributes you most considered when making your choices?

To do this click and drag the options to the correct order such that 1 = most considered attribute and 4 = least considered attribute.

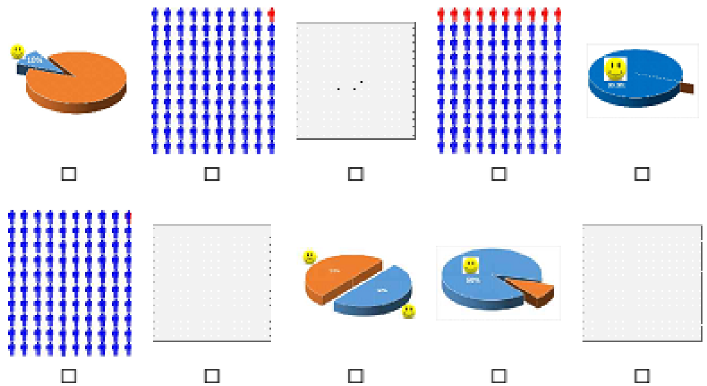
① Safety ☐

② Taste and Odour ☐

③ Colour ☐

④ Price ☐

Q 3. We are going to show you 10 pictures. Please, could you tick only one picture that you couldn't see in your choice cards?



Some questions about you and your perceptions of the proposed technology. Please indicate the extent to which you agree or disagree with the following statements.

	Strongly disagree	disagree	A little bit disagree	neutral	A little bit agree	agree	Strongly Agree
I prefer water resource policies aiming to prevent contamination of water environment should be enhanced.	①	②	③	④	⑤	⑥	⑦
I want to know more about information of the safety of drinking water.	①	②	③	④	⑤	⑥	⑦
I am interested in looking for the information of the taste and odour of drinking water.	①	②	③	④	⑤	⑥	⑦
I usually pay attention to the colour of drinking water.	①	②	③	④	⑤	⑥	⑦
I don't spend much time reading the safety problem of drinking water.	①	②	③	④	⑤	⑥	⑦
I read about the taste and odour problem of drinking water in newspapers and on air.	①	②	③	④	⑤	⑥	⑦
I would like to receive additional information about drinking water.	①	②	③	④	⑤	⑥	⑦

Part E. Questions about social and economic factors

Q 1. Regarding your gender, which of the following would you select?

① Male ② Female

Q 2. Are you household?

① Household ② Non-household

Q 3. How old are you? (years old)

Q 4. Regarding your family, how many in your family and how many income earners are there?

Total number of family ( ),
the number of income earners ( )

Q 5. Regarding to age, please, insert the number of family members, except you.

0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-

Q 6. Regarding your family composition, which of the following would you select?

① Have children less than 3 years old
② Have not children less than 3 years old

Q 7. How do you drink water in your home?

① Drink tap water as it is. ② Don't drink tap water as it is.

Q 8. If you don't drink tap water as it is, how do you drink your drinking water? You can tick which ones you use.

① Drink water after boiling tap water. ② Using a purifier.
③ Purchasing bottled water. ④ Drink groundwater from fountain well.
⑤ Others ( )

Q 9. Regarding your dwelling, which type is your house?

① Apartment ② Detached house
③ Terraced house ④ Multiplex house
⑤ Others ( )

Q 10. Regarding your water usage and bill, how much do you consume the drinking water and how much do you pay for your drinking water bill, a month on average?

(m^3), (KRW)

Q 11. Regarding your working condition, which of the following would you select?

① Full-time worker ② Part-time worker
③ Retired ④ Unemployed and looking for a job
⑤ Unemployed and not looking for a job
⑥ Other ( )

Q 12. Regarding your education, circle how many years you studied?

n/a	Primary school	Middle school	High school	College, university	Graduate school
0	1 2 3 4 5 6	7 8 9	10 11 12	13 14 15 16	17 18 19 20 21 22

Q 13. Regarding your personal average income per month, which of the following would you select?

(KRW million)

< 1.0	< 1.5	< 2.0	< 2.5	< 3.0	< 3.5	< 4.0	< 4.5	< 5.0	5.0 <

Q 14. Regarding your household average income per month, which of the following would you select?

