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Evaluating the Feasibility of an Investment for Improving Drinking Water Quality in South Korea

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A thesis submitted for the degree of Doctor of Philosophy in Economics.

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ABSTRACT

This dissertation aims to test the feasibility of improving the quality of drinking water in a target area in South Korea. The problem with drinking water quality is caused by pollution of the water environment. Most waterworks in South Korea are unable to handle problems like an unpleasant taste or odour in tap water. Improving raw water quality through prevention of water pollution is explored in pursuit of a long-term solution. However, this research focuses on advanced water treatment systems for a short-term solution and mainly tests the extent to which an investment in one chosen waterworks is feasible. Cost-benefit analysis (CBA) is used to test the feasibility of two advanced water treatment systems: granular activated carbon (GAC), and ozone plus GAC treatment. Three main steps are involved: measurement of the social benefits, cost estimation of the two alternatives and the CBA.

Choice experiments are chosen for measuring the benefits with three alternatives: the status quo, GAC, and ozone plus GAC. Four key attributes are selected: safety, taste and odour, colour and cost. The experimental design consists of 32 choice cards. Three types of treatment for hypothetical bias are used: budget constraint reminder, cheap talk and an honest priming task. In July/August 2015, 573 people participate in the survey; ineffective data, potential label heuristics, and outliers are filtered. Thus, 406 data items are examined for representativeness of the sample regarding socioeconomic factors and used in the analysis.

The marginal willingness to pays (MWTPs) is estimated using three types of logit models (multinomial logit, random parameter logit and latent class logit). To detect the effectiveness of the treatments for mitigating hypothetical bias, dummies and interaction terms are included in the models and the coefficients of the variables are examined. After measuring the social benefits using MWTP, the cost of installing the two alternatives is estimated. While the mean MWTP is the correct measure to use from the standpoint of economic efficiency, the median WTP is probably the more appropriate measure to assist a democratic decision-making

process and can be considered a more cautious value to avoid hypothetical bias. Thus, the median values of WTP are also used for the CBA.

The economic feasibility is tested by comparing the costs and benefits of the two alternatives. Both net present values (KRW[1] 15.8 billion for GAC and 13.1 for ozone plus GAC) are larger than zero. Internal rates of return of the two alternatives are 8.97% for GAC and 7.46% for ozone plus GAC. The benefit to cost ratio of GAC, 1.389, is greater than of ozone plus GAC, 1.225. Note that the GAC seems to be a more robust option than ozone plus GAC in terms of the decision rules of three discount cash flow methods.

Concerning risk and uncertainty, sensitivity analyses are performed using several scenarios with the following factors: increase of discount rate, costs and construction period, and decrease of business life, benefits and beneficiaries. The worst case scenarios would likely be when the social benefits decrease to zero within the business life. In such a case, the three feasibility values cannot sustain the validity of the two alternatives.

In conclusion, the results of this research suggest that investment in the two advanced water treatment systems is feasible, but it depends on situations that may change in practice, such as reduction in the business life. The research also shows that prevention of water pollution can and should be a complementary approach for supplying safer and cleaner drinking tap water. Protecting the water catchment area along with the installation of the two advanced water treatment options should be considered for a more comprehensive and sustainable solution in the long run.

Keywords: Drinking Water Quality, Water Pollution, Protection of Catchment, Stated Choice Methods, Choice Experiments, Levels of Attributes, Experimental Design, Sample Size, Hypothetical Bias, Survey Methods, Random Parameter and Latent Class Logit, Willingness to Pay, Cost-Benefit Analysis, B/C ratio, Net Present Value, Internal Return Rate, Sensitivity analysis.

[1] South Korea Won

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I am responsible for all mistakes in the thesis.

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List of Abbreviations

AIC	Akaike's Information Criterion
ANA	Attribute Non-Attendance
AUD	Australian Dollar
B/C	Benefit to Cost ratio
BIC	Bayesian Information Criterion
BOD	Biochemical Oxygen Demand
CBA	Cost-benefit Analysis
CE	Choice Experiments
CSR	Corporate Social Responsibility
CVM	Contingent Valuation Methods
DO	Dissolved Oxygen
FAA	Full Attribute Attendance
GAC	Granular Activated Carbon
GBP	Great British Pounds
GDP	Gross Domestic Product
IIA	Independence from Irrelevant Alternatives
IRR	Internal Rate of Return
KDI	Korea Development Institute
Korea-Water	Korea Water Resources Corporation
KRW	South Korean Won
LCM	Latent Class Logit Model
LPCD	Litre Per Capita Day
MD	Marginal Damage
MNL	Multinomial Logit

MSOC	Marginal Social Opportunity Cost of Capital
MWTP	Marginal Willingness to Pay
NOAA	National Oceanic and Atmospheric Administration, U.S.
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squared
PMB	Private Marginal Benefit
PMC	Private Marginal Cost
RP	Revealed Preference methods
RPL	Random Parameter Logit
SMB	Social Marginal Benefit
SMC	Social Marginal Cost
SP	Stated Preference methods
SPTP	Social Rate of Time Preference
TCU	True Colour Unit
USD	United States Dollar
WTP	Willingness to Pay

Chapter 1. Introduction

1.1 Problems of Drinking Tap Water in South Korea

The subject of this thesis is related to drinking tap water in South Korea. Two facts can describe the starting point. One is the problem; most South Koreans are not satisfied with the quality of drinking tap water. The other is the solutions, such as installing new advanced treatment systems or improving the raw water quality in the catchment area. The problem is that many Koreans complain about unpleasant experiences of an earthy smell and fishy taste from drinking tap water. Consequently, the proportion of Koreans drinking tap water is very small (Beaumais et al., 2010). Table 1.1 shows the proportion between 2009 and 2011.

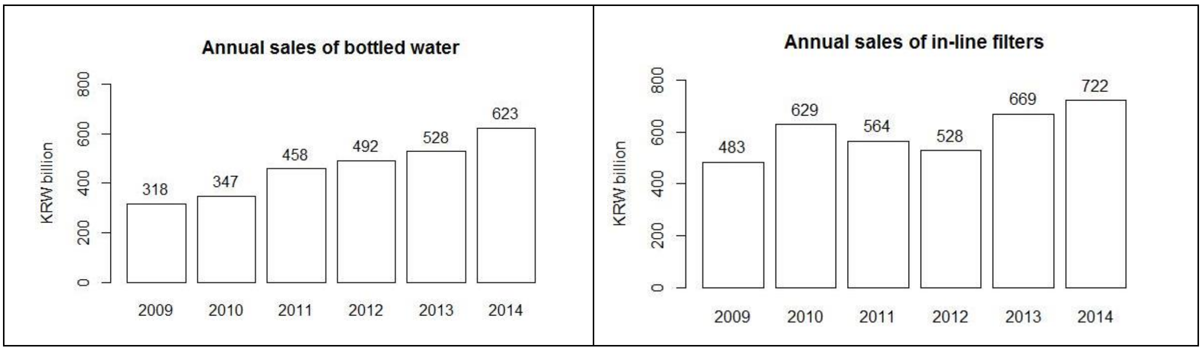
Table 1. 1 *Proportion of people drinking tap water as it is in South Korea*

Year	2009	2010	2011
Percentage	3.0	4.1	3.2

Note. Ministry of Environment, South Korea[a] , 2013.

Only a few of Koreans drink tap water as it is. This implies that almost Koreans are dissatisfied with the quality. Thus, it can be presumed that many Koreans have already adopted alternatives such as drinking bottled water or using in-line filters, devices installed on any water line usually to clean tap water for drinking. Figure 1.1 shows the nationwide annual sales of bottled water and in-line filters from 2009 to 2014 in South Korea.

Figure 1. 1 *Nationwide annual sales of bottled water and in-line filters in South Korea*



Note. Source from the Database of the Korean Statistical Information Service. KRW (South Korea Won)

Since 2009, the nationwide trend of sales of bottled drinking water and in-line filters in South Korea have been increasing. This likely means that Korean people have already reacted to the quality of drinking tap water not being good enough to drink as it is. Table 1.2 shows the average spending on bottled water per household.

Table 1. 2 *Monthly spending in bottled water per household in KRW and U.S. Dollars (USD)*

KRW	2009	2010	2011	2012	2013	2014
Monthly spending (USD)	1,377 (1.18)	1,454 (1.28)	1,904 (1.65)	2,028 (1.89)	2,151 (2.04)	2,506 (2.28)

Notes. Source from the Database of the Korean Statistical Information Service. These values are calculated as nationwide annual sales of the bottled water divided by the number of household plus 12 months in South Korea.

The average monthly spending on bottled water per household increased from KRW 1,377 (USD 1.18) in 2009 to 2,506 (USD 2.28) in 2014. These costs represent very small portions (0.06 %), of the average monthly household income (KRW 4.42 million) in South Korea. These values will be explored in more detail in Chapter 5. Table 1.3 shows the comparison of monthly spending on bottled drinking water per household between the top five countries in consuming bottled drinking water per capita in the world and South Korea.

Table 1. 3 *Monthly Spending in purchasing drinking bottled water of six countries*

Country	United States (U.S)	China	Mexico	Japan	Germany	South Korea
Sales per year in 2014 (USD billion)	18.8	18.5	7.8	6.9	5.2	0.6
Household (million) (year)	134.0 (2014)	248.4 (2012)	31.6 (2012)	49.1 (2005)	37.6 (2011)	19.6 (2014)
(A) Monthly spending in bottled water (USD)	11.70	6.21	29.19	11.72	11.53	2.28
Household expenditure[1)] in 2015 (USD billion)	12,003	7,369	1,454	2,854	2,039	824
(B) Monthly Household expenditure per household[2)] (USD thousand)	7,464	2,563	3,840	4,844	4,519	3,505
Proportion of (A)/(B) (USD)	0.16 %	0.24 %	0.76 %	0.24 %	0.26 %	0.06 %

Notes. Clarke, 2016. The U.S Census Bureau, 2016. National Bureau of Statistics, China, 2013. United Nations Statistics Division, 2011. Source from Deutschland Census Database.[1)] The data were from the database of OECD, and [2)] the values was the household spending divided by the household and 12 months.

The values of the monthly spending on bottled water are calculated as sales per year divided by number of households and 12 months by country. As shown in Table 1.3, South Koreans' monthly consumption of bottled water is lower than that of the top five countries worldwide. The proportion of monthly spending on bottled water per household is also lower in South Korea. Even though the bottled water is an alternative to drinking tap water, it doesn't seem to be a main option in South Korea. As shown in Figure 1.1, many Koreans purchase in-line filters every year. Thus, in-line filters are also an alternative to drinking tap water. In the case of in-line filters, it is more important to look at the average cost of maintaining in-line filters per household. Park et al. (2006) report that the average annual cost of maintaining an in-line filter per household is about KRW 21,337 (USD 23.05). Those values reveal the preference among Koreans regarding consuming drinking tap water. In this respect, Um et al. (2002) study the revealed willingness to pay for improving the quality of drinking tap water in South Korea. They estimated the WTP as USD 4.2 ~ 6.1 per month; these values are used later for comparing the willingness to pay for improving the quality of drinking tap water. This will be explored in the literature review.

Consumers' distrust of the water industry may indicate why many Koreans are dissatisfied with the quality of drinking tap water. Kim et al. (2016) conduct a nationwide survey of 1,000 Koreans in 2014 and report the social perceptions related with tap water in South Korea. Table 1.4 shows perceptions of the reliability of organisations related to drinking tap water in South Korea.

Table 1. 4 *Perceptions of the reliability of organisations related to drinking tap water in South Korea*

Highly distrusted	Distrusted	Trusted	Highly trusted
14.1 %	58.0%	27.4%	0.5%

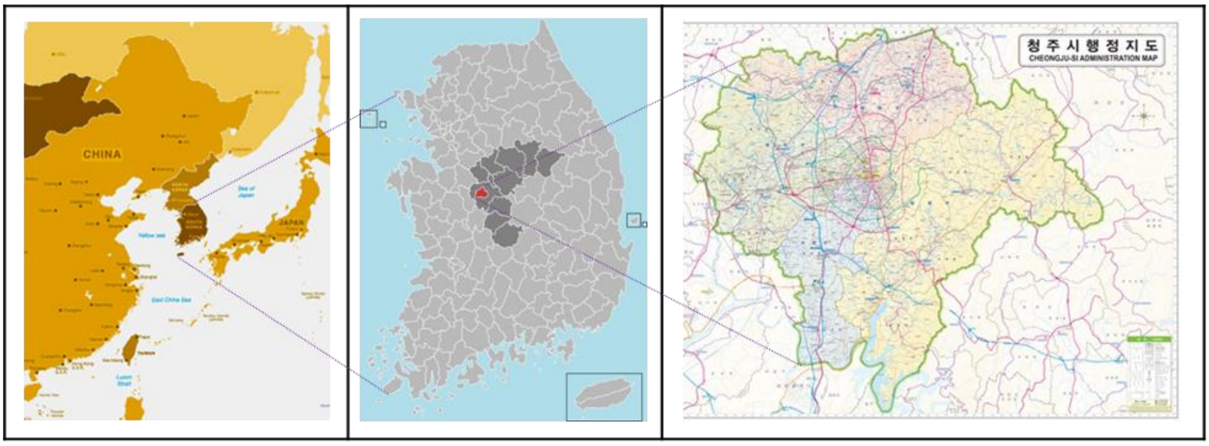
Note. Kim et al., 2016.

The proportion of respondents who trust the organisations related to drinking tap water is reported at 27.9% while the proportion of people who distrust are at 72.1%. This may be why many Koreans do not like to drink tap water as it is, as shown in Table 1.1. Subsequently, the Korean government wanted to resolve the issue and decided to improve drinking tap water quality. However, it would be difficult to measure the economic feasibility of investment for improving drinking water quality nationwide because there are many differences in socio-economic factors between cities and areas. For this reason, this research focuses on one city supplied by one chosen waterworks to investigate economic feasibility.

1.2 Cheongju City

The purpose of this research is to test the feasibility of new advanced water treatment systems for supplying drinking tap water in Cheongju City, South Korea. Before exploring the methods for improving drinking tap water in the target area, it is useful to look at the target area. Cheongju City is the capital city of the province of Chungcheongbuk-Do, which is located in the middle of South Korea, about 125km from Seoul; the capital of South Korea. Figure 1.2 shows the location of the city.

Figure 1. 2 *Location of Cheongju City*



Note. Source from Cheongju City government.

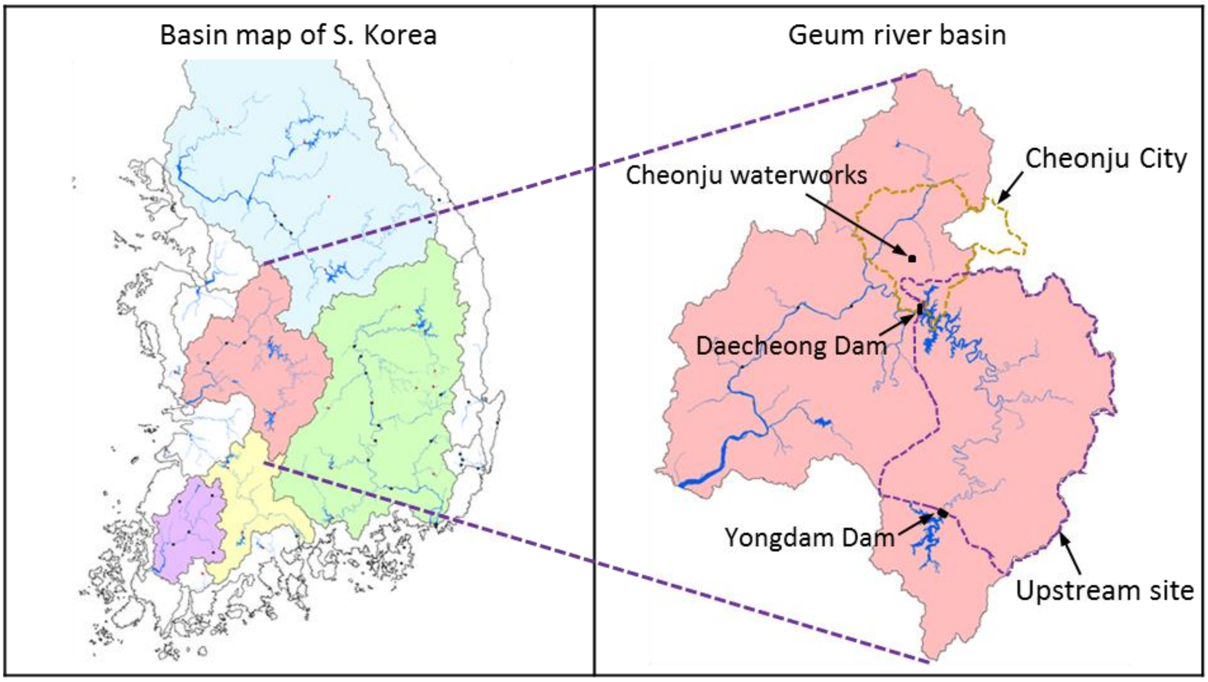
The population of the city was 843,286 at the end of 2015, and the number of households was 324,341 (the average family size per household was 2.60). The area is approximately 940.3 km^2. There are four distinct seasons; spring is mild and dry, summer is very hot and humid, autumn is clear and cool, and winter is very cold. The average temperature is 11.6 ℃, and the average annual precipitation is 1,200mm usually concentrated from June through August. Thanks to the abundant water resource of Lake Daecheong located in a nearby southern site, Cheongju City can sufficiently use the water resource and provide drinking and industrial water to the people in the city. In a drought season like spring, green algae usually break out because the algae need nutrients, plenty of sunlight, high temperatures and little rainfall. Spring in Korea is full of conditions conducive to such outbreak. Consequently, the algae give rise to the problems of unpleasant taste and odour in the drinking tap water in the area.

1.3 Geum River Basin

1.3.1 Overview of the Basin

People may question how to resolve the issue of drinking water. Several approaches can be used, like installing new advanced water treatment systems or improving raw water quality in the watershed. Some people think that new advanced water treatment systems would not be necessary any more if the raw water quality in the basin improved. Others argue that it would be difficult to take raw water to the level that the new advanced water treatment systems would not be necessary. In other words, improving the raw water quality might be very difficult to achieve at a level that would eliminate the need for advanced water treatment. Therefore, a combination with other approaches should and could be taken into account to supply safe and clean drinking water. In this regard, it is useful to describe the river basin before discussing the alternative approach. Figure 1.3 shows the location of the Geum River Basin.

Figure 1. 3 *Location of the Geum River Basin in South Korea*



Note. Source from Korea-Water.

Kim et al. (2013) report that 3,302,812 people (1,376,172 households) live in the area. The catchment area is approximately 9,911.83km^2, which is about 10 % of the width of South Korea (99,720km^2) and the river length is 397.79km. As shown at the right of Figure 1.3, Lake Daecheong created by Daecheong Dam is located in the middle of the basin, and Cheongju Waterworks pumps raw water from an intake close to Daecheong Dam.

If the raw water quality improves, the waterworks can use cleaner raw water. To ensure safe and clean water, people must try several approaches. The most desirable solution is improvement of raw water quality in the watershed because then most people can enjoy the clean water environment. If the process of water pollution continues, the water quality will become worse and worse to the point that it is no longer possible to treat and use for drinking. In this regard, improvement of the raw water quality in the lake should be considered a complementary approach to investing in the waterworks.

1.3.2 Water Pollution

Water pollution has spread according to economic development across the world. The main sources of water pollution are domestic sewage, industrial and agricultural wastewater and livestock excrement (Norwood, et al., 2015). Table 1.5 shows the main sources of water pollution according to three different studies.

Table 1. 5 *Sources of Water Pollution*

Pollutant Sources	Source type	Pollutant type	water quality problem
Domestic sewage	Point	Pharmaceuticals, hormones	Ecotoxicological effects in rirvers, feminization of fish
Industrial wastewater	Point	Heavy metal, chemicals	Metal remobilization, acute toxicity
Agricultural farm land	Non-point	Fertilizer, pesticides	Contamination of ground and surface water
Livestock	Point, Non-point	Excrement	Eutrophication in rivers, lakes, and seas

Note. Schwarzenbach, et al.,2010. Jeong et al., 2013. Norwood, et al., 2015.

The sources of water pollution can be classified into two main categories: point and non-point pollution sources. Point pollution sources refer to pollutants that come from a certain point or a relatively narrow area, and it is possible to clarify the point where pollutants are discharged. Domestic sewage and industrial wastewater are examples. On the other hand, non-point pollution sources refer to pollutants that come from unspecified discharge routes, such as urban road drains and agricultural drainage (Jeong, et al., 2013). Agricultural farm lands are the typical example. Livestock excrement is somewhat tentative. If the livestock is group-raised in a narrow place, that place could be a point pollution source. When the livestock is put out to pasture, it is a non-point pollution source.

The domestic sewage and industrial wastewater are point pollution sources which are considered to be comparatively easy to control because they can be detected when factories are registered and permitted before their construction. The pollutants from domestic and industrial usage are discharged after treatment in many developed countries (Schwarzenbach, et al., 2010). However, there are still public concerns about potential pollutants, such as pharmaceuticals, hormones, heavy metals, and chemicals even though the wastewater is discharged after treatment because the modern wastewater treatment technologies cannot completely control every pollutant.

Agricultural farm land seems to the most problematic pollution source because it has intrinsically unspecified sources. The main components of fertilizer are nitrogen and phosphorus, which feed crops, vegetables, and fruit trees. Plants in farm land cannot consume all the fertilizer applied to a field. Some amount of the fertilizer leaves the farm land due to runoff of surface soil and leaching of the subsurface. The excess fertilizer feeds plants, trees growing along the side of a field and bacteria and algae in rivers and lakes. If fertilizers arrive at a body of water (e.g. river or lake) their arrival might lead to an outbreak of bacteria and algae. When the population of bacteria and algae grows in a river and lake, it consumes the oxygen in the water so that other aquatic lives cannot survive because they cannot take in sufficient oxygen. This phenomenon is called “eutrophication”.

Livestock excrement is one of the main sources of water pollution. In dry regions like Middle East countries, livestock manure has been a main source of fertilizer. However, livestock excrement contains excessive nitrogen and phosphorus (Choi et al. 2015). If the livestock excrement is discharged into a watershed, it gives rise to eutrophication by the same process as explored above.

In addition to the four pollution sources described above, other types of pollution can be responsible for the water pollution in a specific area. Mining is one of these sources. Leaching agents, heavy metals, and acids from abandoned mines can lead directly to water pollution. Areas such as disused military camps are suspected of discharging a variety of hazardous leachate. Also, various types of garbage cause water pollution including oil, manure, food waste and plastic bags and empty bottles from roads, camps, fishing grounds, amusement parks and water facilities. The biggest problem with water pollution is that the excessive amount of pollutants paralyses the self-purification capacity of rivers, lakes, and seas. Contaminated water can cause a variety of waterborne infectious diseases and dermatitis. Therefore, it is better to reduce pollutant emissions as far as possible and to purify remaining pollutants before they enter rivers and lakes.

The main causes of water pollution are different in different areas of the world. Norwood, et al. (2015) summarises the main causes in various areas. They report that fertilizer is the main source of water pollution in the Gulf of Mexico and livestock manure accounts for most of the water pollution in the Illinois River and the Chesapeake Bay. In the U.S. Great Lakes, phosphorus from dishwashing detergents is the main pollutant.

1.3.3 Causes of Water Pollution in the Lake

It is helpful to understand the level of lake's contamination. To examine the level of lake contamination, two types of water quality standards are used. One is biochemical oxygen demand (BOD[2]); the other is dissolved oxygen (DO[3]). Figure 1.4 shows the comparison of the BOD and DO between three countries and Lake Daecheong.

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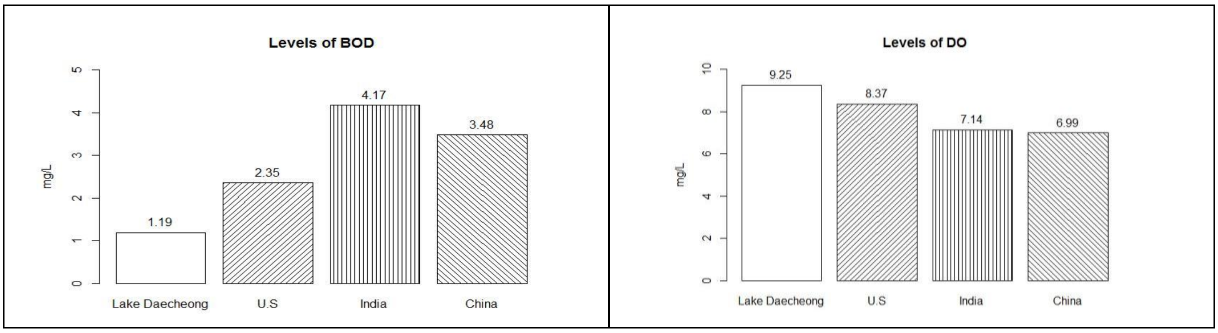
[2]BOD is the milligram amount of dissolved oxygen needed by aerobic biological organisms to break down organic material present per litre of water sample during 5 days of incubation at 20°C, used as a surrogate of the degree of *organic* pollution of water. To express the level of the indexes, the unit of parts per million (PPM) is used. If BOD is 10 PPM, it means that the amount of oxygen consumed by microbes to decompose pollutants contained in one million gram of water (1 m^3) within a certain period of time, five days, is 10 gram. Subsequently, it is necessary to wait to measure the BOD. When the BOD of water is 2 PPM or less, the water can be used as a source of drinking water. If the BOD of water exceeds 5 PPM, rivers, lakes, and seas are considered to lose the self-purification capacity.

[3] DO defines the amount of oxygen in a body of water as an indication of the degree of health of the water and its ability to support a balanced aquatic ecosystem; an increase in DO signals lower levels of pollution.

Figure 1. 4 *Comparison of BOD and DO between three countries and Lake Daecheong*



Notes. The values for Lake Daecheong were calculated as the average of monthly values from 2010 to 2014 (data from Korea-Water). The values for U.S and India are calculated from 1998 to 2002 data and the values for China were calculated for the year of 1995. The data for the three countries were from Greenstone et al., 2014.

The value of BOD for Lake Daecheong is lower and the value of DO is higher than the values of the three countries, which means that the levels of pollution in the lake are not as bad as in the other countries[4]. Although the pollution levels for Lake Dacheong are not as bad as other countries, this does not mean that the water quality for the lake need not to be improved. Because green algae have broken out in the lake in the spring and summer this problem must be resolved. In this sense, the causes of the pollution in the lake also should be explored.

Kim et al. (2013) study the causes of green algae rampancy and also suggest solutions for preventing the outbreak of green algae in the lake, as shown in Table 1.6.

Table 1. 6 *Methods for controlling the water pollution in the basin*

Method	Explanation
Livestock sewage treatment facilities	Installing new livestock manure treatment plants in the upstream areas to treat the manure.
Artificial swamps	Building artificial swamps for deterring an inflow of water into the catchment. In the swamps, aquatic plant can resolve pollutants.
Planted waterways	Growing aquatic plants which can resolve pollutants, in the waterways.
Detention ponds	Building detention ponds to deter an inflow of water into catchments.
Detention facilities of sewage treatment plants	Building detention facilities of sewage treatment plants, which can deter an inflow of water into the catchment.

[4] The water pollution values for India were calculated by using city-rivers and the values for China were weighted by a number of monitoring sites within six major river systems. The values for the U.S. were calculated across the country.

Note. Kim et al., 2013.

The solutions they suggest focus on treating domestic, industrial, and livestock sewage. Therefore, the solutions focus on the effects of water pollution rather than the causes. These solutions can help in partially reducing water pollution. However, to solve the problem of water pollution more efficiently, other approaches focusing on the causes should be taken into consideration.

The upstream site of Daecheong Dam is approximately 3,204.4km^2, and there are 109 streams. The census shows that 224,896 people live there in 2012.Table 1.7 shows the main causes of pollution loading amounts according to the index of BOD and total Phosphorus (T-P)[5] in Lake Daecheong.

Table 1. 7 *Pollution loading amount in the lake*

kg/day	Sum	Livestock	Farming	Industry	Domestic
BOD (percentage)	102,685.3 (100 %)	64,749.8 (63.1 %)	15,480.1 (15.1 %)	11,357 (11.1 %)	11,094.5 (10.8 %)
T-P (percentage)	9,569.3 (100 %)	5,084.5 (53.1 %)	862.2 (9.0 %)	3,308.0 (34.6 %)	315 (3.3 %)

Note. Kim et al., 2013.

As shown in Table 1.7, the livestock sewage is the greatest loading source for the pollution levels in the two indications. Wastewater from farmhouses and livestock facilities is more contaminated than sewage in terms of concentration. Livestock sewage is the main cause for water pollution which gives rise to deterioration of the raw water quality in the catchment. People might ask why livestock sewage is the main cause of water pollution in the lake. Table 1.8 shows the daily amounts and types of pollutants in the Geum River Basin.

[5] T-P is defined as the sum of all phosphorus compounds in a body of water. Phosphorus is an essential nutrient of plants and animals and exists primarily as orthophosphate or in organic compounds in water. Phosphorus flows in a body of water from fertilizers used in farming lands, cleaners used in industry and household sewage. A High level of phosphorus in a body of water causes eutrophication or the premature aging of the body of water. This process depletes sunlight and oxygen in the water body so it affects fish and aquatic life.

Table 1. 8 *Daily amounts of types of pollutants in the basin*

m^3/day	Amount of produced	Amount of treated	Number of treatments	Rate of treated
Domestic + Industry	58,288	44,663	152	76.6%
Livestock	6,009	188	3	3.1%

Note. Ministry of Environment, South Korea., 2016.

As shown in Table 1.8, the sewage of domestic and industry is treated at 76.6%, but the sewage from livestock is treated at 3.1% (Ministry of Environment, South Korea, 2016). In addition, Jeong et al. (2013) report that livestock sewage is only 1% of the amount of overall wastewater generated, but accounts for 37 % of the water pollution load. They also argue that the BOD load due to livestock sewage is about 90 times higher than that from domestic wastewater (Jeong et al., 2013). Even though other non-point pollution causes stem from growing rice and other types of farming, Kim et al. (2012) report that the main cause of pollution in the lake is livestock sewage. Other studies have been undertaken to detect the causes of water pollution in Lake Daecheong. Park (2014) studies the main cause of pollution in the largest branch of the lake, So-Ok-Cheon River. He also argues that the main cause of water pollution in the lake is livestock sewage. Several studies have revealed that livestock sewage is the main cause of water pollution in the catchment (Kim et al., 2012; Kwon et al., 2002; Lee, 1999).

The pollution source from farming should be discussed. As shown in Table 1.7, the pollution loading amount from farming is 15.1% in terms of BOD and 9.0% in terms of T-P. Therefore, farming in the basin has had a relatively small impact on water pollution. In South Korea, most farmers cultivate rice on their land. Thus, farming in South Korea is considered as a non-point pollution source. Song (2014) argues that it is difficult to reduce water pollution by installing specific facilities for non-point pollution sources because the non-point pollution sources have a wider range of emission. To control the non-point pollution sources, other approaches should be considered, such as dealing with the causes of water pollution not the effects.

Among the residents in the basin (3,302,812 people), the residents upstream of the lake are estimated at 224,896 (6.8%). Table 1.9 shows the change in residents living in the basin.

Table 1. 9 Change of the residents living in the basin

Year	2010	2011	2012	2013	2014
population	227,436	226,632	224,896	224,538	222,710
Area under cultivation (hectare)	55,394	54,856	55,740	54,891	54,797

Note. Source from the database of the Korean Statistical Information Services.

The population in the basin has decreased steadily and the area under cultivation showed a small reduction between 2010 and 2015. It can be assumed that the farming land decreases according to the population reduction.

In the upstream area, many farms raise livestock. Table 1.10 shows the number of livestock types in the area.

Table 1. 10 *Number of types of livestock in the area*

Sum	Chicken	Pig	Cow	Dog	Sheep	Deer	Horse
2,975,750	2,768,968	85,284	76,072	37,454	6,316	1,592	64

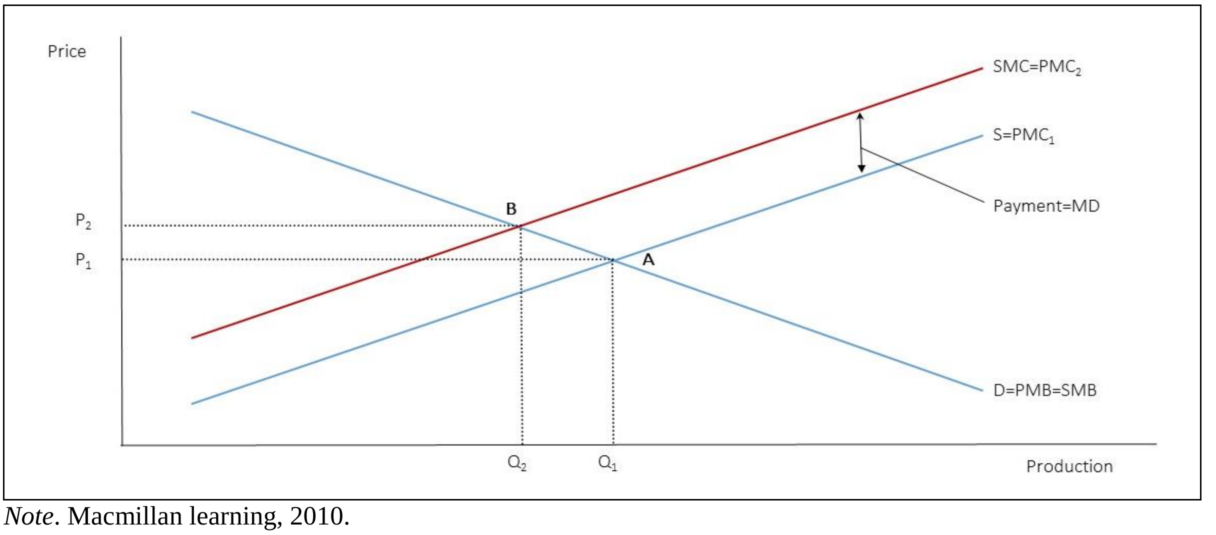
Note. Kim et al., 2013.

Cows, pigs and chickens are the main types of livestock. Even though other sources reach the catchment, the livestock excrement causes the main water pollution in the catchment.

1.4 Prevention of Water Pollution

So far, the main causes of water pollution in the target catchment have been explored. To improve the water quality in the basin, other approaches can be considered in terms of environmental economics. Water pollution is an economic externality; specifically, it is a negative economic externality leading to external costs. Figure 1.5 shows the negative externality problem between the residents upstream and downstream.