(KRW million)

< 1.0	< 1.5	< 2.0	< 2.5	< 3.0	< 3.5	< 4.0	< 4.5	< 5.0	5.0 <

Appendix 2. Profiles for the Attributes and Choice Sets

Some assumptions for developing appropriate profiles from reality should be considered. First, the status quo is the current state of supplying drinking water by using a conventional type of water treatment. The attributes of the status quo should reflect the present levels of drinking water quality. Alternatives 2 and 3 should reflect the improvements in the attribute levels compared to the status quo. Second, regarding performance, the GAC system produces drinking water equal to or better than the status quo, and ozone plus GAC treatment provides water equal to or better than GAC alone. Thus, it is possible to create six reasonable profiles related to the three attributes as shown in Table A2.1 below.

Table A2.1. *Profiles for the attributes*

	Alternative 1	Alternative 2	Alternative 3
Treatment 1	level 0	level 0	level 0
Treatment 2	level 0	level 0	level 1
Treatment 3	level 0	level 0	level 2
Treatment 4	level 0	level 1	level 1
Treatment 5	level 0	level 1	level 2
Treatment 6	level 0	level 2	level 2

Regarding the price level (additional average monthly water bill per household), the status quo should be zero because choosing the status quo means that people don't want to pay an additional amount for improvement in drinking water quality. Moreover, the price level of alternative 3 should be higher than the price of alternative 2 which in turn should be more expensive than the price of the status quo. Thus, the number of profiles related to the price level is 10 as shown in Table A2.2.

Table A2.2.*Profile of price*

KRW	Alternative 1	Alternative 2	Alternative 3
Treatment 1	0	500	1000
Treatment 2	0	500	2000
Treatment 3	0	500	3000
Treatment 4	0	500	4000
Treatment 5	0	1000	2000
Treatment 6	0	1000	3000
Treatment 7	0	1000	4000
Treatment 8	0	2000	3000

Treatment 9	0	2000	4000
Treatment 10	0	3000	4000

Therefore, the total number of profiles reflecting all the cases of the four attributes is 2,160 (= 6×6×6×10).

Table A2.3. ***Final version of the 32 choice sets***

Card number	Granular activated carbon				GAC plus Ozone				Block
	Safety	T&O	Colour	Cost	Safety	T&O	Colour	Cost	
1	1	0	0	3	2	1	1	4	4
2	0	1	0	3	0	1	2	4	4
3	0	2	0	1	1	2	2	2	3
4	0	2	1	1	1	2	2	3	4
5	0	2	1	3	2	2	2	4	3
6	0	1	0	0.5	1	1	1	1	3
7	1	0	1	1	1	1	1	2	4
8	1	1	0	2	2	2	2	4	1
9	0	1	0	0.5	0	1	1	1	3
10	1	0	1	0.5	2	1	1	3	3
11	2	1	0	1	2	2	2	4	1
12	2	0	0	0.5	2	0	2	4	3
13	1	1	0	0.5	1	2	2	3	2
14	0	1	0	2	0	2	2	3	1
15	0	0	1	0.5	2	0	2	3	4
16	0	1	2	3	1	1	2	4	1
17	2	0	0	0.5	2	2	2	1	2
18	0	1	0	0.5	1	2	1	4	4
19	0	0	1	2	2	0	1	3	1
20	1	1	0	2	1	2	0	3	4
21	0	1	0	0.5	1	2	2	3	3
22	1	1	1	3	2	2	1	4	2
23	0	2	0	0.5	0	2	1	2	1
24	0	1	1	2	0	2	1	3	2
25	0	0	1	0.5	2	0	1	2	1
26	0	1	0	0.5	1	2	2	3	1
27	0	1	0	1	2	1	2	4	2
28	2	0	2	0.5	2	1	2	2	2
29	1	1	0	1	2	1	2	3	2
30	1	1	2	0.5	2	2	2	2	4
31	0	1	0	2	1	2	1	3	3
32	1	2	0	0.5	2	2	0	2	2

Note. 0, 1, 2 means the three levels of the three attributes and the unit of cost is KRW thousand.