Figure 1. 5 *Elimination of Market Failure through Private Negotiation*



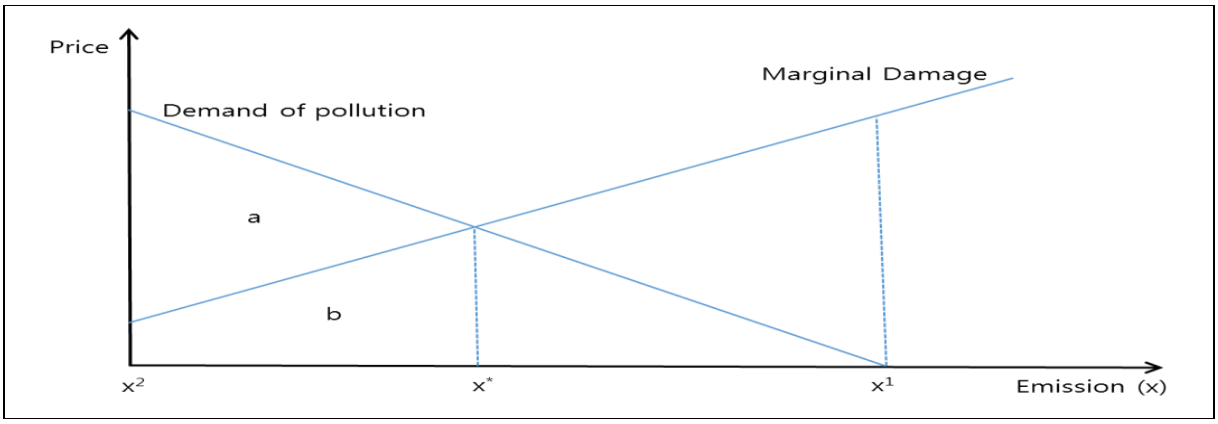
Note. Macmillan learning, 2010.

In Figure 1.5, the horizontal axis represents the amount of production by residents upstream and the vertical axis shows the price. Residents upstream release pollutants for production activities. In Figure 1.5, *D* represents the demand of pollution equal to the private marginal benefit (*PMB*) and social marginal benefit (*SMB*),while, *S* represents the private marginal cost (*PMC*) which is not equal to the social marginal cost (*SMC*). In this case, the *SMC* is equal to the sum of *PMC* and marginal damage (*MD*) leading to social marginal costs being larger than private marginal costs, which implies a negative production externality per unit of production of residents upstream.

To internalise the negative externality, those who cause the externality need to pay the cost. By this the private marginal cost will increase to be equal to the social marginal cost and the level of pollution will decrease from Q_1 to Q_2. Administrative regulations to prevent water pollution have been implemented in many countries around the world. Imposing taxes or penalties on those who pollute is the most typical way to prohibit water pollution. If the central or local governments impose a tax per unit of emission in the upstream areas, the residents upstream emit a level of pollutants equal to the marginal value of the cost per unit of the pollutant. Therefore, the emission of pollutants by the residents upstream will decrease to the point of Q_2 where social marginal benefit equals social marginal cost.

Figure 1.6 shows the way in which the market failure can be eliminated through private negotiation according to Gravelle and Rees (2004).

Figure 1. 6 *Elimination of Market Failure through Private Negotiation*



Note. Gravelle and Rees, 2004.

In Figure 1.6, the horizontal axis represents the amount of pollutants emitted by residents upstream and the vertical axis shows the price. Residents upstream would release pollutants for consumption and production activities. Therefore, it can be assumed that the residents upstream have a demand for pollutant emission. The demand for pollution can be regarded as a marginal utility of pollutants by the residents upstream. As the residents upstream emit more pollutants, the damage to the residents downstream increases, which can be attributed to marginal damage.

If nobody has the legal right to discharge pollutants into the river, the residents downstream can stop the resident upstream emitting pollutants up to zero, which corresponds to x^2. In this case the resident upstream loses the area $a + b$. However, the social optimum amount of emission will be x^*, where the marginal cost of the pollutant would be equal to the marginal damage of the residents downstream. In this case, the optimal level of emission is larger than zero. Assuming that there is only one resident upstream and another downstream, respectively, private negotiation could take place between the two. If the resident upstream proposes that he or she is going to pay a part of the area, $a + b$ to the resident downstream, the person upstream will be able to discharge the pollutant emission up to the point, x^* where the marginal benefit of pollutant emission is equal to the amount that he or she will pay. If the resident upstream pays $\theta a+b$ (here, $0 \leq \theta \leq 1, therefore,\ b \leq \theta a + b \leq a + b)$, the gain for the resident upstream is the area, $(1 - \theta)a = (a + b - \theta a - b)$. However, the resident downstream could gain profit of the area, $\theta a = (\theta a + b - b)$. Through the private negotiation, both of them can gain the profit, and the pollutant emission can reach to the social optimal point, x^*.

1.4.1 Policies for Externality

In this subsection, policy approaches to prevent water pollution in the basin and catchment are explored. Field and Field (2013) present the public policy approaches to change the way people behave on both the production and consumption sides of triggering the economic externality. They mainly identify two groups for the centralised public policy approaches: command-and-control policies and incentive-based policies. In the command-and-control policies, regulation is a typical approach. Taxes, subsidies, and transferable discharge permits are included in the incentive-based policies.

First, legal regulations for protecting water sources have been implemented under laws, the Water Supply and Waterworks Installation Act of 1962 and the Water Quality Conservation Act of 1991, in South Korea. According to those acts, the water source protection zones are established usually in upstream sites. When the zones are established, many acts triggering water pollution are restrained. If someone violates the laws, then he or she is punished and must pay penalties. According to the Water Quality and Aquatic Ecosystem Conservation Act of South Korea, persons who discharge wastewater or sewage without permission or without proper treatment are punished by imprisonment with labour for not more than five years, or by a fine not exceeding KRW 50 million. For example, in 2015, a company in the upstream of the Geum River Basin was punished with a fine of KRW 5 million because it discharged industrial wastewater without permission. In other countries, legal regulations are also being implemented. For example, in the U.S., the Clean Water Act was established in 1972 to regulate the discharges of pollutants into the water and the quality standards for surface water. In India, the Water Act of 1974 was enacted to enforce water quality protection policies (Greenstone, et al., 2014).

New establishment of water source protection zones in the basin is an alternative for water quality improvement. However, the expansion of water source protection zones can cause political problems. In general, cities and industries have developed the downstream area of the basin, but the upstream areas remain agricultural areas. In such circumstances, the residents in the upstream area oppose expansion of the water source protection zones in their area. In addition, the local governors who have authority to designate the zones are elected by residents according to a democratic process. Therefore, the local governors are reluctant to expand water source protection zones. For these reasons, it has been difficult to expand water source protection zones in the upstream area (Lee, 1999).

In terms of environmental taxes and subsidies, the water use charge according to the Act on the Improvement of Water Quality and Support for Residents of Four Major Rivers of 1998, South Korea may offer another alternative for improving the water quality in the basin. The water used charge is imposed on the residents downstream according to the benefit principle. In the Geum River Basin, the water use charge is imposed and collected from the residents in the downstream areas. Table 1.11 shows the collection of the water use charge of the Geum River Basin between 2010 and 2014.

Table 1. 11 *Collection of the water use charge of the Geum River basin from 2010 to 2014*

Year	2010	2011	2012	2013	2014
KRW billion (USD million)	89.4 (78.5)	94.6 (82.0)	99.2 (92.6)	102.0 (96.7)	102.6 (93.3)

Note. Source from the database of Ministry of Environment, South Korea

The subsidies from the collected charge are provided to the upstream areas to improve the water quality, for example, by installing new sewerage facilities and (or) providing organic fertilizers to the farmers in the upstream areas.

With respect to tradable permits, there have been some successful application cases for water pollution across the world. Borghesi (2008) report on application cases of tradable water pollution rights across the world. In the U.S., 42 programs for tradable rights of fishing and swimming have been started for more than 40% of rivers, lakes, and estuaries to reduce water pollution from nutrients since the 1980's. In Australia, the Australian Agency for Environmental Protection introduced a license system of giving 11 coal mines and 2 electrical centres permission to release limited saline water into the rivers since the 1970s and developed a tradable permits system in 1995. The project is considered a success because the violations decreased and transactions increased after launching the project (Borghesi, 2008). Even though some tradable permit applications are reported to be successful, an application of the tradable permit programs for reducing pollution has not yet been introduced in South Korea. Therefore, tradable permit programs can be considered another approach to reduce the pollution level in South Korea in the future.

1.4.2 Direct Treatment of the Storage

Treating the raw water in storage is another approach to reduce water pollution. Tal (2006) reports that Lake Kinneret (called the Sea of Galilee, which supplies roughly one-third of water in Israel) is and has been treated for reduction of salinity. However, the difficulty in treatment of all the water in the lake is understandable when comparing the amount of water between Lake Daecheong and Lake Kinnert. Table 1.12 shows the details of Lake Daecheong.

Table 1. 12 *Detail of Lake Daecheong*

Catchment area	Annual precipitation	Pondage	Annual inflow	Annual water supply
4,134 km^2	1,230 mm	1,490 million m^3	2,450.5 million m^3	1,649 million m^3

Note. Korea-Water, 2016.

The pondage of water in Lake Daecheong is about 1,490 million m^3 and in Lake Kinnert it is 4,000 m^3. As an estimate, Lake Daecheong can supply about 372,000 times more water than Lake Kinnert. It would be extremely expensive to treat the water in the lake to make it clear. The average unit cost of treating raw water in South Korea is KRW 667 per m3 in 2014 (Ministry of Environment, South Korea, 2014). Simply calculating the costs for treating the amount of water inflow into the lake, the total would be approximately KRW 1,634 billion (USD 1,388 million) per year. Thus, it would be nearly impossible to treat all of the water in Lake Daecheong. Therefore, instead of treating the water directly, other approaches should be considered. Actually, improving raw water quality by protecting the water environment upstream may be a more reasonable approach than treating all the water in Lake Daecheong.

As shown in Table 1.8, just three facilities treat livestock sewage in the basin. If livestock excrement is substantially reduced and managed in the upstream area of the lake, the raw water quality in the lake would be improved. There are many ways to manage livestock sewage suitable to the environment of each country. The first solution is “manure management”. In this regard, the Ministry of Agriculture, Food and Rural Affairs, South Korea (2013) announced the Mid and Long Term Plan for Recycling Livestock Excrement. According to the program, livestock sewage disposal into the ocean has been prohibited in South Korea since 2012, and recycling livestock sewage in substituting chemical fertilizers is set as the first policy target. Since 2013, the Korean government has tried to recycle the amount of livestock manure. Recycling livestock manure is a desirable and reasonable approach to prevent water pollution in terms of controlling the cause instead of the effect.

Many countries regulate livestock manure. In the U.S., livestock farmers must properly manage their livestock manure according to the laws. One such law is Clean Water Act, which obliges livestock farmers to ensure that surface water and groundwater are not contaminated by livestock manure; another is the Federal Water Pollution Control Act, which allows the federal government to enforce water pollution regulations. Emission standards for livestock waste are also regulated; environmental pollution caused by raising livestock is minimised by establishing prohibited areas for livestock breeding (https://www.epa.gov /enforcement/national-enforcement-initiative-preventing-animal-waste-contaminating-urface-and-ground). In the U.K, the Water Resources Act prohibits the expansion of livestock facilities by restricting the distance between the livestock breeding facilities and houses. The amount of manure sprayed on the farmland is also limited (https://www.legislation.gov.uk /ukpga/1991/57/section/85). In Germany, storage of livestock wastewater is not allowed. When stored, the German government prohibits the inflow of contaminants due to rainwater and specifies the BOD concentration of treated effluent as 15–20mg per litre. Permission is required to install a livestock breeding facility. The size of breeding facilities is specified for the prevention of environmental pollution caused by livestock manure, and it is stipulated that licensed facilities should be separated from the housing area by more than 500m (Ministry of Environment, S. Korea, 2011).

In Japan, the water quality standard of effluent water is prescribed by law when treating wastewater. The principle is to return livestock manure as a resource and to reduce it to soil. In addition, different livestock manure standards are set and managed for each species, area, and subject. The regulations related to livestock excrement are stipulated in the Water

Pollution Control Act, Waste Treatment and Cleaning Act, River Law, and Special Measures for Water Quality Protection and the Marine Pollution Act (Choi, 2015).

On the other hand, installing livestock excrement treatment systems may be another approach that focuses on the effect. When installing specific treatment systems for livestock sewage, regional constraints and cultural peculiarities should be studied. Burton and Martinez (2008) assert that cultural concerns prescribes the use of manure to fertilize soils and climate conditions have a major impact on the selection of treatment, the dilution of the waste and the potential for runoff in Japan and Southeast Asia. The major facilities for treating livestock sewage in South Korea are based on biological and physical process (Ministry of Environment, South Korea., 2016). The treatment facilities first separate dregs and urine in livestock sewage. After that, the system decomposes the dregs by using microbes and treats the urine following the wastewater treatment process. Usually, the decomposed dregs are used for fertilizer in farming. Kim, Ji-Won., et al. (2013) suggests that new livestock sewage treatment systems in the upstream site of the lake offer a main practical solution for improving water quality in the basin.

As discussed in subsection 1.4.1, incentive systems such as taxes or subsidies on management of livestock manure can also be an alternative solution. A tax relief system could be provided for better management of livestock manure such as recycling it for organic agriculture. For example, the Organisation for Economic Co-operation and Development (OECD) (2008) has reported that income tax relief on capital expenditure on pollution control facilities has been implemented in European Union countries since 2005. This type of approach can ameliorate the problem of livestock manure before the manure reaches the water catchment.

Additionally, subsidies for best practices with respect to manure management can be offered as an incentive. For example, Pan (2016) reports that the Chinese government introduced a biogas subsidy program in 2005. The program has encouraged farmers growing livestock to install biogas digesters. Wang et al. (2010) suggest that 8% of livestock excrement in China is used to produce biogas in 2006.

As a result, this approach may be more appreciated by the people because they can enjoy a cleaner river environment surrounding their habitat. Therefore, improving river water quality should be tested for an alternative solution. This approach will be explored together with the main approach of installing new advanced water treatment systems, in Chapter 8.

1.4.3 Improving the Raw Water Quality in the Catchment

Improving raw river water quality in the catchment offers another approach to improve drinking tap water quality in the target area. When an analysis integrated with other approaches is conducted, the costs and benefits of the alternative approach will be revealed.

As shown in Table 1.7, the main causes of water pollution in the lake are livestock excrement and farming, which are responsible for about 78.2% of the pollution load in the lake. First, the livestock excrement contains enough nitrogen and phosphorus to lead to eutrophication in the catchment and result in water pollution. Several solutions have been tried in many areas and regions. One potential solution is using manure as a substitute fertilizer for crops. Also, injecting it into the soil instead of spraying would reduce the nutrient runoff. This is understandable because the injected manure would not spill out from the soil as the simply sprayed manure would. No-till system can also affect the water pollution. According to Devlin and Barnes (2009), no-till management might reduce soil erosion. They mention that the no-till management generally increases soil macropores, aggregate stability, and soil surface infiltration rates. Macropores are small channels in the soil made by earthworms, soil cracking, or root development and allow water to infiltrate the soil with speed, which would increase the possibility for rapid downward movement of pesticides and nutrients through the soil. However, tillage system will destroy the macropores. Thus, the no-till system can reduce the runoff of pesticides and nutrients in the soil.

Another potential solution is installing new treatment facilities that can decompose the excrement to match the level needed for nature's plants and crops. The last solution is to reduce meat consumption, which is a fundamental approach. For example, the Dutch government has discussed the issue of reducing meat protein consumption since 2008 (De-Bakker et al, 2012).

With respect to new excrement treatment facilities, the livestock excrement can be treated by the process of decomposing the nutrient and chemical component. Kim, J-W., et al. (2013) study the methods for solving the problems. They also measured the amount of livestock excrement as 5,821m^3per day which the livestock manure treatment systems should manage to prevent outbreaks of green algae in the lake. However, the amount of livestock sewage, 5,821m^3 per day, is discharged without treatment because only three facilities are working to treat part of that amount (3.1%).

Regarding the costs of treating the untreated amount (5,821 m^3per day), the National Institute of Animal Science, South Korea presented the life-cycle cost in 2016. The average cost for treating the livestock sewage per m^3 is calculated as KRW 18,781/$m^3$for 30 years, which is the business life for the facility. As a result, the total cost per year to treat the amount of the livestock sewage would be KRW 39.9 billion (KRW 18,781 x 5,821 m^3/day x 365 days).

Another problem to discuss is related to who should pay the costs for the treatment. In total, 3,302,812 people are reported to live in the basin. The issue of who should pay the costs for improving the river water quality is not simple because many possible combinatorial cases exist with respect to sharing the cost. All people living in the basin would be the maximum number of the payers. In this case, the costs for each household would be at the minimum. If the residents in the target area (Cheongju City) have to shoulder the costs for improving the river water quality, they might feel that such a burden is unfair. When the raw water quality improves, many people around the lake can enjoy the improvement. Moreover, they are not the ones that have caused the pollution.

Assuming that all households in the basin share the costs leads to a lower bound. Table 1.13 shows a comparison of the costs for protecting against water pollution in the catchment.

Table 1. 13 *Comparison of the costs for treating the livestock sewage in the basin*

KRW (USD)	Annual cost for treating the livestock sewage	In the basin	In Cheongju City
Household		1,270,312 (USD 1,082.04)	324,341 (USD 276.27)
Annual Cost per household	39,903,333,365 (USD 34,032,693)	31,412 (USD 26.79)	123,029 (USD 104.93)
Monthly Cost per household	3,325,277,780 (USD 2 836 057)	2,618 (USD 2.23)	10,252 (USD 8.74)

Note. Kim et al., 2013. Cheongju City Government, 2016. The exchange rate is based on 31/12/2015.

If all the citizens in Cheongju City pay all the cost, each household must pay KRW 10,252 (USD 8.74) per month to treat the amount of untreated livestock sewage in the catchment. If all the households in the basin pay, each household will have to pay KRW 2,618 (USD 2.23) per month. However, this cost covers the livestock sewage in the catchment. The entire costs for protecting against water pollution in the catchment will increase when including pollutants from farming and domestic and industrial sewage.

The second main source of water pollution is chemical fertilizer used by farmers in the basin. As discussed in subsection 1.3.2, the nitrogen and phosphorus in fertilizer remains in the soil because they are not used completely by the crops. Therefore, the primary solution for preventing water pollution should be to reduce the use of fertilizer. Several methods can be used to encourage farmers to use less fertilizer in their fields. The first is to increase the tax on fertilizer. Norwood et al (2015) provide examples of a fertilizer tax. For instance, in 2013, the California Water Resource Control Board instituted fees on fertilizer use to make up the cost of treating drinking water polluted with excess nitrogen. The authors also report that fertilizer use in Sweden dropped by 15% to 20% due to a fertilizer tax imposed in 1992. The state of Illinois introduced a fertilizer tax to fund research on the environmental impact of fertilizer and ways to reduce runoff. Even though some Korean farmers would dislike a new fertilizer tax, the Korean government should consider introducing a new fertilizer tax to prevent water pollution in the country.

Other solutions for preventing water pollution are worthy of consideration. Banning cultivating crops close to streams is one approach. For example, the Minnesota government has imposed a ban on crops within 50 feet of a stream to confer a legal protection buffer between most waterways and farmlands (Environmental Working Group, 2014). New technologies in precision agriculture offer another solution by helping farmer apply the proper amount of fertilizer across the field and reduce excess fertilizer. Also, Installation of filter strips as a buffer of unfertilized permanent grass between the crop and the edge of a field would catch fertilizer runoff. Norwood et al. (2015) reported that the filter strips can remove more than half of all fertilizer runoffs, decrease soil erosion and reduce the amount of land for crops. For example, the Iowa government has subsidised programs of installing filter strips. Decreasing the subsidies for chemical fertilizer and increasing subsidies for a reduction in the use of chemical fertilizer is the next solution. They also highlight that the runoffs of nitrogen and phosphorus from fertilizer in the U.S. has decreased by around 21% and 54% respectively, through some of these activities, undertaken with governmental assistance or spontaneously by spontaneous farmers at their own cost.

To this end, to protect the Geum River Basin, the Korean government enacted Act of Water Management and Resident Support in the Geum River Basin in 2002. The law intended to promote effective water quality improvement and resident support projects in the upper streams and to manage appropriately the water resources and pollution sources in the basin but the result seems to ineffective until now. Following to the law, the Committee for Managing the Geum River Basin has been working toward these goals. Table 1.14 shows the projects for preventing pollutants in the basin that the Committee has planned for 2017.

Table 1. 14 *Projects for preventing pollutants in the Geum River Basin in 2017*

Sum, KRW million (USD thousand)	Maintenance of drainage systems	Provision of eco-friendly agricultural materials	Building a buffer	Afforestation	Garbage disposal
2,730 (2,328)	920 (785)	897 (765)	700 (597)	136 (116)	77 (65)

Note. The Committee of Managing the Geum River Basin, 2016. USD 1 = KRW 1172.5, on the basis of the exchange rate of 31/12/2015.

As shown in Table 1.14, the Committee has implemented a variety of projects to prevent water pollution in the basin. Three types of projects have something in common with the activities for preventing water pollution described above: provision of eco-friendly agricultural materials, building a buffer and afforestation. First, the management of drainage system means improving the drainage systems for sewage or wastewater by reducing the leakage from the system. If the leakage of sewage or wastewater is prevented, water pollution would decrease because of the reduction of pollutants. The second program is providing eco-friendly agricultural materials, which are defined as environmentally -friendly materials harmless to humans, livestock and nature, used for supplying nutrients to crops and controlling pests, such as organic fertilizers. Moreover, the Committee has been providing eco-friendly fertilizer to farmers in the upstream areas of the basin; it has plans to provide about KRW 897 million in 2017. The third program is building buffers, which means building facilities to reduce pollutants by improving the purification capacity of wetlands such as sediment, filtration, adsorption, degradation of microorganisms and purification of aquatic plants by storing water runoff. Last, afforestation means planting trees in an area where there is no tree cover. An established forest provides many types of benefit, such as preventing dryness in the soil by retaining rainfall, mitigating erosion of soil and limiting the runoff of water. As a result, the new forests could reduce the inflow of pollutants to a catchment from the upstream site. The work of Ernst Gotsch[6] is a prominent example of afforestation.

Organic production is strongly recommended to prevent pollutants from livestock and farming. According to an experiment in Michigan fields, nitrogen runoff can be reduced through the use of organic production systems, as compared to systems using chemical fertilizer (Norwood et al., 2015). In addition, using nitrogen-fixing legumes and no-till systems is helpful in reducing excessive nitrogen. In this sense, the Korean government has supported organic agricultural production. In 2016, the Ministry of Agriculture, Food and Rural Affairs, South Korea announced the Fourth Five-Year Plan for the Development of Environmental-Friendly Agriculture in 2016 according to the Act for Environmental-Friendly Agriculture enacted in 1998. In the plan, the Korean government highlights two main parts for increasing the organic production. The first part relates to projects to expand the production bases and to promote the organic farming material industry in terms of processing, distribution and consumption. The second part focuses on fostering the management of agriculture-environmental resources, such as expanding the provision of organic fertilizer, supporting the education of farmers to diminish the amount of chemical fertilizer and pesticides used, inducing farmers to apply fertilizer properly and improving projects for livestock manure recycling (Kim et al, 2016).

Furthermore, Kitzmueller and Shimshack (2012) reported that many companies across the world voluntarily contribute to their societies beyond that which is required for regulatory

[6]He moved to Bahis in Brazil and has implemented agroforestry systems in a land since the 1980s. In less than 20 years, he transformed 300 hectare of degraded land to a forest where more than 300 species per hectare live. Also, the forest can ensure that the temperature in Bahis is 5 degrees cooler than in the rest of the region.

compliance. In this sense, corporate social responsibility (CSR) is considered a different approach to protect water quality. CSR is defined as a business's commitment to behave ethically and to contribute to sustainable economic development by working with all relevant stakeholders to improve their lives in ways that is good for business (Kitzmueller and Shimshack, 2012). They argue that CSR produces higher welfare than public or other private provision channels. With effective CSR, farmers in the upstream areas of the lake would reduce pollutants through voluntary compliance because they are concerned about the environment surrounding their lives. Organic farming, often considered in the CSR literature, would further contribute to protection of water quality (Jespersen. et al., 2017). Thus, promotion of CSR in the basin would be useful in preventing water pollution.

So far, this study has explored approaches to improve raw water quality in terms of water pollution. Many approaches can and should be used simultaneously to prevent water pollution. Preventing pollutants in the upstream site of the basin is a basic solution. Introduction of new taxes or penalties for people who emit pollutants or incentivising them to reduce livestock manure or recycle and better manage it are more fundamental approaches to achieve a complementary solution to supply safe and clean drinking water.

However, prevention of water pollution for protecting the raw water quality would be a long way to achieve the goal; cleaning raw water in the basin. Many approaches were discussed in this subsection and they could be categorized in management of manure, reduction of the use of chemical fertilizers, building the buffers such as uncultivated zones, organic production, and inducement of corporate social responsibility. As mentioned earlier, the Korean government has executed policies for protection of the water quality in the basin by enacting the laws but the effects have made slow progress. The reason of the slow progress could be considered the budget constraint. As mentioned in Subsection 1.3.1, the catchment area of the Geum River Basin is 9,911.83 km^2. The annual collection of water use charge in the basin between 2010 and 2014 are shown in Table 1.11. Table 1.15 shows the average budget needed per unit squared km to improve water environment in the basin.

Table 1. 15 *Average budget per unit squared km for improving water environment in the basin*

Year	2010	2011	2012	2013	2014
KRW thousand (USD)	9,019 (7,692)	9,544 (8,140)	10,008 (8,536)	10,290 (8,776)	10,351 (8,828)

Note. http://www.index.go.kr/potal/main/EachDtlPageDetail.do?idx_cd=1068. The values are calculated by dividing the total annual budget by the width of the basin. The Korea government considered the budget per unit squared km needed for improving water quality in the basin by measuring the costs like installing and operating new sewage and manure treatment facilities to meet the standard of BOD.

As shown in Table 1.15, the budgets per unit squared km needed are much higher than the water charges which are considered to be a small amount to improve the water quality in the basin speedily.

Also, Lee (2013) reported another reason why the effects showed slow progress. He argued that the governmental policies for managing water quality in the basin have mainly focused on solutions for point pollution sources. However, he claims that non-point pollution source accounts for approximately 10% pollution load in water environment, South Korea on the basis of 2010 and the pollution load from the non-point sources will steadily increase. Therefore, he suggests that the Korean government concentrate on the solutions for the non-point pollution sources to improve the raw water quality. In this respect, the Korean government started to recognize the importance of managing the non-point pollution sources (such as fertilizer, pesticides and livestock excrements) and to reflect the solutions for them in the water environment policy (Ministry of Environment, South Korea[c], 2015).

To achieve the level at which people in the basin can drink tap water without advanced treatment, it is necessary to invest more budget money and time. In this respect, the approaches that focus on the improvement of the source water protection cannot be considered immediate alternative solutions. Subsequently, people would suffer from the unsafe and unclean drinking water in the short term. Therefore, it is worthy to consider short term solutions for supplying safe and clean drinking water to people. Installing new advanced treatment systems is one such potential short term solution (Na, J-Y., 2013, Kim, D-W., 2011) that could be considered together with long-term solutions designed to protect the water source. In the next section, advanced treatment systems will be explored in terms of a short term solution of suppling safe and clean drinking water.

1.5 Water Treatment Systems

Installing new advanced treatment systems is a direct solution for improving drinking water quality, in contrast to improvement of raw water quality which is an indirect approach. In terms of the time needed to achieve the goal of people enjoying clean drinking water, preventing water pollution would take a long time, but installing new advanced treatment systems in waterworks is a short-term alternative. In this regard, it is necessary to investigate the economic feasibility of new investment in improving drinking tap water quality.

Modern civilisation is based on many important inventions. One of them is the water supply system. Public water supply systems have contributed to the longevity of human life. To date, three main types of systems for purifying water have been employed. Slow sand water filtration, which was introduced by Robert Thom of Scotland in 1804, is called the first -generation system (Jung, 2012). Following that, the rapid filtration system was introduced in New Jersey in the U.S. in 1844; this system provided water at a rapid speed. In rapid sand filtration systems, unfiltered water flows through the sand filter under pumped pressure so it can be treated rapidly. In contrast, slow filtration systems filter raw water through a sand filter under gravity so they cannot provide purified water for large -quantity production.

After an accident involving cryptosporidium in Milwaukee in 1993, 1 million people were infected, and about 100 died. At that time, alternative advanced filtration systems were studied for supplying much safer water. Typical methods are Ozone, activated carbon, membrane, and ultraviolet treatment. These methods are called advanced or tertiary systems in the field. For more than 100 years, the rapid filtration system has been the main method used to supply drinking water to the public; this system is, called the “conventional type”. However, advanced systems are gradually being installed to supply even safer drinking water. Table 1.16 shows the proportions of waterworks process types in South Korea.

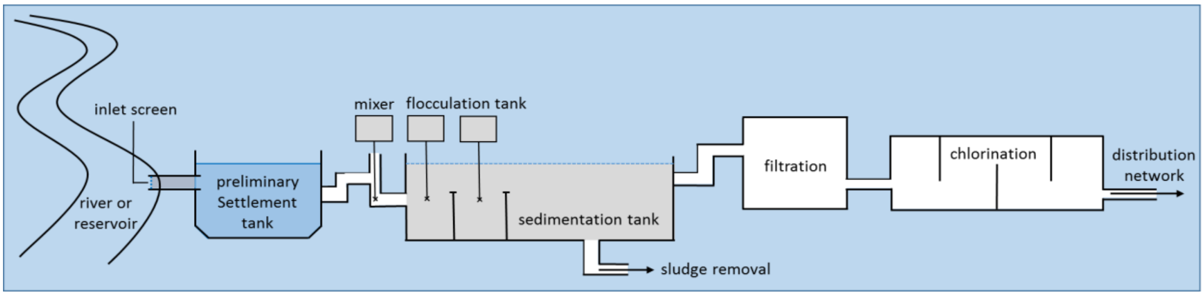
Table 1. 16 *Proportions of waterworks process types in South Korea in 2013*

Filtration type	total	slow sand	rapid sand	advanced	rest
thousand ㎥/day	27,168 (100 %)	605 (2.2 %)	20,171 (74.2 %)	5,931 (21.8 %)	461 (1.7 %)

Note. Ministry of Environment of Korea, 2014.

In South Korea, rapid sand filtration is the main system for purifying drinking water. The proportion is about 74 % in 2013. Figure 1.7 shows the main components of the system.

Figure 1. 7 *Rapid sand filtration components*



Note. Source from Korea-Water.

The process is divided into five stages. Pre-sedimentation removes particles such as silt, sand, gravel, ash, metal and glass. Mixing is the process whereby a solution is added to the water to make the particles bigger and easier to remove. Sedimentation is a physical water treatment process using gravity to remove suspended solids from water. Filtration is the process whereby water is passed through a tank full of sand to remove the invisible particles. The sand traps these particles as the water passes through. Last, chlorine disinfection involves adding a tiny amount (less than one milligram per litre) of chlorine which kills any remaining organisms or bacteria and keeps the water safe until it reaches each household tap.

After industrialisation in the 1970s, many problems with contamination of the water environment emerged. The Korean government began to install advanced treatment systems to supply much safer drinking water at the end of the 1990s. Which type of advanced treatment system should be chosen depends on the hydrological and water environmental characteristics of an area. Two advanced water treatment systems, granular activated carbon and ozone, are favourites in South Korea (Ministry of Environment of Korea, 2014). Granular activated carbon is usually added to the process of filtration, as in Figure 1.7, and ozone treatment is added to the system of chlorine disinfection as an additional method to remove fine particles and to create chemical reactions in the water.

1.6 Cheongju Waterworks

It would be difficult to measure the economic feasibility of investment for improving drinking water quality nationwide because of many differences in socio-economic factors between the cities and areas supplied by different waterworks. For this reason, this research focuses on one waterworks, Cheongju Waterworks which is located in the middle of South Korea, to investigate economic feasibility. Figure 1.8 shows the location of the waterworks.

Figure 1. 8 *Location of Cheongju Waterworks*

Note. Source from Cheongju City and Korea-Water

Cheongju Waterworks was constructed between 1984 and 1987 and was passed as an investment in kind, to Korea-Water by the Korean Government in 1988. At that time, the waterworks started to supply drinking water, at a capacity of 250,000 m^3 per day. Between 1996 and 2002, the construction of a second waterworks was undertaken by the Korea-Water to enlarge the capacity from 250,000 m^3 per day to 403,000 m^3 per day to meet the increased demand for water in the area.

The area is not restricted to Cheongju City. The waterworks also supplies drinking tap water to part of Sejong City and Yeongi-Gun (Ministry of Environment, South Korea, 2014). In these places, there are only a few waterworks including those belonging to the local governments. The specific population served is not reported, so it must be estimated, which will be explored in Chapter 8. The water purification system of the waterworks is rapid sand filtration. Therefore, when problems of unpleasant taste and odour caused by green algae arose, powdered activated carbon was added to the process between the preliminary settlement tank and the mixer as a temporary measure, as shown in Figure 1.7.

1.7 Research Objectives

To examine the economic feasibility of public investments, it is necessary to estimate the costs and benefits. The costs for improving water quality maybe relatively straightforward to measure because there is much information available from the engineering fields. However, it is more complex to value the benefits of improved drinking water quality because there is no market to transact it. Therefore, it is necessary to find alternatives for measuring the benefits. To determine the benefits of public goods or services, many methods are used. The main ones are contingent valuation and choice experiments (CE). However, unlike CE, contingent valuation cannot detect the benefits of improving each attribute of drinking water. CE also has other advantages. One is that respondents consider trade-offs between attributes[7] because CE can separately identify the value of each attribute of a good or service (Hanley et al., 2001). Another is that it avoids order effects[8] by randomizing the order of attributes in choice cards (Auspurg et al., 2015). Therefore, a choice experiment is used for this research.

1.8 Chapter Overview

The thesis consists of nine chapters. After the Introduction, Chapter 2, Literature Review introduces research papers and methods in mainly three domains: water quality studies, cost-benefit analysis studies, and choice modelling methodology. The first part summarises the studies for measuring the economic value of improving drinking water quality. In total, 13 studies are reviewed. The second part explores the development of cost-benefit analysis and some issues related to the methods used, such as period, risk, uncertainty and the social discount rate, using data from the U.S., the U.K. and South Korea. The third part looks into the choice modelling methodology literature. After summarising the economic valuation of the environment, the two primary categories of the stated preference methods, contingent valuation and choice experiments, are outlined, and discrete choice models are also investigated. Carson et al. (2007) describe choice experiments as a part of discrete choice models, in which several types of questionnaires are used to generate data of the discrete choice models, includig sequences of binary choices and of multinomial choices.

[7] In terms of multi-attribute utility theory by Keeney and Raiffa (1976), trade-off between attributes refers to the situation when a decision maker is asked to choose the most preferred options among several alternatives that consist of the multi-attributes (Klüppelberg et al., 2014).

[8] Order effects are defined as the observation of systematic change in any individual attributes and particular options, and the degree of variability in respondents' choice behaviour relating either to position in the sequence of tasks or to the nature of options in previous tasks (Day et al., 2012).

Chapter 3 presents the methodology for measuring the social benefits of improving the quality of tap water. First, the sample size is explored necessary to obtain a representative sample. Second, the experimental design is explained. Third, the methods for mitigating hypothetical bias are discussed. Next, the random parameter logit and latent class logit model are explored. Beginning with random utility theory, choice probability is derived. Following this, the maximum likelihood function and simulation method to estimate the coefficients are investigated. The study also shows how to calculate the willingness to pay (WTP).