Appendix 3. Socio-economic characteristics

Table A3.1. ***Correlation coefficients between nineteen individual specific variables***

	g	a	e	p	h	b	fa	e	in	el	H	sp	b	p	b	a	M	F	e
ge	1.	0.	0	**0**	-	0.	-	-	0.	0.	**0.**	-	-	-	0.	0.	0.	0.	-
ag		1.	-	**0**	-	0.	-	-	-	0.	**0.**	0.	-	0.	-	-	-	-	-
ed			1	**0**	0	0.	0.	0.	0.	-	0.	-	-	-	0.	0.	0.	**0.**	0.
pi				1	**0**	0.	0.	0.	0.	-	**0.**	-	-	-	0.	0.	-	**0.**	0.
hi					1	-	**0.**	**0.**	-	-	-	-	-	0.	-	0.	-	0.	0.
bil						1.	-	-	-	-	0.	-	0.	-	0.	-	-	-	0.
fa							1.	**0.**	0.	0.	-	0.	-	0.	-	0.	-	-	-
ea								1.	-	-	-	-	0.	-	0.	0.	-	0.	0.
inf									1.	-	0.	0.	0.	0.	0.	0.	-	0.	0.
el										1.	-	-	0.	-	-	-	-	-	0.
he											1.	-	-	0.	0.	0.	0.	**0.**	-
sp												1.	0.	0.	-	0.	-	-	0.
Bo													1.	-	0.	0.	-	-	0.
pu														1.	-	0.	-	-	-
bo															1.	-	0.	0.	0.
ap																1.	-	0.	-
m																	1.	-	-
ful																		1.	0.
en																			1.

Note. Numbers in parentheseses are p-values. The bold figures mean that the correlations are equal to or more correlated than the correlation ±0.25 at a 99 % significance level.

Table A3.2. Individual specific variables

Variable	Description
gender	dummy, 1 indicating a male, 0 female
age	respondent’s age
edu	years of education
pinc	personal income
hinc	the income per household of each respondent
bill	the average monthly water bill for each respondent’s household
family	the number of people in the family
earner	the number of earners in their household
infant	the number of infants in a respondent’s house; less than 4 years old
elderly	the number of elders in a respondent’s house; more than 59 years old
environ	the scale value of the preference for water-environment friendly policy
head	dummy, 1 indicating if a respondent is a head of household
spouse	dummy, 1 indicating if a respondent is a spouse of the household head
others	dummy, 1 indicating if one is neither a head of household nor a spouse
boil	dummy, 1 indicating a respondent drinks after boiling drinking water
purify	dummy, 1 indicating a respondent drinks water by using purifier
bottle	dummy, 1 indicating a respondent purchases bottled water
well	dummy, 1 indicating a respondent drinks water from well
apart	dummy, 1 indicating a respondent lives in an apartment
detach	dummy, 1 indicating a respondent lives in a detached house
terrace	dummy, 1 indicating a respondent lives in a terraced house
multiple	dummy, 1 indicating a respondent lives in a multiplex house
full	dummy, 1 indicating a respondent has a full time job
part	dummy, 1 indicating a respondent has a part time job
retired	dummy, 1 indicating a respondent is retired
lookjob	dummy, 1 indicating a respondent is unemployed and looking for a job
notlook	dummy, 1 indicating a respondent is unemployed, not looking for a job
otherjob	dummy, 1 indicating a respondent has other jobs; student, homemaker