Chapter 4 describes questionnaire and the data collection process. The selection of key attributes is first. After this, the arrangement of the levels of the chosen attributes is explained and the experimental design is examined. The next section examines methods to mitigate hypothetical bias. Other questions relate to socio-economic factors and debriefing questions distinguishing between effective and ineffective data. Last, the process of collecting the data, including the survey methods, is described, and the outcome of the survey is presented. Furthermore, potential label heuristics are discussed.

Chapter 5 analyses the representativeness of the collected data. Five socio-economic factors (average monthly water bill per household, gender, age, income, education year) are examined using a variety of statistical tests: Z-test, T-test, and chi-squared. Descriptive statistics of other socio-economic factors are presented. The last section of this chapter illustrates how the debriefing questions work to identify the extent to which the respondents prefer environmentally -friendly policies.

Chapter 6 presents the results of measuring the social benefits of the investment in the chosen waterworks in the target area. Before estimating the coefficients of the utility function, several types of utility function forms are debated. In total, eight logit models are used for measuring the parameters. Several utility function forms are explored to describe the true

WTP. Estimation of the WTP is the essential aim of this research. Therefore, the discussion of how to calculate the WTP follows and the WTP statistical confidence intervals are explored. Last, the social benefits of improving drinking tap water quality are discussed.

Chapter 7 estimates the costs of installing the two advanced water treatment systems, granular activated carbon (GAC) and ozone plus GAC. Starting from a description of the waterworks process, assumptions are set for estimation of the costs. The costs are estimated using the standards the Seoul local government and other research performed in South Korea. In addition, to justify the estimates of cost, data from other previous projects in South Korea are described. Finally, this chapter concludes by stating the cash flow of the estimated costs.

Chapter 8 implements the cost-benefit analysis (CBA). This chapter tries to show the feasibility of the investment in the target waterworks for installing the advanced water treatment systems. Other factors like business life length and the social discount rate are also discussed here. Comparing the costs and the benefits of improving drinking tap water qualities, the results provide the quantitative basis regarding feasibility. Sensitivity analysis is used to address uncertainty in the future regarding some social and economic changes such as changes in the social discount rate, an increase in the operating and maintenance costs and changes in the social benefits. Furthermore, another solution, improving raw water quality in the basin is discussed.

Chapter 9 concludes with summaries and highlights the results and findings of this research. This chapter also includes policy implications, limitations, and future research challenges.

Chapter 2. Literature Review

This thesis aims to evaluate the feasibility of investment in improving the quality of drinking water in South. Korea. Decision-makers in public sectors have had difficulty in confirming whether public projects are feasible because there is no market in which to measure the benefits. It is necessary to measure their economic value of public investments such as such as new roads, dams and waterworks. The most important reason for measuring the value of public projects is to rationally manage the government's budget by selecting the most effective project through objective, scientific analysis.

A large share of the budget would be required to improve the quality of drinking water. A judgment regarding the feasibility of a project should precede any investment. To conduct the study, other studies of water quality valuation are examined. Next, cost-benefit analysis will be considered as it is widely used to evaluate the feasibility of an investment project in public sectors as a whole. Last, as benefit assessment is thought to be more difficult than cost assessment, various methods of benefit assessment for improving drinking water quality and the most appropriate method to use to assess value will be analysed.

Literature relevant to the proposed analysis will be explained in three parts; water quality studies, CBA studies and choice modelling methodology studies. The first part, water quality studies looks into research on the improvement of drinking water service. The second, CBA studies, describes the methods for a prominent decision making rule. The third, choice modelling methodology studies, looks at a variety of methods for measuring the value of non-market goods.

2.1 Water Quality Studies

Water is essential for human life. Much effort has been put into providing a better quality of and greater quantity of water. Large budgets have been invested to obtain clean, abundant, and safer water across the world. Many studies have been carried out to value cleaner environments with respect to water resources like rivers, lakes, and seas or oceans. However, not many studies have measured the value of improvements in drinking water quality because studies have focused primarily on the *quantity* of drinking water, or the supply. This part reviews studies that evaluate the value of changes in attributes related to drinking water through both revealed and stated preference methods.

2.1.1 Studies Using Revealed Preference Method

Three papers using the revealed preference (RP) method for valuing the improvements in drinking water supply are reviewed. Asthana (1997) studies the household choice of water supply system in India. He analyses the connection decision of a sample of 250 households to the piped water system in the peri-urban areas of Bhopal city in Central India, using RP data. He uses a binary logit model for the pipe network connection decision and several multinomial logit models for the choices of water supply source. Regarding the source choice, the alternatives consist of five cases, private piped water, public stand post, hand-pump, dug well and surface water and independent variables are examined: household characteristics; income, education, household size and presence of storage tank in the house and source characteristics; source quality perception and the change in the quality of the piped water supply. The paper clearly shows the empirical relationship between income and the preference for the piped water but it limited in that he did not calculate any monetary value for the benefit of connecting to the water supply pipeline.

McConell and Rosado (2000) study the willingness to pay (WTP) for a potable water supply in Grande Vitoria in Brazil, using defensive expenditure (i.e. averting behaviour[9]) with a nested logit model. They survey 917 households to find information on WTP for drinking

[9] Averting behaviour is defined as the defensive actions on which some people are willing to spend to prevent damages to environmental quality.

water quality, water supply, and defensive expenditures to avoid unsafe drinking water. The alternatives analysed include the oxidation filter, ceramic filter, boiling, purchasing bottled water, and doing nothing. The independent variables are cost, safety and taste, and household characteristics. The estimated WTP is between USD 2.77 and USD 2.92 per month for safe drinking water. Apart from the overall outcome, they do not estimate the value of each attribute of drinking water.

Um et al. (2002) explored WTP for drinking water safety in Pusan, the second largest city in South Korea, using the averting behaviour method with a probit model. They insert perception levels about drinking water quality into the averting behaviour model of Bartik (1998) to overcome inconsistency between people's actual activity and measured pollution. This inconsistency means that although objectively measured figures of drinking water safety are acceptable, people nevertheless avoid drinking tap water. They interview 256 households in Pusan for data with five averting alternatives: bottled water, a filtering system, drawing spring water, drawing underground water, and overall averting behaviours. They assumed that the perception level is a significant determinant in choosing averting behaviour. They use two types of averting behaviour models. One is setting up actual attributes of drinking water (residual chloride, suspended solid, tri-halo-methane, and nitrogen in the form of nitrates) as independent variables; another is using the perception level measured with five Likert scales as shown in Table 2.1.

Table 2. 1 *Measurements of perceived drinking water quality*

1	2	3	4	5
Drinkable without any treatment	Drinkable after boiling	Drinkable after using filtering system	Drinkable after boiling and filtering	Undrinkable with any treatment

Note. Um et al., 2002.

They conclude that the citizens are willing to pay 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.

2.1.2 Studies using Stated Preference Methods

2.1.2.1 Contingent Valuation Method

After the Exxon Valdez accident, the contingent valuation method (CVM) became popular. Many studies have used CVM to measure the value of environmental goods and services. In this part, studies measuring the value of drinking water quality using CVM are reviewed.

Kwak (1994) evaluates the WTP for an attribute of tap water (safety) in Seoul, the largest city in South Korea. He uses face-to-face interviews to gather data from a sample of 298 through discrete responses (called, "take-it-or-leave-it" by Bishop and Herberlin, 1979). The CVM survey data are analysed with the Tobit model. He estimates the mean WTP of Seoul citizens at USD 3.28 (KRW 2,603) per month for an automatic monitoring system and complementary reservoirs for an emergency.

Park et al. (2007) estimated the WTP for supplying good quality tap water in South Korea. They collect data from 1,000 households by using a CVM questionnaire in the seven largest cities in South Korea, including the capital city of Seoul. The respondents are asked to answer yes or no about a suggested amount of additional fees in the monthly water bill for safer and tastier tap water corresponding to the quality of bottled or in-line filtered water. The additional monthly water bill per household is measured between KRW 1,183 (USD 1.26) and 3,011 (USD 3.22).

Bilgic (2010) estimates the WTP to improve drinking water quality in southeast Anatolia, Turkey, as a means for mitigating exposure to waterborne contaminants. He collects 1,140 face-to-face CVM surveys and obtains results by analysing the data with the bivariate probit model to avoid non-response bias. After questions about household characteristics and respondents' knowledge, attitudes, and behaviour related to health and water, several open-ended WTP questions are asked. He reports that bid prices, food expenditure, perception indexes, the number of working members in a family, the head of household's educational level, gender, a resident's housing status, the condition of the residence, and seasonal differences affected the WTP for quality improvement of tap water. Also, he calculates the mean WTP for improved water quality as USD 4.85 (TL 6.009) per month.

Similarly, Cho et al. (2010) evaluate the WTP for the new U.S. arsenic standard in drinking water at a small rural community in Minnesota, the U.S., using a CVM survey; he also conducts a CBA of the new standard using benefits through the WTP and costs from the Minnesota Department of Health. The authors collect data from 377 respondents who are city water users in 30 rural communities in west central and north-western Minnesota, in 2007. The respondents are asked to make a double-bounded dichotomous choice of WTP responses from a mail-in survey. They estimate the WTP for the new arsenic rule at USD 6 - 23 per household annually for a relatively low level of arsenic communities (less than 10μg/L in their water) while at USD 31 - 78 for a higher level of arsenic communities (more than 10μg/L) by using the bivariate probit model. They computed a benefit/cost (B/C) ratio of only 0.01 – 0.19 by comparing the benefits and cost. After that, they compared their estimates with the new treatment costs per capita for the new arsenic rule provided by the U.S. Environmental Protection Agency (the average annual cost to be USD 203 - 408 per household for public water systems serving fewer than 500 people annually and USD 73 - 88 for communities of 500 to 3,300). The authors conclude that many small Minnesota communities are worse off as a result of the new arsenic rule.

Polyzou et al. (2011) investigate the connection between the WTP for drinking water quality improvement and the influence of social capital through a CVM in Mytilene, an insular community of the North Aegean Sea in Greece. They use as independent variables four concepts of social capital: social trust, institutional trust, social norms, as well as civic participation and activation of citizens, measured on a 0 - 10 Likert scale including demographic data. Using an open-ended question, they ask 152 citizens what additional payment they would be prepared to pay to improve the quality of drinkable tap water. They analyse the result with linear regression models. The average mean amount of WTP for the improvement of water quality is calculated as EUR 10.38 every two months, except for respondents who refused to pay for the improvement of water quality. They report that social capital positively influences the monetary valuation for the improvement of water quality.

Kwak et al. (2013) measure WTP for tap water quality improvement in Pusan in South Korea, using CVM. At the time, the policy makers in the city are supposed to carry out new projects for improving tap water quality, for example, installing advanced water treatment facilities, new pipes, and monitoring systems. Therefore, they confirm the feasibility of the projects with conventional CBA. They face-interview 400 people asking questions like, "Would your household be willing to pay a higher amount in the monthly water bill for tap water quality improvement?" They use a one and one-half bounded dichotomous choice model and estimated a mean WTP at USD 2.2 per month for improvement of tap water quality. One interesting point from the analysis is that respondents who experience chlorine odour are less likely to pay for improvement of water quality. The main reason reported is that the chlorine odour is one of the crucial elements of refined water and Pusan citizens with experience of chlorine odour are sceptical about any improvement of water quality. Therefore, it is meaningful to consider the odour of tap water as a factor for improving drinking water quality.

These papers show that some attributes of drinking water are important factors that influence consumers' WTP. Five attributes, taste, odour, colour, softness and safety are mentioned as important factors (Bilgic, 2010; Cho et al., 2010; Kwak et al., 2013).

2.1.2.2 Choice Experiments

Choice experiments are regarded as the more suitable method for evaluation of public goods from the viewpoint of measuring the change in attributes of the goods because CEs can enable implicit prices to be estimated for attributes and welfare impacts to be measured for multiple scenarios. In this part, papers using CE to measure the improvement of drinking water attributes are reviewed.

MacDonald et al. (2003) study the application of choice experiments to water services, in what they claim is the first case. They focus on the correlation between the willingness to pay for higher customer service standards and the implicit prices, using a multinomial and random parameters logit. They conduct their survey in the Adelaide metropolitan area of South Australia and obtain 337 WTP survey responses by mail. They set up three alternatives and five attributes, frequency, duration, rebate level, communication and alternative water supply, plus socio-economic variables. They show that the frequency of future interruption in the water supply is the most important attribute of the water supply service in Australia so that a reduction in frequency of interruption is worth the increase in annual water bills (WTP is estimated at AUD 6 – 6.3 in multinomial logit, AUD 15.4 in random parameter logit). They also conclude that CE is a useful ex-ante method and provides the industry and regulators with additional information for standard setting.

Willis et al. (2005) estimate customers' WTP for improvement of the drinking water supply and sewerage services in Yorkshire, U.K., for Yorkshire Water. The organization wanted an integrated decision process for economic optimization of all its investments. The authors try to evaluate marginal changes in the service level related to the water supply, water quality, and wastewater disposal. They establish 14 attributes of the service as shown in Table 2.2, and survey two groups, 1,000 residential customers and 500 businesses in Yorkshire.

Table 2. 2 *Attributes of Willis et al. (2005)*

	Factors
Supply and quality of water (7)	Security of supply, interruptions to supply, drinking water biological quality, drinking water discoloration, leakage, inadequate mains pressure, lead in drinking water
The external disbenefits of wastewater (3)	Sewage flooding into properties, areas flooding by sewage, nuisance from odour and flies from sewage treatment works
Environmental factors (4)	Pollution incidents, ecological quality of rivers, ability to use inland waters for recreation, bathing beach water quality

They analyse the data with a variety of discrete choice models such as standard logit, nested logit, RPM. From the result of one MNL model, they conclude that customers' average WTP per year is GBP 0.317 for each percentage increase in the security of the water supply under drought conditions. They also estimate each reduction in the number of water samples that failed to meet the biological and chemical water purity standard at GBP 0.03 and each reduction of years taken to reach 10μg/L of lead at GBP 0.148 per year. This report provides an example of practical application and makes a strong case for analysing the water supply and sewage services together. However, some attributes they established are not highly identified by customers, which reduces the reliability of the analysis results (Willis et al., 2005).

Hensher et al. (2005) explored households' WTP for water service attributes in Canberra, Australia's national capital. They gather data by mail from 211 households asking respondents to choose between the options described in terms of attributes, levels of drinking water and wastewater. Table 2.3 shows the attributes and the levels identified by Hensher et al. (2005). They analyse the data with a mixed logit model and report the results; the marginal WTP (MWTP) for reduction of the frequency of interruption by 0.1 from 2 per year is AUD 4.15 and the MWTP to reduce the length of an interruption is estimated as AUD 36.5 when customers face interruption of two hours.

Table 2. 3 *Attributes and the levels by Hensher et al. (2005)*

	Factors
Drinking water (6)	The frequency of service interruptions, the average duration of an interruption, the time of day that the water service is interrupted, notification of the interruption, information service provided during an interruption, price (total water and sewerage bill for year)
wastewater (5)	The frequency of disruptions to the wastewater service, the coverage of the disruption, the average duration of a disruption, information service provided in the event of an overflow, price

They point out that the incentive compatibility in choice experiments may be satisfied more easily in the case of public goods than in the case of private goods (Hensher et al., 2005).

Last, Rusliyacob et al. (2013) investigate households' WTP for improvement of drinking water quality in Damaturu, Nigeria. They are interested in the reduction of mortality rates and morbidity caused by waterborne diseases such as diarrhoea and other gastrointestinal disorders. They focus on several attributes of drinking water service such as water quality, supply, pressure and price. They survey 300 households with choice-experimental questionnaires and use a standard logit model for analysis. Comparing the parameters of attributes with water bill price they calculate the marginal WTP. If tap water quality is satisfactory or very good, then respondents accept an increase in water bills of 185% and 220%, respectively (Rusliyacob et al., 2013).

Table 2.4 shows a summary of the studies evaluating WTP regarding drinking water. Six studies measure the WTP in South Korea, although conducted using different methods, areas and years. They show the range of monthly WTP between USD 1.14 and 6.1 (KRW 1,342 – 7,236) per household. These figures can serve as benchmark points for assessing the reliability and validity of the estimates of WTP in this research. The WTPs in this research are estimated from USD 1.78 (KRW 2,094) to 4.56 (KRW 5,370) for the GAC option and between USD 2.03 (KRW 2,391) and 5.13 (KRW 6,035) for the ozone plus GAC.

Table 2. 4 *Summary of the studies for evaluating the WTPs regarding drinking water*

WTP *(USD of value in 2015)**	Attribute	Tool	Country	Author Year
USD 3.28 *(6.64)* monthly per household	For protection from accidental chemical contamination of the drinking water source	CVM	South Korea	Kwak 1994
USD 2.77-2.92 *(7.3-7.69)* monthly per household	For defensive expenditure to avoid unsafe drinking water	ABM	Brazil	McConell & Rosado, 2000
USD 3.60 (5.2) Monthly per capita	Improve the drinking water quality	CVM	South Korea	Yoo & Yang. 2001
USD 4.2-6.1 *(5.9-8.6)* monthly per capita	For improving tap water quality from current pollution level to 'the drinkable without any treatment'	ABM	South Korea	Um et al. 2002
AUD 6-6.3 *(5.97-6.27)* annually per household	For reduction in frequency of interruption of water supply	CE	Australia	Mcdonald et al. 2003
GBP 0.317 *(0.6)* annually per household	For 1% increase in the security of water supply under drought	CE	U.K	Willis et al. 2005
GBP 0.03 *(0.06)* annually per household	For each reduction in the number of water samples that failed to meet the biological and chemical water purity standard			
GBP 0.148 *(0.28)* annually per household	For each reduction of year to reach 10μg/L of Lead			
AUD 4.15 *(3.15)* annually per household	For reduction of water supply interruption frequency by 0.1 from 2	CE	Australia	Hensher et al. 2005
AUD 36.5 *(27.72)* annually per household	For reduction of the length of interruption			
USD 4.85 *(9.03)* monthly per household	For safe drinking water consistent with European Union regulation	CVM	Turkey	Bilgic 2007
USD 6-23 *(6.86-26.29)* annually per household	For new arsenic standard in lower arsenic level communities	CVM	U.S	Cho et al. 2007
USD 31-78 *(35.44-89.16)* annually per household	In higher arsenic level communities			
USD 1.26-3.22(1.23-3.12) monthly per household	Safer and tastier tap water corresponding to the quality of bottled or in-line filtered water	CVM	South Korea	Park et al 2007
EUR 10.38 *(11.40)* every 2 months per capita	To improve the drinking water pipe system and increase the quality of drinkable tap water	CVM	Greece	Polyzou et al. 2010
USD 1.94 (1.98) Monthly per household	Advanced water treatment	CVM	South Korea	Na 2013
USD 2.2 *(2.24)* monthly per household	To supply drinkable water without any treatment	CVM	South Korea	Kwak et al. 2013

Note. CVM; Contingent Valuation Method, AVM; Averting Behaviour Method, CE; Choice Experiment, * reflected CPI of each country between the years and 2015, respectively, by using the data of OECD.