Appendix 4. Latent Class Models

Table A41. *Goodness of fit measures of FAA LCM models*

Classes		FAA of using ASCs of HB	FAA of using interaction terms of HB
Sample size		406	406
2	BIC	**5506.8**	**5537.3**
	AIC	5406.6	5461.2
	Log-likelihood	-2678.3	-2711.6
	Pseudo-R^2	0.2465	0.2379
3	BIC	5384.0	5356.2
	AIC	5231.7	5240.0
	Log-likelihood	-2577.9	-2591.0
	Pseudo-R^2	0.2733	0.2706
4	BIC	5363.7	**5287.4**
	AIC	5159.4	5131.1
	Log-likelihood	-2528.7	-2526.6
	Pseudo-R^2	0.2857	0.2877
5	BIC	**5348.8**	5331.0
	AIC	5092.4	5134.7
	Log-likelihood	-2482.2	-2518.4
	Pseudo-R^2	0.2974	0.2889
6	BIC	5354.5	5349.9
	AIC	5046.0	5113.6
	Log-likelihood	-2446.0	-2497.8
	Pseudo-R^2	0.3063	0.2936
7	BIC	5375.8	5328.5
	AIC	5015.2	5052.1
	Log-likelihood	-2417.6	-2457.0
	Pseudo-R^2	0.3130	0.3040
8	BIC	5437.7	5348.5
	AIC	5025.0	5032.0
	Log-likelihood	-2409.5	-2436.9
	Pseudo-R^2	0.3139	0.3086
9	BIC	5499.5	5398.4
	AIC	5034.7	5041.8
	Log-likelihood	-2401.4	-2431.9
	Pseudo-R^2	0.3148	0.3090

Appendix 5. ANA2 Results.

The model structure derived from the full attendance model for ANA2 is as follows:

$$U_{j|1} = \alpha_{j|1} + \beta_{safe|1}X_{safe} + \beta_{t\&o|1}X_{t\&o} + 0 \cdot X_{col} \quad + \beta_{p|1}X_p + 0 \cdot D_{both}X_p + \gamma_{2j|1}D_{cheap}X_p + \gamma_{3j|1}D_{honest}X_p + \gamma_{jl|1}Z_l + \varepsilon_{j|1}$$

$$U_{j|2} = \alpha_{j|2} + \beta_{safe|2}X_{safe} + \beta_{t\&o|2}X_{t\&o} + 0 \cdot X_{col} \quad + \beta_{p|2}X_p + \gamma_{1j|1}D_{both}X_p \quad + 0 \cdot D_{cheap}X_p + \gamma_{3j|1}D_{honest}X_p + \gamma_{jl|2}Z_l + \varepsilon_{j|2}$$

$$U_{j|3} = \alpha_{j|3} + \beta_{safe|3}X_{safe} + 0 \cdot X_{t\&o} \quad + 0 \cdot X_{col} \quad + \beta_{p|3}X_p + \gamma_{1j|1}D_{both}X_p + \gamma_{2j|1}D_{cheap}X_p + \gamma_{3j|1}D_{honest}X_p + \gamma_{jl|3}Z_l + \varepsilon_{j|3}$$

$$U_{j|4} = \alpha_{j|4} + \beta_{safe|4}X_{safe} + \beta_{t\&o|4}X_{t\&o} + \beta_{col|4}X_{col} + \beta_{p|4}X_p + \gamma_{1j|1}\, D_{both}X_p + \gamma_{2j|1}D_{cheap}X_p + \gamma_{3j|1}D_{honest}X_p + \gamma_{jl|4}Z_l + \varepsilon_{j|4} \qquad (5)$$

where, as opposed to (15), the hypothetical bias treatment dummies are introduced as interaction terms with the price/cost attribute $D_m X_p$, where m is the index for the hypothetical bias treatments. It can be observed, that as in the previous ANA model, the attribute that is most ignored is the colour as it is zero in all classes but class 4. Results of the estimation are presented in Table A5.

Class 1 appreciates safety attribute but the coefficient of taste and odour is insignificant even though it is not set to be zero; in all other classes, when an attribute is estimated its coefficient returns a statistically significant result. Class 4 (23% of respondents) is the only one to consider colour to be important. All classes appreciate the safety attribute and therefore all respondents are willing to pay for it. The taste and odour attribute is appreciated in Classes 2 and 4 meaning that only about 50% of the respondents are willing to pay for it. In all classes the cost coefficient is negative and significant at 95% or better, which means that WTPs can be estimated for all classes. The results estimated with ANA1 and ANA2 are similar in the sense that (almost) all people want to pay for the safety attribute, the next appreciated attribute is taste and odour where 50-60% are willing to pay for it and only about 20% of the sample is willing to pay for an improvement of the colour attribute. The goodness of fit of is similar for both models with a slightly higher pseudo-R^2 and a slightly lower BIC for ANA1. Therefore, we can conclude that the results between the two models are consistent.