These estimates are presented here for convenience and show that the results of the present study align well with previous results reported in the literature. Moreover, the lower bounds are close to the WTP for bottled water USD 2.28 observed in Table 1.2 and 1.3, and it is worth considering that Koreans pay a significant amount for in-line water filters as well. This suggests that the WTP measures obtained in the present study are within a valid range.

2.2 Cost-Benefit Analysis

Many countries across the world have governmental guidelines to test the feasibility of public investments. The U.S. uses the Guideline for Preparing Economic Analysis of the U.S. Environmental Protection Agency. South Korea uses the Korean government's Guidelines for Preliminary Feasibility Study, but little research has assessed projects for improving drinking water quality. The main reason is that the Korean government strengthened the guidelines for public companies, including in the water sector, only in and after 2011. The next subsection will look at decision rules for public investments.

2.2.1 Introduction of Cost-Benefit Analysis

A variety of methods exist for studying the feasibility of investments in public sectors such as public roads, airports and water/air quality. Among these methods, cost-benefit analysis has played the most important role. CBA is a good method for evaluating the benefits and costs of public investments such as new roads, large dams and waterworks (U.K Department for Transport, 2002).

Although the basic theory of CBA can be related to the welfare economics of the 19^{th} century, introduction of the Flood Control Act of 1936 in the U.S. is considered as the first example of CBA in practice (Pearce, 1983). The subsequent demand for CBA is illustrated by Executive Order 12291, issued by President Reagan in early 1981. The Order required that a regulatory impact analysis accompany every major regulatory initiative (more than USD 100 million in cost) from government agencies. A regulatory impact analysis is essentially a CBA that also identifies distributional and fairness considerations. President Clinton confirmed the federal government's commitment to CBA in Executive Order 12866 in 1994. Quite a few U.S. federal laws, such as the Unfunded Mandates Reform Act and the Government Performance and Results Act, specifically mandate some form of ex ante analysis (Boardman et al., 2014). The Principles for Federal Infrastructure Investment from Executive Order 12893, issued by President Clinton on 26^{th} of January, 1994, indicates that the Order covers spending for transportation, water resources, energy, and environmental protection (U.S. National Achieves, 1994). Also, U.S. courts have used CBA methods. For example, the Exxon Valdez case is famous for using CBA and CVM (Boardman et al., 2014).

In South Korea, the Korea Development Institute (KDI) has carried out a preliminary feasibility study to encourage a cautious approach to new large-scale projects (more than KRW 50 billion in cost) since 1999 according to the National Finance Law. The purpose of the preliminary feasibility study is to enhance the efficiency of fiscal investment by verifying the feasibility of a project in such aspects as its economic feasibility, policy analysis, proper timing and financing methods by conducting general research on large scale projects. If a project for improving drinking water quality is likely to cost more than KRW 50 billion, KDI should carry on a preliminary feasibility study. Otherwise, an ex-ante feasibility study should be conducted by the organization that plans the investment (KDI, 2013).

2.2.2 Cost-Benefit Analysis

In cost-benefit analysis, three discount cash flow rules are used in general; net present value (NPV), benefits/costs ratio (B/C), and internal rate of return (IRR). Table 2.5 shows the three decision rules.

Table 2. 5 *Decision rules*

Net Present Value (NPV)	$NPV = \sum_{t=1}^{T} \frac{E(NB_t)}{(1+r)^t} - I_0$ $NB_t = B_t - C_t$ (the flow of net benefits in time t period)
B/C ratio (B/C)	$\frac{B}{C}\text{ ratio} = \sum_{t-0}^{T} B_t/(1+r)^t \Big/ \sum_{t=0}^{T} C_t/(1+r)^t$
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 discount cash flow, it is necessary to have information on the future costs and benefits. Estimates of business incomes and costs over the project life are used as substitute variables in private business. In NPV, if NPV is greater than zero for the project, it can be accepted. If many projects are being considered, the project with the largest NPV should be chosen. 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. If there are many projects, then the project with the greatest IRR should be chosen. Finally, in the case of B/C, if there is one project and B/C is larger than one, the project is feasible. If there are many projects, the project with the largest B/C should be chosen.

The decision rule is more complex. The condition that NPV is larger than zero is not sufficient but is necessary because of the problem caused by budget limits (Pearce, 1983). Boardman et al. (2014) have argued that there is some confusion about the appropriate decision rule in using the three criteria. The appropriate criterion to use is the NPV rule; while other rules sometimes give incorrect answers, the NPV rule does not. However, in practice, these three criteria are used to complement each other. In the case of South Korea, the three criteria should be used complementarily according to the general guidelines for the preliminary feasibility study (KDI, 2013). Moreover, these methods are useful for the strategic analysis of a project through estimating future benefits and costs and also have merit ensuring that the direction of investment is realistic and concrete. These methods can also be used easily by private sector firms, given their financial statements.

2.2.3 Time Period, Risk and Uncertainty Studies

Different time periods should be applied for CBA projects according to their life cycle. Many countries' guidelines set the time periods for each project. In the case of equipment for improving drinking water quality (i.e. an advanced treatment equipment, there is a definite project life cycle because the equipment consists of waterworks machinery. The time period for machinery is generally assumed to be a maximum of 20 years. Equipment has a shorter life cycle in business than other public investments.

In the U.S., water utility property is defined as (1) property that is an integral part of the gathering, treatment, or commercial distribution of water, and that, has a 20-year recovery period (CCH Tax Law Editors, 2013). In South Korea, the life cycle of waterworks treatment systems including the advanced treatment system is set at 15-20 years according to the enforcement regulation of the Local Public Enterprises Act (Ministry of Government Legislation of South Korea, 2014).

Two other most debated issues of discount cash flow models are risk and uncertainty around the future flow of costs and benefits. In practice, it is difficult to calculate the costs and benefits with certainty so it is important to consider these two issues. Risk is defined as a situation in which the probability distribution is known and, on the other hand, uncertainty is a situation in which the probabilities attached to the sizes of the costs and benefits are not known (Pearce, 1983). To cope with these two situations, several methods are used, including sensitivity analysis, certainty equivalent, Monte Carlo simulation, and decision tree analysis. In practice, sensitivity analyses are widely used despite practical limits; for example, one of the limits is that CBA is susceptible to the errors of those who are conducting it.

In South Korea, to manage the uncertainty accompanying CBA, sensitivity analysis is mandatory. Sensitivity analysis refers to test how much the discount cash flow is changed by the variables that influence the result of CBA, such as initial investments, operation and management costs and change in discount rate. According to the characteristics of each project, different variable changes and their extent are allowed in the analysis (KDI, 2013).

2.2.4 Social Discount Rate Studies

Another controversial issue for conducting CBA is selecting an appropriate social discount rate. Boardman et al. (2014) argue that there are two main reasons why the discount of future value to present value is needed. The first is to quantify the opportunity cost of the resources used in a project. The second is common time preference. In this instance, the values are not nominal but real because the inflation rate is not taken into account (Boardman et al., 2014). The social discount rate plays a crucial role in CBA so it is important to decide which social discount rate should apply to a project. Lind (1982) has summarised the social discount rate as five concepts and the U.S National Service Centre for Environmental Publication (1993) has also accepted the concepts as the key factors determining its discount rate as follows;

1) Social rate of time preference: the rate at which society is willing to exchange present consumption for future consumption.
2) Consumption rate of interest: the rate at which individuals are willing to exchange present consumption for future consumption.
3) Marginal rate of return on private investment: the incremental return on the last unit of investment by a private firm.
4) Opportunity cost of public investment: the cost of a government investment measured in terms of forgone private consumption or investment.

5) Risk: the degree to which investment in a public project will affect the variation in the outcome of all public investment (Lind, 1982; the U.S. National Service Centre for Environmental Publication, 1993).

Zhuang et al. (2007) state that market distortion gives rise to difficulty in setting the social discount rate. The supply price of investible funds is the marginal social rate of time preference as their demand price is the marginal social opportunity cost of capital. If a market is perfectly competitive then an interest rate in the capital market clears the match between the supply of, and demand for, investible funds. However, if the market is not perfectly competitive due to market distortions like taxes, risks, information asymmetry, and externalities, these distortions make the marginal social rate of time preference and the marginal social opportunity cost of capital diverge from the market interest rate. In this case, it is difficult to select an appropriate social discount rate (Zhuang et al., 2007).

From the 1930s, when the practice of CBA was started, to the 1950s, the social rate of time preference was widely used and there was almost no controversy about the social discount rate. However, since 1960, many economists have had an interest in the efficient allocation of resources between the private sector and public sector and have tried to find an appropriate social discount rate based on social opportunity cost. In particular, Baumol (1968) provides the theoretical fundamental that the social discount rate should be the social opportunity cost. In the 1970s, researchers argue that the social rate of time preference is again appropriate. However, the debate on an appropriate social discount rate is not finished. In the 1990s, the discussion about the social discount rate came to the fore again in relation to climate changes and global warming (Zhuang et al., 2007).

Differences exist in applying the social discount rate among different developed countries such as the U.S. and the U.K. because not only has there been much discussion about the appropriate social discount rate but there have also been difficulties in applying a particular rate to real cases. In the case of the U.S., in principle the one social discount rate determined by the Office of Management and Budget applies to CBAs of public projects, but, other rates can be applied when other laws or administrative orders prescribe the particular exception. The Office of Management and Budget set the social discount rate from 1972 to 1992 at 10% but after 2016, 1.2% applied for 20 year public projects.

In the U.K., according to the "Green Book", one social discount rate recommended by the Treasury applies. The Treasury has in principle applied 6% for 20-year projects as the social discount rate. However, it adjusted the rate from 6% to 3.5% in 2003 and the following social discount rates apply for certain time periods as shown in Table 2.6.

Table 2. 6 *Social discount rate, the U.K*

Period of years	0-30	31-75	76-125	126-200	201-300	301+
Discount rate	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%

Note. Source from HM Treasury, 2011. USD 1 = KRW 1172.5, based on the exchange rate of 31/12/2015.

In South Korea, the appropriate social discount rate is 5.5% for the first 30 years and 4.5% for the next 20 years based on a 2007 amendment of the General Guideline of Preliminary Feasibility Study of KDI. KDI computes the social discount rate using the base interest rate of the Bank of South Korea, the social time preference rate and financial interest rates. In 2011, the government of South Korea also widened the application of the preliminary feasibility study to large-scale investments by public companies and organizations.

2.2.5 Examples of a CBA Case Studies in the Water Sector

In 2000, the Korean government announced the cancellation of a plan to build 'the Dong-Gang Dam' in Youngwol-Gun. The event is a typical example of a governmental policy being rejected by the citizens and subsequently cancelled. For a long while, controversial debates had been ongoing about whether the dam should be built or not. The Korean government examined the feasibility of the dam in 1992 and re-examined the feasibility in 1996, but many citizens and non-governmental organizations opposed the plan because of environmental damages. In the report of the 'preliminary feasibility study for the dam in 1996', the Korean government implemented a CBA of the project at the constant price of 1996. The government applies the discount rate of 8.5% according to the guidelines at that time for a 55-year project, 5 years for constructing the dam with a 50-year, life-cycle for the dam. Table 2.7 shows the estimated costs and benefits.

Table 2. 7 Example of a Cost-benefit analysis for a public investment in South Korea

Costs	Benefits
□ Sum (nominal price) : 1,306,616 (USD 1,114 million) • Construction : 397,332 • Compensation : 611,100 • Design : 17,482 • Operation and so on : 280,702	□ Sum (nominal price) : 1,876,617 (USD 1,601 million) • Water use : 1,143,108 • Electricity : 149,459 • Reduction of flood : 584,050
□ Present Value : 922,398 (USD 787 million)	□ Present Value : 936,398 (USD 798 million)
□ NPV : 14,067 (USD 12 million) = 936,398 – 922,398	
□ B/C ratio : 1.02 = 936,398/922,331	

Note. The price unit is KRW million at the constant price of 1996. USD 1 = KRW 1172.5.

As seen above, the government calculated the NPV (KRW 14,067 million) and B/C (1.02) of the project. To allow for uncertainty in the project, it implemented sensitivity analysis and analyse the cases for changes in the discount rate as shown in Table 2.8 (Ministry of Land, Infrastructure and Transport of South Korea, 1996).

Table 2. 8 *Example of a sensitivity analysis by using discount rates*

Discount rate	5%	6%	8.5%	10%
B/C ratio	1.10	1.07	1.02	0.99

Note. Ministry of Land, Infrastructure and Transport of South Korea, 1996.

However, Kwak et al. (1999) report on research they conducted in a paper titled "The study for alternative and analysis of economic effects of construction of Youngwol Dong-Gang Dam". In the report, they reconsidered the results of the CBA of the dam. They also used CVM to assess the environmental value of the Dong-Gang River and recalculated the NPV by adding the environmental value of the river as shown in Table 2.9.

Table 2. 9 *Assessment of the environmental value of the Dong-Gang River*

Private cost (PC)	Environmental cost (EC)	Social cost (SC)	Benefit (B)	Private net benefit (B-PC)	Social net Benefit (B-SC)
114,969 (USD 98.08 m)	111,875 (USD 95.42 m)	226,844 (USD 193.47 m)	115,603 USD 98.6 m)	634 (USD 0.54 m)	-111,241 (USD -94.88 m)

Note. The cost unit is KRW million at the constant price of 1996. USD 1 = KRW 1172.5.

Consequently, they express concern about the feasibility of the project (Kwak et al. 1999). As a result, the government officially cancelled the plan. The research is an archetypal example of how CBA can affect policy decisions in South Korea.

Another example is more closely related to this research. Na (2013) conducts an ex-post CBA of an advanced water treatment system in a waterworks in An-San City in South Korea. The installation of advanced water treatment system is completed in 2009. She calculates the costs with initial investment costs, operating costs and the social costs of environmental pollution, and the benefits with conventional operation costs and water quality improvement benefit. For the water quality improvement benefit, she uses the average of WTPs (KRW 2,160 per month per household) estimated in preceding CVM studies about other regions from 1994 to 2011. She conclude that the investment is valid as shown in Table 2.10.

Table 2. 10 *Result of the Cost-benefit analysis*

Present value of costs	Present value of benefits	NPV	B/C	IRR
13,057 (USD 11.14 m)	39,409 (USD 33.61 m)	26,352 (USD 22.48 m)	3.0	38.3%

Note. The price unit is KRW million at the constant price of 2005. USD 1 = KRW 1172.5.

However, there are drawbacks to using the WTPs of other CVM studies for benefits. First, it is inappropriate to apply the WTPs estimated in different regions and at different times. Second, the WTPs calculated by CVMs using hypothetical situations with different attributes might deviate from the right path. If an advanced water treatment system has a specific goal to improve specific attributes of drinking water quality, CE is recommended to estimate the benefits, because CE can estimate various ranges of the changes of attributes of goods.

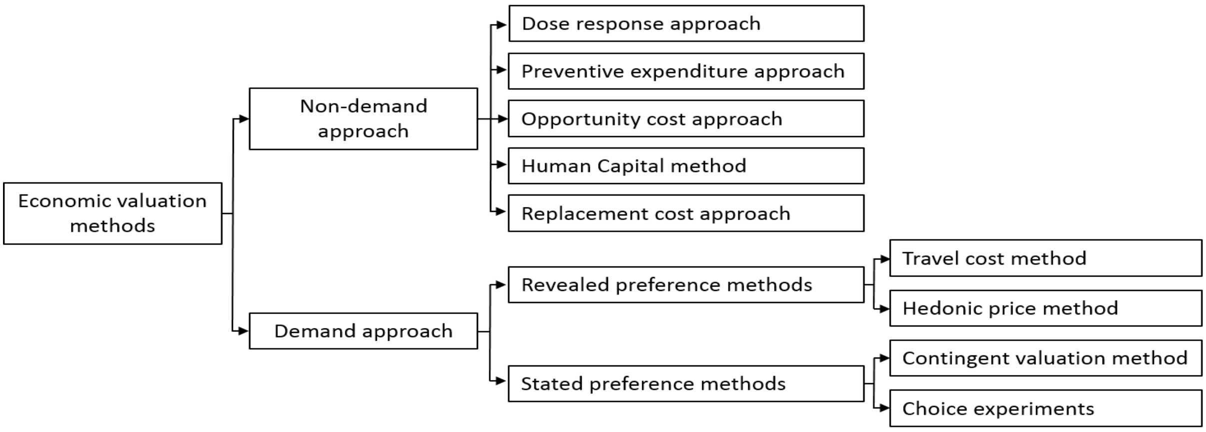
2.3 Choice Modelling Methodology

Since the 20th century, environmental pollution has become a serious issue. Environmental goods and services have several characteristics. First, they are non-market commodities. Second, improvement of environmental goods and services is seen as a good thing but enormously costly. Third, investment in the environment influences the long term, even in some cases future generations. For these reasons, evaluation of such goods and services has become a more important issue. This part looks at how to measure environmental and other non-market goods and services.

2.3.1 Economic Valuation of the Environment

In everyday life, individuals choose the goods and services they want. All societies must determine the quantity and quality of many environmental resources for consumption and preservation. Turner et al. (1994) argue that the choice logically implies some form of valuation and many techniques are available to value environmental goods in economic terms. These techniques are divided into two main categories. One is the valuation of environmental commodities through the demand curve, a market demand approach and the other is the non-demand valuation, like dose-response, preventive expenditure, opportunity cost and replacement cost approaches, as well as the human capital method. Demand approaches are categorized into revealed preference and stated preference methods. These categories are shown in Figure 2.1.

Figure 2. 1 *Economic valuation methods (Source from Garrod and Willis, 1999)*



Even though non-demand approaches have been used extensively in governments' assessment of the cost of environmental impact, the approaches have drawbacks in assessing the value on the cost side. That is, non-demand approaches cannot measure the value of consumer surplus (Garrod and Willis, 1999). Therefore, to assess environmental goods on the benefit side, market demand approaches are more useful. In addition, market demand approaches can measure the non-use value of environmental goods as well as the use value while non-demand approaches cannot measure values like option, existence and bequest.

2.3.2 Demand Approaches

To consider the value of environmental goods in terms of consumer surplus, it is more appropriate to use demand approaches. Which have two main categories: revealed preference methods (RP) and stated preference methods (SP). Both methods have limitations.

First, RP provides only ex-post information. Thus, when ex-ante information is needed, RP may not be useful. Second, RP methods cannot measure the non-use value of environmental goods or can do so only with difficulty. Third, RP data reflect actual choices but such data are restricted to the choice situation and alternatives with current or historic existence. RP data are unavailable for new situations such as the demand for a new product. In addition, Train (2009) argues that while some products exist in the marketplace with very little variability in explanatory variables it is not sufficient to estimate the relevant factors with the revealed preference data. In this case, he claims that the paradox[10] is inherent in RP data (Train, 2009). Garrod and Willis (1999) also classify the methods for valuing environmental goods but in a different way, indirect methods and direct methods. Indirect methods include the hedonic price method, the defensive expenditure or averting behaviour models, and the weak complementary model. However, indirect methods have several limitations, including inaccuracy, complexity, difficulty in gathering data, and constraints on using the method (when the revealed data cannot be obtained because the alternatives and the attributes of them don't exist or have not existed yet).

In contrast, SP methods (also called direct methods) can overcome the limitations of RP methods, Louviere et al. (2000) summarises the seven areas for using SP as follows;

1) Organisations need to estimate demand for new products with new attributes or features.
2) Explanatory variables have little variability in the marketplace.
3) Explanatory variables are highly collinear in the marketplace.
4) New variables are introduced that now explain choices.
5) Observational data cannot satisfy model assumptions and/or contain statistical 'nasties' which lurk in real data.
6) Observational data are time consuming and expensive to collect.
7) The product is not traded in the real market.

[10] Train (2009) uses the case of California households' choice of energy supplier as an example. While there has been practically no difference in price among suppliers' offers, customers' response to price cannot be estimated on data that contain little or no price variation.

Therefore, despite well-developed economic theory for dealing with real market choices, many economists and social scientists are interested in SP methods in hypothetical or virtual markets instead of real markets as shown above in the seven areas noted (Louviere et al., 2000). Garrod and Willis (1999) state that the merit of SP methods is that there is no need to seek a complementary or substitute good to derive a demand curve for estimating individuals' implicit valuations of environmental goods or services. In summary, for ex-ante measurement of the effects of a policy or costs and benefits of public investment without market data, SP methods are useful and practical.

2.3.3 Contingent Valuation Methods

SP methods fall into two main categories: contingent valuation methods and choice experiments. CVM is defined as a method measuring the value of various environmental effects through the choice that individuals make to maximise their utility with budget constraint when respondents are provided with a contingent (or virtual) situation. That is, the estimated value is the contingent value given in a hypothetical situation. CVM is a typical stated preference method measuring the trade-off caused by changes between environmental goods and willingness to pay (Garrod and Willis., 1999).

Ciriacy-Wantrup (1947) first propose CVM as a method for measuring the benefits of preventing soil erosion. Mitchell and Carson (1986) describe the first use of CVM as when economist Robert K. Davis estimated the benefits of outdoor recreation in a Maine back woods area of the U.S. in 1963, while Hanemann (1994) argues that the empirical practice of CVM can be traced to the study of outdoor recreation in the Delaware River Basin area, funded by the U.S. National Park Service in 1958.

The methods begin to be used more interestingly in the 1960s. From the 1980s, a large number of case studies has been carried out in the U.S. following the Comprehensive

Environmental Response, Compensation and Liability Act in 1980 which incorporated CVM in institutional decision-making as a technique to measure the extent of natural resource damage from spillage of hazardous substances as in the Exxon Valdez incident. In particular, the Exxon Valdez oil spill on 24th of March, 1994 is seen as the turning point in promoting empirical studies for valuing the natural environment. In the 1990s, CVM attracted enormous attention from many economic theorists across the world. Subsequently, the U.S. National Oceanic and Atmospheric Administration (NOAA) formed a blue-ribbon panel of independent economic experts to evaluate the use of CVM in determining passive use values.

CVM has the limitation that environmental valuation is usually restricted to measuring the change in one attribute of environmental goods or services. It is not easy to apply the method, when there are many kinds of attributes of environmental commodities. Therefore, instead of CVM, choice experiments, which overcome the limitation of CVM, can measure the trade-off between environmental impacts with multiple attributes and respondents' WTP. The next part will explore the CE, including how the methods have been developed, and disseminated.

2.3.4 Choice Experiments

Another example of SP is choice experiments, which also have a variety of names, including stated choice in transportation and environmental economics literature and conjoint analysis in marketing (Garrod and Willis., 1999). CE originated in the mathematical psychology literature of Luce and Tukey in 1964. After that, CEs were quickly developed in the field of marketing researches in the USA. In particular, the field of transport planning became the initial point of practical application (Louviere et al., 2000). Since then, application has widened to include demand forecasting and estimating the value of travel time. In 1992 in the U.K., the Department of Transport suggested that CVM and CE studies should be included in the formal CBA of each highway scheme (Pearman, 1994). In the U.S., NOAA has also accepted CE as a useful method for assessing the damage to resources (Adamowicz et al., 1998). The use of CE has continuously increased following the application to environmental economics.

In practice, it is broadly accepted that CE might be more suitable for measuring resource compensation than CVM because CE is a survey-based method to value several important attributes of public commodities considering individuals' choices. Many private business companies have also used the tool for designing new products. In addtion, it is possible to incorporate two representative SP methods: CVM and CE, for more accurate information about the public value of compensation for the injury from public investment.

2.3.5 Comparison between Contingent Valuation Methods and Choice Experiments

As stated, CE have been widely used in many fields such as marketing, transportation, and health care since the 1970s. To date, the most common method of SP for environmental valuation has been CVM (Carson et al., 1994). However, CVM cannot provide information where there are changes in several attributes of goods and services, where it is widely accepted that CE can. In short, CE can provide more flexible information than CVM. In this part, CVM and CE are compared.

Adamowicz et al. (1998) report several potential advantages of CE compared to CVM in measuring both use values and non-use values. For example, CE usually provides much information about the trade-offs of attributes that respondents are willing to make, the variances of welfare estimates from the CE are smaller than those from CVM in general, and the error variance of CE is not significantly different from CVM (Adamowicz et al., 1998).

Hanley et al. (1998) also compare CVM and CE. They state that CE provides researchers with three advantages over CVM:

1) Easiness to disaggregate each value of attributes for environmental resources
2) Avoidability of the part-whole bias problems of CVM
3) Avoidability of the 'yea-saying' problem in dichotomous choice CVM.

They also point out that CE has unresolved issues, such as how to choose such attributes from the large attainable set and how this choice affects the "total package" welfare measures from CE. Other drawbacks included that CE is responsive to the information set presented to as well as held by respondents, welfare estimates from CE are sensitive to the functional form of choice, there is a possibility of omitting some essential attributes that are important to consumers' preference and CE cannot test all interaction effects between attributes. However, they conclude that CE is the more suitable method due to its many advantages (e.g. regarding benefits transfer) despite the handicaps (Hanley et al., 1998).

Stevens et al. (2000) also assert some advantages of CE versus CVM. CE methods may provide respondents with an opportunity to explore their preferences and trade-offs in more detail. This is the same point made by Adamowicz. Another merit is that CE has a relatively lower non-response and protest rate because CE provides more options that respondents can choose while CVM provides only one option, (e.g. whether or not; Stevens et al., 2000).

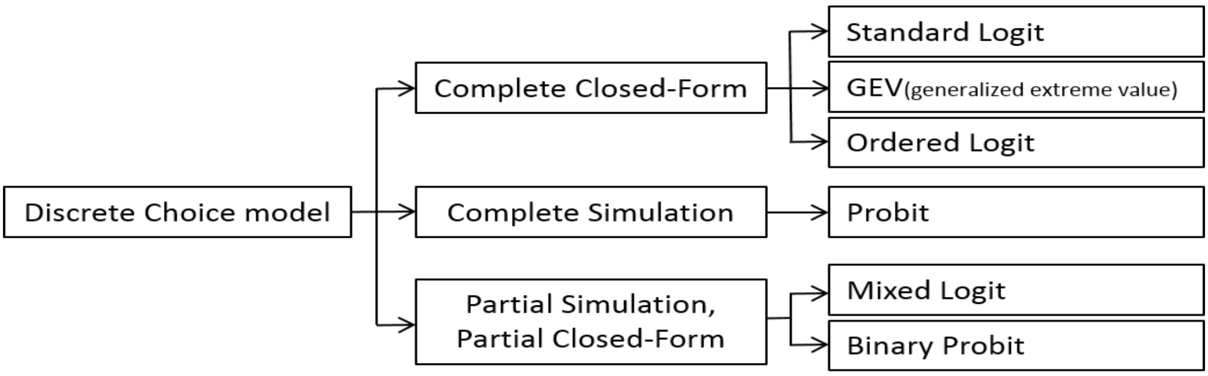
To sum up, CE has been a more popular method because it offers more advantages than CVM. For example, CE measures the value of changes in several attributes at several levels. When no markets exist in which to trade some goods or projects improve some attributes of public goods, CE is the most suitable method.

2.3.6 Discrete Choice Models

From the above results, CE is a more suitable method for assessing the improvement of drinking water quality because it is necessary to measure each value of each attribute of drinking water quality. For evaluation of the values of attributes, several econometric models have been developed. In this part, some of the econometric models will be outlined.

Train (2009) summarises the models into three categories: complete closed-form expression, complete simulation, and partial simulation-partial closed form from the viewpoint of whether the choice probability can be calculated from the closed form or not, as shown in Figure 2.2.

Figure 2. 2 *Discrete Choice models (Source: Train, 2009)*



Looking at the division, when a decision-maker chooses one among many alternatives, a consumer selects the one that provides maximum utility. Every alternative has its own levels of each attribute. The attributes that affect the decision include those that can be observed by researchers and those that cannot be observed. The unobserved attributes were once considered error terms in the utility function. The point that divided the categories is related to the error term. Because researchers cannot observe the error term, they cannot predict the decision of consumers exactly; rather, they can only calculate the probability of choice. To find the probability of choice, the integral of the distribution of the error term (i.e. the cumulative distribution function) is needed.

The complete closed form models assume that the error terms have complete closed form cumulative distribution functions like logit, whereas complete simulation models assume that the error term does not have complete closed form so that the cumulative distributions functions must be simulated like probit. The third category decomposes the error term into two parts, like mixed logit.

Luce (1959) formulates the standard logit model with the assumption of independence from irrelevant alternatives (IIA). For IIA, the error terms among alternatives have no correlations between any two terms so that there is no substitution pattern between any two attributes. Under the IIA assumption, the ratio of the choice probability for any two alternatives does not change even though the third alternative is introduced. One of the earlier, remarkable examples of using logit models is from McFadden who predicted the ridership of a new rail system, Bay Area Rapid Transit, in San Francisco in the mid-1970s. After that, innumerable studies using the logit model have been carried out. However, the logit model has three crucial limitations; (1) inability to represent random taste variation (2) restrictive substitution patterns due to the IIA property and (3) unavailability of panel data when unobserved factors are correlated over time for each decision maker.

Generalised extreme value models are defined as models that mitigate the IIA assumption, when the distribution of the unobserved term of utility for all alternatives is related to generalised extreme-value. The most familiar model of the generalised extreme-value models is nested logit which has been used in many studies regarding, for example, transportation, telecommunications, energy and housing.

In the case of probit models, Thurstone (1927) first derives a binary probit for the terminological stimuli, and Marschak (1959) applies the model to economic terms as utility. Later, Hausman and Wise (1978) and Daganzo (1979) sorted out the generality of the specification for representing various aspects of choice behaviour.

Mixed logit has high flexibility that can avoid the three limitations of standard logit by accepting random taste variation, unrestricted substitution patterns, and correlation in unobserved factors over time. After Boyd and Mellman (1980), and Cardell and Dunbar (1980) first applied the model to automobile demand, many studies have been conducted (Train, 2009).

Discrete choice models provides a more accurate interpretation of the mechanism of choices. To achieve a better understanding and more appropriate analysis of choice situations, it is necessary to compare the results using a variety of econometric models.

2.4 Summary of Literature Review

In conclusion, little research has investigated valuing improvements in drinking water quality, as compared with more evaluation studies focused on the water quality of rivers, lakes, and basins. The common method used in measuring the benefits of improved water quality has been CV. This part summarises points from the literature review.

First, with respect to drinking water quality, some attributes like taste, odour, clarity, and safety, are seen several times within the reviewed papers as important factors to drinking water service. When a project focuses on improvement of drinking water quality, these factors must be considered crucial attributes.

Second, it is particularly important to note that people's perceptions have a significant effect on environmental evaluation. It is well reported that consumers' perceptions are often biased or based on inaccurate information, and consumers tend to overestimate low probability events. Therefore, provision of accurate information is important.

Third, on the one hand, the matter of an incentive compatibility criterion can be mitigated in the case of public goods and services, as Carson et al. (1994) point out. On the other hand, if customers have an option to buy or not to buy in the case of private goods, they tend to exaggerate their interest and WTP for a private good to make the suppliers produce more goods. However, with the drinking water supply, all consumers should pay their allocation of the total costs, regardless of whether the benefit that they obtain from the investment, surmount the costs.

CBA is the most widely used method for studying the feasibility of public investments. In many countries, governments use CBA to confirm the validity of public investments in the decision-making process. In that case, they also use NPV, B/C, and IRR, complementarily.

When there is a need to estimate the value of each attribute of a public good or service, CE is a more suitable method than CVM, because CE has advantages in obtaining useful information for choosing any practical option by providing several choice options.

Moreover, with regard to analysing the CE data, a variety of statistical models: standard logit (e.g. nested logit, probit, mixed logit) have been developed. Discrete choice models have provided reliable information on people's choice among many kinds of real goods and services, as well as virtual goods and service. In most cases analysing the models, it is assumed that utility functions must be additive, although this might be unrealistic in real markets.

It is not long since CE was first used to study WTP for changes in attribute levels of drinking water quality (Willis et al., 2005). For more accurate analysis, it is important to define the attributes of drinking water services and to design suitable survey questionnaires.

Chapter 3. Methodology

Choice experiments are chosen to assess the benefits from improvement of drinking water quality in this research. For implementing a CE, this section explores four parts: sample size, experimental design, methods for mitigating hypothetical bias and methods for evaluating improvements in the attributes. The first subsection describes how to choose an appropriate sample size. The second explores the experimental design. The third describes hypothetical bias and the treatments for mitigating it. The next seven subsections specify the methods for evaluating the improvements in attributes such as the multinomial logit model, random parameter model and latent class logit model.

3.1 Sample Size

3.1.1 Sample Size for Multinomial Choice

In statistics, a representative sample is defined as a small quantity that accurately reflects the characteristics of a population. In this case, the difference between one entity of the sample and the population is called the sample error. Statistically, a representative sample is one that minimizes the sample error. In choice experiments, researchers have wanted to determine the proportions of the alternatives that their respondents have chosen in their surveys. Therefore, the sample error in CE can be defined as the differences in the choice proportion by the sample and the population. This part will discuss how the sample size of the present study is determined. To obtain a representative sample for a population of one chosen target city; Cheongju City in South Korea, two statistical methods will be discussed.

Sample size is an important factor in CE for testing the representativeness of the sample. However, there is no complete theory relevant to the requirements of sample size for stated preference data so many researchers have relied on rules of thumb or subjective criteria (Rose and Bliemer, 2005). This part examines the sample size necessary for representativeness.