Table A5. *Estimation of the coefficients of the ANA2*

variable	Class 1	Class 2	Class 3	Class 4
x1 (safety)	-0.0555 (0.0000)	-0.0705 (0.0000)	-0.0195 (0.0084)	-0.0184 (0.0066)
x2 (t&o)	0.0009 (0.7565)	0.0130 (0.0000)	0.0 (fixed)	0.0180 (0.0000)
x3 (colour)	0.0 (fixed)	0.0 (fixed)	0.0 (fixed)	0.0687 (0.0103)
X4 (cost)	-1.4094 (0.0000)	-0.2147 (0.0286)	-0.5189 (0.0036)	-0.4821 (0.0027)
Dboth·X4	0.0 (fixed)	-0.0157 (0.9041)	-0.4940 (0.0145)	0.1479 (0.3916)
Dcheap·X4	-1.9072 (0.0000)	0.0 (fixed)	-1.1236 (0.0000)	-1.1481 (0.0000)
Dhonest·X4	-0.4544 (0.0813)	-0.4846 (0.0000)	-2.2527 (0.0000)	-0.0075 (0.9676)
of Ozone, one	2.7718 (0.0452)	-0.5507 (0.6403)	-20.0354 (0.0000)	3.6846 (0.1042)
Elderly	0.9762 (0.0081)	1.0050 (0.0537)	-1.6422 (0.0001)	-1.7735 (0.0013)
Earner	0.7379 (0.0050)	0.1541 (0.4670)	0.9853 (0.0165)	-1.7423 (0.0000)

Head	0.3198 (0.5887)	0.0259 (0.9400)	-3.2343 (0.0000)	-0.3343 (0.5643)
Environ	-0.7098 (0.0014)	-0.0060 (0.9741)	3.8208 (0.0000)	0.2481 (0.4315)
of GAC, one	1.9160 (0.0354)	-0.7432 (0.5123)	-4.3930 (0.0001)	5.0241 (0.0335)
Elderly	0.2812 (0.2812)	1.4865 (0.0076)	-2.1602 (0.0000)	-0.8539 (0.0335)
Earner	0.1336 (0.4376)	0.2585 (0.2424)	0.4307 (0.2178)	-1.2149 (0.0000)
Head	0.6989 (0.0403)	0.1711 (0.6260)	-1.1805 (0.0007)	-0.9570 (0.0628)
Environ	-0.2380 (0.3259)	-0.0245 (0.8873)	1.3374 (0.0000)	0.0191 (0.9543)
Class probability	0.223 (0.0000)	0.288 (0.0000)	0.254 (0.0000)	0.235 (0.0000)
Sample size; 406, BIC; 5432.3, Log-likelihood; -2521.0, AIC; 5171.9, Pseudo-R^2; 0.2864				

Note. The values in the parentheses represent P-values.

Appendix 6. Confidence Intervals for the Median WTP

The simulation method used in calculating the standard error of one WTP includes the steps below:

1) Use the coefficient vector and the variance-covariance matrix of an LCM model, to generate one coefficient vector from the multivariate distribution and to calculate a WTP measure of each class.

2) Simulate an LCM model and calculate the individual class probabilities according to the generated coefficient vector.

3) Multiply the simulated individual class probabilities with the simulated WTPs of all classes, and generate one WTP for each respondent.

4) Make one WTP distribution of calculating the WTPs of all respondents, and measure one median WTP from the distribution.

5) After repeating the steps 1 to 4 for many times, the median WTP space[24] can be obtained, and the standard error of the median WTP can be calculated.

Repeat the simulation 1,000 times, and calculate a median WTP space[25]. The ANA 1 model is chosen for the simulation. Table A6.1 shows the result of simulation for calculating the median WTP space of the ANA1.

Table A6.1. *Confidence interval of the median WTPs of ANA 1 model*

Attribute	Average	Standard deviation	95% confidence interval	Simulation
Safety	0.04531	0.00505	0.03649 – 0.05450	1,000
Taste and odour	0.00629	0.00235	0.00614 – 0.00643	1,000

[24] Thiene and Scarpa (2009) report that MWTP space is defined as in Train and Weeks (2005), who calculated the space by using the ratio of the attribute's coefficient to the price coefficient in a random parameter logit model.

[25] NLOGIT 5 was used for the simulation, and a code is attached.

The reason why colour is not included here is because each median estimate for the attribute is simulated at zero. The 95% confidence interval of the WTPs of the two attributes includes the WTPs of the ANA1 model but the two average WTPs from the space are larger than the mean values.

The second approach to estimate the confidence interval is 'statistical bootstrap'. From the individual WTPs of the ANA 1 model, the bootstrapped samples can be generated with replacement. In this paper, the samples were simulated for a 200,000 sample size because the number of households served by the waterworks equals 196,712. Through simulation of the re-sampling 1,000 times, the median values of the WTPs are measured. Table A6.2 shows the confidence interval of the median WTPs of the ANA1 model constructed using 'bootstrapping'.

Table A6.2 *Confidence interval of the median WTPs by using 'bootstrapping'*

Attribute	Mean	Standard error	95 % confidence interval	Simulation
Safety	0.04671	0.000057	0.0465 – 0.0470	1000
Taste and odour	0.00623	0.000079	0.0060 – 0.0066	1000

In the case of the confidence intervals, the bootstrapping method produces narrower ranges for the safety attribute, but a lower values range compared to the taste and odour attribute of the simulation method. These two results can provide the ranges of the WTPs for sensitivity analysis.

Nlogit code for producing the space of the median WTPs of the safety attribute

```
LCLOGIT  ; Lhs=y  ; Choices=Ozone,GAC,Status      ; Pds=8
     ; Rhs=x1,x2,x3,x4
     ; Rh2=one,eld,bill,environ,all,cheap,honest
     ; LCM   ; Pts=5
     ; RST=  b1,b2,b3,b4,b5,b6,b7,b8,b9,b10,b11,b12,b13,b14,b15,b16,b17,b18,  ? Class 1
             c1,0,   0,  c4,c5,c6,c7,c8,c9,c10,c11,c12,c13,c14,c15,c16,c17,c18,       ? Class 2
             d1,0,   0,  d4,d5,d6,d7,d8,d9,d10,d11,d12,d13,d14,d15,d16,d17,d18,  ? Class 3
e1,e2, 0,  e4,e5,e6,e7,e8,e9,e10,e11,e12,e13,e14,e15,e16,e17,e18,  ? Class 4
              f1,f2,  0,  f4,f5,f6,f7,f8,f9,f10,f11,f12,f13,f14,f15,f16,f17,f18,            ? Class 5
     ; parameters$

Matrix      ; newb1=[ b(19)/b(22)/ b(37)/b(40)/b(55)/b(58)/b(73)/b(76)]$
Matrix      ; nvarb1=[
     varb(19,19),varb(19,22),varb(19,37),varb(19,40),varb(19,55),varb(19,58),varb(19,73),varb(19,76)/
     varb(22,19),varb(22,22),varb(22,37),varb(22,40),varb(22,55),varb(22,58),varb(22,73),varb(22,76)/
     varb(37,19),varb(37,22),varb(37,37),varb(37,40),varb(37,55),varb(37,58),varb(37,73),varb(37,76)/
     varb(40,19),varb(40,22),varb(40,37),varb(40,40),varb(40,55),varb(40,58),varb(40,73),varb(40,76)/
     varb(55,19),varb(55,22),varb(55,37),varb(55,40),varb(55,55),varb(55,58),varb(55,73),varb(55,76)/
     varb(58,19),varb(58,22),varb(58,37),varb(58,40),varb(58,55),varb(58,58),varb(58,73),varb(58,76)/
     varb(73,19),varb(73,22),varb(73,37),varb(73,40),varb(73,55),varb(73,58),varb(73,73),varb(73,76)/
     varb(76,19),varb(76,22),varb(76,37),varb(76,40),varb(76,55),varb(76,58),varb(76,73),varb(76,76)]
$

Matrix      ; medis1=init(1,1,0)$

Procedure=median_w$
Matrix      ; bi=Rndm(newb1,nvarb1)$
     LCLOGIT          ; Lhs=y ; Choices=Ozone,GAC,Status       ; Pds=8
```

```
                    ; Rhs=x1,x2,x3,x4
                    ; Rh2=one,eld,bill,environ,all,cheap,honest
                    ; LCM ; Pts=5 ; Alg=BHHH
                    ; RST=   b1,b2,b3, b4,b5,b6,b7,b8,b9,b10,b11,b12,b13,b14,b15,b16,b17,b18,        ? Class 1
                             bi(1),0,0,bi(2), c5,c6,c7,c8,c9,c10,c11,c12,c13,c14,c15,c16,c17,c18,        ? Class 2
                             bi(3),0,0,bi(4), d5,d6,d7,d8,d9,d10,d11,d12,d13,d14,d15,d16,d17,d18,   ? Class 3
          bi(5),e2,0,bi(6),e5,e6,e7,e8,e9,e10,e11,e12,e13,e14,e15,e16,e17,e18,  ? Class 4
                             bi(7),f2,0,bi(8),f5,f6,f7,f8,f9,f10,f11,f12,f13,f14,f15,f16,f17,f18              ? Class 5
                    ; parameters; quietly$
          Matrix  ; wtp_c2=b(19)/b(22)
     ; wtp_c3=b(37)/b(40)
                    ; wtp_c4=b(55)/b(58)
                    ; wtp_c5=b(73)/b(76)
                    ; wtp_i=[0/wtp_c2/wtp_c3/wtp_c4/wtp_c5]$
          Matrix  ; clpro_i=classp_i$
          Matrix  ; wtp_m=clpro_i*wtp_i$
          Create  ; wtp1=wtp_m$
          Calc    ; med_1=med(wtp1)$
          Matrix  ; medis1=[medis1/med_1]$
          Delete  ; wtp1$
     Endprocedure

     Execute      ; n=900;procedure=median_w;silent$
     create       ; safety=medis1$

     dstat        ; Rhs=safety$
     calc         ; list; mdwtp1=qnt(safety,0.025)$
     calc         ; list; lwwtp1=qnt(safety,0.975)$
     calc         ; list; lwwtp1=qnt(safety,0.75)$
```

Appendix 7. Cost Estimation

Designing the project is assumed to be conducted in the first year. 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 will be used as a more cautious approach for the sensitivity analysis although those cases hardly ever occur.

Project 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 S. Korea. This period can be used as an institutional business life of the water treatment systems.

To justify the setting of the project service life, it is useful to look into the physical service lives of the two facilities. The two advanced treatment systems consist of ozonization equipment and the GAC concrete structure. The technical properties of the equipment and concrete structure imply the project service lives of the two options. In this regard, the Korean Appraisal Board (2013) reports the service lives of tangible fixed assets in terms of the technical properties.

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. When the costs occur first and the returns will follow, a longer business life usually provides a higher NPV and (or) B/C. However, some scenarios with shorter business will also be explored in the cost-benefit analysis.

Social Discount Rate

The social discount rate plays an important role in calculating the present values of costs and benefits. In cost-benefit analysis, economic feasibility usually has an inverse relationship with the discount rate. A rise in the social discount rate usually increases expenditure, and decreases return. Therefore, the risk comes from an increase in the social discount rate. The legal social discount rate for calculating the present value is set at 5.5% according to the General Guideline of Preliminary Feasibility Study of the Korea Development Institute (2013); however, the growth of the Korean economy has recently been depressed along with the world economic situation. Therefore, it is reasonable to reconsider the discount rate.

There are two main ways of estimating the social discount rate: social rate of time preference (SRTP) and marginal social opportunity cost of capital (MSOC). The social discount rate can be regarded as the social opportunity because it substitutes the return to investment in the private sector (Watson, 1992). Even though there is no agreement in setting the social discount rate, many countries in Europe and the U.S government use the SRTP approach with rates varying between 3% for Germany and the US, and 5% for Italy (Spackman, 2008).

Choi and Park (2015) estimated the social discount rate in S. Korea and report that the social discount rate is between 3.3% and 4.5%, which is approximately one percentage point less than the institutional rate of the Korean government. This seems reasonable when considering the present economic conditions, including the decrease in GDP growth triggered by low fertility per household and fast aging in S. Korea and the drop in the interest rate caused by a decrease of saving rate. In our benchmark results, we use a social discount factor of 4.5% but allow this to range between 1% and 10% in our sensitivity analysis.

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 S. Korea, the feasibility of public projects is usually investigated. Thus, the investigating costs can be included in the cost of the basic design.[26]

Cheongju Waterworks

The target waterworks on which this research focused is the Cheongju Waterworks, which is run by Korea-Water, owned by the Korean government. Cheongju Waterworks has been providing tap

[26] The Korean government has introduced electronic procurement for public contracts in order to save contracting costs (Enforcement Decree of the Act on Contract to which the State is a Party, South Korea). Therefore, the marginal contracting cost is considered to be close to nil so the cost is not calculated in the total cost in this research.

water to Cheongju City citizens since 1987. The total capacity of the waterworks is 596,000 m^3 per day but 193,000 m^3 per day is for supplying industry; therefore, 403 thousand m^3 per day is for drinking tap water. A utilization rate (defined as the fraction of supply to capacity) in waterworks should be assumed for measuring the operating costs because the operating cost will be proportional to the rate. Between 2010 and 2015 the utilisation rate has increased year on year from 38.0% to 47.7% (Korea Water). To be prudent, the utilisation rate of 2015, is used to measure operating costs.

Construction Costs

In 2008, the Office of Waterworks of Seoul Metropolitan Government examined the unit cost of constructing two advanced treatment systems in S. Korea and published the data for reference and precedent. Table A7.1 shows the unit cost.

Table A7.1 *Unit cost of constructing two advanced treatment systems adjusted for inflation*

Capacity	thousand m^3/d	100	200	400	700	1000
Granular Activated Carbon	KRW thousand (USD)	117.4 (100.13)	109.0 (92.96)	93.7 (79.91)	89.0 (75.91)	80.6 (68.74)
Ozone	KRW thousand (USD)	32.7 (27.89)	30.5 (26.01)	27.2 (23.20)	25.1 (21.41)	21.8 (18.59)

Note. The exchange rate is based on 31/12/2015.

Because 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[27], 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 A7.2 shows the total costs including the estimation of design costs and construction supervision costs.

Table A7.2 *Estimation of costs of design and construction supervision*

KRW thousand	Sum	Basic design	Working design	Construction supervision	Construction
GAC (USD thousand)	39,868,162 (34,003)	532,432 (454)	1,072,415 (915)	502,223 (428)	37,761,100 (32,206)
Ozone (USD thousand)	11,573,257 (9,871)	154,559 (132)	311,309 (266)	145,789 (124)	10,961,600 (9,348)
Sum (USD thousand)	51,441,419 (43,873)	686,991 (586)	1,383,724 (1,180)	648,012 (553)	48,722,700 (41,555)

Note. The exchange rate is based on 31/12/2015.

To further justify the estimates of the unit construction costs, the costs of eight previous projects installed the same treatment systems in S. Korea were analysed and compared with the costs for Cheongju Waterworks (KRW 127,645 based on 2015 prices). The unit cost of the eight previous projects range from KRW 60,960 to 153,425 for the Ozone plus GAC systems.[28] Therefore, the estimates of the

[27] 27.2+93.7=120.9, 120.9*403=48,722.7

[28] Ministry of Environment, South Korea, 2009. The unit costs based on 2015 price were calculated by using the producer price index.

two advanced treatments in the target waterworks are acceptable for investigating the feasibility of the project and the values can be used for basic estimates for the two alternatives. The range is used for sensitivity analysis in the cost-benefit analysis. In particular, the highest value of the unit cost, KRW 153,425, acts as an upper bound for estimating the construction cost.

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 ozonisation and GAC facilities of two waterworks of Korea-Water are explored. The study reveals that the operation costs for GAC are nearly constant, but the ones of ozone treatment shows the merits of economies of scale.

We use the upper bound from Lee et al (2008), 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.