Thompson (1987) studied proper sample sizes of multiple options. If there are K options, there are also K proportions of population. For proper sample size to maintain representativeness of the population, he uses the probabilities of all differences of proportions between population and sample. Let there be *i* options among *K* alternatives ($i = 1, \cdots, K$), then the proportion that all people in population *N* choose option *i* can be expressed as π_i ($0 \leq \pi_i \leq 1, \sum_1^k \pi_i = 1$). The proportions of sample, p_i can be observed when the sample size is *n*. Thus, the probability of the absolute value of differences between p_i and π_i for all i can be expressed as below,

$$Pr\{\forall i,\ |p_i - \pi_i| \leq d_i\} \geq 1 - \alpha,\ \ \alpha; significance\ level \qquad (3.1).$$

Here, d_i is an already chosen difference between p_i and $\pi_i$like 0.05. Then, the probability that the estimate p_i lies outside the specified interval is as below,

$$\alpha \geq \ \sum_1^k \alpha_i\ ,\ \ \alpha_\mathrm{i} = Pr\left\{|z_i| \geq d_i \frac{\sqrt{n}}{\sqrt{\pi_i(1-\pi_i)}}\right\} = 2\big(1 - \Phi(z_i)\big) \qquad (3.2).$$

Here, $\Phi(z_i)$; the cumulative standard normal distribution is as below,

$$z_i = \ \frac{p_i - \pi_i}{\sigma_p} = \frac{d_i}{\sigma_p},\ \ \sigma_{p_i} = \ \sqrt{\frac{\pi_i(1-\pi_i)}{n}}\ ; standard\ deviation\ of\ population.$$

$\sum_1^k \alpha_i$ is maximized if all proportions of the population choose all of the options equally; $\pi_i = 1/m,\ m \leq k$, m is the number of choices. He simulates the sample size n as below,

$$n = \max_m z^2 \frac{(\frac{1}{m})(1-\frac{1}{m})}{d^2} \qquad (3.3).$$

Equation (3.3) can also be changed with regard to α_i, as below,

$$\alpha_\mathrm{i} = 2\big(1 - \Phi(z_i)\big), \text{ where } z_i = \ \frac{p_i - \pi_i}{\sigma_p} = \frac{d_i}{\sigma_p},\ \ \sigma_{p_i} = \ \sqrt{\frac{\pi_i(1-\pi_i)}{n}}$$

$$\alpha_\mathrm{i} = 2(1 - \Phi(\frac{d_i}{\sqrt{\frac{\pi_i(1-\pi_i)}{n}}}))\ ,\ \ \therefore \Phi(\frac{d_i}{\sqrt{\frac{\pi_i(1-\pi_i)}{n}}}) = 1 - \frac{1}{2}\alpha_\mathrm{i},\ \frac{d_i}{\sqrt{\frac{\pi_i(1-\pi_i)}{n}}} = \ \Phi^{-1}(1 - \frac{1}{2}\alpha_\mathrm{i}),$$

$$\therefore n \geq \frac{\pi_i(1-\pi_i)}{d_i^2}\left[\Phi^{-1}(1-\frac{1}{2}\alpha_i)\right]^2 \quad (3.4).$$

Louviere et al. (2000) describe Equation (3.4) as simple random sampling. This research has three alternatives: the status quo, GAC and ozone plus GAC. If the three proportions are equal at a 1/3 ratio, a 510 sample is sufficient for estimating the three proportions with a 95% confidence level and under 0.05 with total sum of differences between actual proportions and estimated proportions, regardless of population size. Therefore, 500 is the target sample size for this research.

3.1.2 S-efficiency

The other method for determining the required sample size for representativeness is S-efficiency. When several choice tasks are given to each respondent in a survey, s = 1,⋯,S, Rose and Bliemer (2013) suggest that the variable S can be added in Equation (3.4) because respondents are usually asked to answer multiple choice cards as below,

$$n \geq \frac{\pi_i(1-\pi_i)}{S \cdot d_i^2}\left[\Phi^{-1}(1-\frac{1}{2}\alpha_i)\right]^2 \quad (3.5).$$

From Equation (3.5), the minimum sample size can be calculated. However, this equation just provides the sample size for the proportions of the population. When conducting choice experiments, many combinations of levels of attributes exist. Therefore, it is necessary to consider this aspect of the experimental design. Rose and Bliemer (2013) addressed the S-efficiency measure by using mixed logit models. Assuming b is the parameters as mentioned earlier and $se_n(\bar{b})$ the predicted vector of asymptotic standard errors of the estimates with sample size *n*, $se_n(\bar{b})$ would be the square roots of the diagonal elements of the predicted asymptotic variance-covariance matrix. In most surveys, all respondents are asked to answer the same kind of choice cards. Therefore, $se_n(\bar{b})$ can be expressed by using the first person's, $se_1(\bar{b})$ as below,

$$se_n(\bar{b}) = \frac{se_1(\bar{b})}{\sqrt{n}} \qquad (3.6).$$

Equation (3.6) shows the diminishing effectiveness of larger sample size. Thus, it is important to employ more efficient designs. The asymptotic t-ratio with a given sample size, N, and prior parameter estimates, b_k^*, can be expressed as follows,

$$\frac{se_N(b_k^*)}{b_k^*} \geq t^* \qquad (3.7).$$

At a 95 % confidence level, t^* can be 1.96 and $se_N(b_k^*)$ can be substituted by $se_n(\bar{b})$ in Equation (3.7), when $se_n(\bar{b}) = se_N(b_k^*)$. Then, Equation (3.7) can be expressed as below,

$$N_k \geq \left[\frac{1.96 \cdot se_N(b_k^*)}{b_k^*}\right]^2 \qquad (3.8).$$

In Equation (3.8), N_k means the minimum sample size of each attribute and the minimum sample size will differ. Using Equation (3.8), they define the S-error as the sample size when the design minimizes the largest sample size for all parameters to be statistically significant. In this research, the target sample size is 500 respondents. Therefore, the D-efficiency will be measured for testing the efficiency of the experiment design. Also, the S-efficiency will be explored for testing the representativeness of the sample size later.

3.2 Experimental Design

Usually, enormous numbers of treatment combinations are available because of the number of attributes and the levels of the attributes. However, researchers cannot put all treatment combination to use and don't have to do so. Thus, this part explores how to build practical treatment combinations. Treatment combination is defined as each combination of attribute levels that marketers prefer to call profiles (Louviere et al., 2000). In this research, three options (or alternatives) are considered: the status quo, granular activated carbon, and ozone plus GAC treatment. Also, there are four attributes (or factors): safety, taste and odour, colour, and cost. Three attributes have three levels, and cost has six levels. Therefore, the complete factorial design will be 4,251,528 ($3^{3\times3} \times 6^3$). When assuming there is no restriction, like the status quo, we can have all levels of each attribute. It is impossible to ask respondents to answer such an enormous number of choice sets, and also not necessary to do so. In addition, in reality some restrictions are applied to the experimental design. For instance, the status quo represents the unchanged state of drinking water quality, so it cannot have any other levels except the lowest levels of each attribute like zero additional monthly water bill per household. In this case, the complete factorial design will be reduced to 18,225 ($3^{2\times3} \times 5^2$). Thus, the realistic cases for design can be reduced. This subsection will explore three methods of experimental design but mainly two methods will be discussed more specifically: D-efficiency and S-efficiency.

3.2.1 Orthogonal Design

Statistical experimental designs originally developed in the field of experimental science and agricultural research, and have helped reduce the number of choice sets (Bateman et al., 2009). The first method for reduction of the choice set is orthogonal design in which each of the variables has zero correlation with any of the other variables. In practice, orthogonal designs help researchers measure the influence of changes in each attribute on the respondents' choices. For example, if there is a design in which one attribute and another attribute always vary together with perfect correlation, then it is impossible to address which attribute has an effect on a dependent variable. Furthermore, orthogonal designs work for measuring only the main effects, that is, it is impossible to measure interaction effects. In orthogonal design, the dependent variable (usually utility in stated choice surveys) varies with the independent changes of each attribute. It is assumed that each attribute is not dependent on any other attributes. Therefore, it is impossible to measure the interaction effect because there is no simultaneous change of any two attributes. As a result, orthogonal design can reduce the number of choice sets given to respondents. However, even though orthogonal design is a useful method in choice experimental design, there are also reasons why it should be departed from in practice. The first is that the alternatives presented to respondents might be unrealistic (Bateman et al., 2009).

3.2.2 D-efficiency Approach

Another method is called D-optimal design, which is the most prevalent approach for measuring the efficiency of experimental design (Ferrini and Scarpa, 2007). D-optimal designs minimize D-error, which is defined as the determinant of the asymptotic variance-covariance matrix (Kerr and Sharp, 2009). For example, if there is a multinomial linear regression model, $y = X\beta + \epsilon$, this equation can be rewritten in matrix form as below,

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}_{n\times 1} = \begin{bmatrix} 1 & X_{11} & \cdots & X_{k-1,1} \\ 1 & X_{12} & & X_{k-1,2} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & X_{1n} & \cdots & X_{k-1,n} \end{bmatrix}_{n\times k} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_n \end{bmatrix}_{k\times 1} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_n \end{bmatrix}_{n\times 1} \quad (3.9).$$

In Equation (3.9), the ordinary least squared estimate can be written as below,

$$\hat{\beta} = (X'X)^{-1}X'y \quad (3.10).$$

From $y = X\beta + \epsilon$, y can be changed with $X\beta + \epsilon$ in Equation (3.10) as below,

$$\hat{\beta} = (X'X)^{-1}X'(X\beta + \epsilon) = \beta + (X'X)^{-1}X'\epsilon, \qquad \because (X'X)^{-1}X'X = I$$

$$\hat{\beta} - \beta = (X'X)^{-1}X'\epsilon \quad (3.11).$$

Thus, it is possible to derive the variance of $\hat{\beta}$ as follows,

$$\begin{aligned} \mathrm{E}\left[(\hat{\beta} - \beta)(\hat{\beta} - \beta)'\right] &= E[((X'X)^{-1}X'\epsilon)((X'X)^{-1}X'\epsilon)'] \\ &= E[(X'X)^{-1}X'\epsilon\epsilon'X(X'X)^{-1}] \\ &= (X'X)^{-1}X'E[\epsilon\epsilon']X(X'X)^{-1} \quad (3.12). \end{aligned}$$

In ordinary least squared estimations, the expectation of the variance-covariance of residuals $E[\epsilon\epsilon']$ is presumed to have two assumption of homoscedasticity and no auto-correlation. Thus, $E[\epsilon\epsilon']$ is written as below,

$$E[\epsilon\epsilon'|X] = \sigma^2 \begin{bmatrix} 1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{bmatrix} = \sigma^2 I \qquad (3.13).$$

Then, Equation (3.13) can be changed as follows,

$$\mathrm{E}\left[(\hat{\beta} - \beta)(\hat{\beta} - \beta)'\right] = \sigma^2 (X'X)^{-1} \qquad (3.14).$$

The right side employs the inverse matrix of $(X'X)$. Let the dimension of the matrix $X'X$ be $k \times k$; then, the inverse matrix can be written as follows,

$$(X'X)^{-1} = \frac{1}{|X'X|} \begin{bmatrix} M_{11} & -M_{21} & \cdots & (-1)^{k+1}M_{k1} \\ -M_{12} & M_{22} & & (-1)^{k+2}M_{k2} \\ \vdots & \vdots & \ddots & \vdots \\ (-1)^{k+1}M_{1k} & (-1)^{k+2}M_{2k} & \cdots & (-1)^{k+k}M_{kk} \end{bmatrix} \qquad (3.15).$$

$(-1)^{i+j}M_{ij}$ is the cofactor of the $X'X_{ij}$ on the matrix $X'X$. In (3.15), D-efficiency is defined as the value of minimizing the determinant of the inverse matrix of the matrix $X'X$. A-optimality means the case of minimizing the trace of the information matrix $X'X$, which means that the sum of only variances (not covariance) is minimized.

However, it is more complicated to measure the D-efficiency of discrete choice models. This paper reviews how to measure the D-optimal of a multinomial logit model to make the optimal choice sets. In the multinomial logit model, the utility functions usually are specified as simple additive forms as below,

$$U_{ij} = V_{ij} + \varepsilon_{ij} = \sum_{k=1}^{K_j} b_{jk} x_{jk} + \sum_{k=1}^{K^*} b_{jk}^* x_{jk}^* + \varepsilon_{ij} \qquad (3.16).$$

Here, U_{ij} expresses the utility of alternative *j* ($j = 1, \cdots, J$) chosen by individual *i* (i$= 1, \cdots, I$). x_{jk} is the vector of observable alternative-specific independent variables and $x^*_{jk}$is the vector of observable generic independent variables. b_{jk} is the coefficient of the alternative-specific variables and b^*_{jk} is the coefficient of the generic independent variables, of the ideal representative consumer to be estimated and ε_{ij} is the error term with a stochastic distribution. In the multinomial logit model, the error term ε_{ij} is assumed to be independent and identically distributed variables (type 1 extreme values distribution). The choice probability of individual *i* choosing alternative *j* in the MNL is derived as below,

$$P_{ij} = \frac{\exp(V_{ij})}{\sum_{k \in J_i} \exp(V_{kj})} \tag{3.17}$$

For measuring the coefficients of the MNL model, maximum-likelihood procedures are used. The probability of individual *i* choosing alternative *j* can be expressed as below,

$$\prod_j \left(\frac{\exp(V_{ij})}{\sum_{k \in J_i} \exp(V_{kj})} \right)^{y_{ij}} \tag{3.18}$$

Where, $y_{ij} = 1$ if individual *i* choses alternative *j* and zero otherwise. From Equation (3.18), it is possible to measure the likelihood function; which is the probability of all individuals in the sample with size I ($i = 1, \cdots, I$) choosing the alternative *j* as below,

$$L(b) = \prod_{i=1}^{I} \prod_j \left(\frac{\exp(V_{ij})}{\sum_{k \in J_i} \exp(V_{kj})} \right)^{y_{ij}} \tag{3.19}$$

Because the logarithm is a monotone function, the estimators of the coefficient vector *b* that maximize the likelihood Equation (3.19) will be the same with the vector as below,

$$LL(b) = \sum_{i=1}^{I} \sum_j y_{ij} \frac{\exp(V_{ij})}{\sum_{k \in J_i} \exp(V_{kj})} \tag{3.20}$$

Equation (3.20) is the log-likelihood function of the probability of all individuals in the sample. To have efficient choice-experiments sets, the asymptotic variance-covariance matrix of the efficient design of choice sets should be estimated. The asymptotic variance-covariance matrix,, Ω_i can be computed using the second derivatives of the log-likelihood function, $LL(b)$ as below (Train, 2009),

$$\Omega_i = I_i^{-1}, with\ I_i = -E_i(\frac{\partial^2 logLL}{\partial b \partial b'}) \qquad (3.21).$$

In Equation (3.21), I_i is called the Fisher information matrix in statistics. The mathematical calculation of the second derivative of the $LL(b)$ can be expressed as follows,

$$\frac{\partial^2 logLL}{\partial b^*_{k_1} \partial b^*_{k_2}} = -\sum_{i=1}^{I} \sum_{j=J_i} x^*_{ijk_1} p_{ij} (x^*_{ijk_2} - \sum_{n=1}^{J} p_{in} x^*_{ink_2}) \qquad (3.22).$$

$$\frac{\partial^2 logLL}{\partial b_{j_1k_1} \partial b^*_{k_2}} = -\sum_{i=1}^{I} \sum_{j=J_i} x_{j_1k_1} p_{j_1} (x^*_{j_1k_2} - \sum_{n=1}^{J} x^*_{nk_2} p_n) \qquad (3.23).$$

$$\frac{\partial^2 logLL}{\partial b_{j_1k_1} \partial b_{j_2k_2}} = \begin{cases} \sum_{i=1}^{I} \sum_{j=J_i} x_{j_1k_1} x_{j_2k_2} p_{j_1} p_{j_2}, & if\ j_1 \neq j_2 \\ -\sum_{i=1}^{I} \sum_{j=J_i} x_{j_1k_1} x_{j_2k_2} p_{j_1} (1 - p_{j_2}), & if\ j_1 = j_2 \end{cases} \qquad (3.24).$$

Equation (3.22) is the second derivative with a generic independent variable, x^*_{jk}, and Equation (3.23) counts the second derivatives with both generic x^*_{jk} and alternative-specific independent variable, x_{jk}. Equation (3.24) calculates the second derivative of alternative-specific independent variable, x_{jk}. In many utility function forms for a CE, the two types of variables, generic and alternative-specific independent are used. Thus, all three equations, (3.22), (3.23) and (3.24), must be used to calculate the second derivative of the *LL(b)*.

Given the asymptotic variance-covariance matrix, Ω_i, how to produce an initial design depends on which efficient value is chosen. The literature describes many types of efficient measures, expressed as an efficient error (i.e. a measure of inefficiency), aiming to produce a choice set design that minimizes the efficiency error, as in the case of ordinary least squared (OLS), D-optimality; in other words, D-error is the most widely used measure to minimise the determinant of the asymptotic variance-covariance matrix Ω_i (Rose and Bliemer, 2008).

A-optimality minimizes the value of the trace of the asymptotic variance-covariance matrix. At this stage, one problem related to the coefficients to be estimated emerges. The aim in many stated choice experiments is to estimate the parameters. This seems to be a circular argument. If the parameters were already known, it would not be necessary to estimate them. To date, three types of D-error have been suggested as follows,

$$D_0 - error = det(\Omega_i(x, 0)^{\frac{1}{k}} \quad (3.25)$$

$$D_p - error = det(\Omega_i(x, b_p)^{\frac{1}{k}} \quad (3.26)$$

$$D_B - error = \int det(\Omega_i(x, 0)^{\frac{1}{k}})f(b|\theta)db \quad (3.27).$$

Here, k is the number of parameters to be estimated, which can be used for normalizing when comparing the values of other choice sets with other numbers of parameters. D_0-error of Equation (3.25) optimizes the D-optimality assuming all the coefficients zero because there is no information about the parameter. D_p-error of Equation (3.26) generates the design, optimizing the D-optimality with prior b vector if information on the coefficients is given. D_B-optimality of Equation (3.27) generates an efficient design, assuming that b is a vector of random variables with a joint density function $(b|\theta)$ with given parameters, θ.

Subsequently, the coefficients from the pre-test sample are used to test the D-efficiency of the experiment design, ex-post. Therefore, Equation (3.26) is used for ex-post testing the practicality of the experiment design and Equation (3.25) and Equation (3.27) are not used.

3.3 Mitigation of Hypothetical Bias

3.3.1 Hypothetical Bias

Hypothetical bias has been reported in many stated preference valuation studies. Thus, this subsection will explore what hypothetical bias is and how to mitigate such bias. Samuelson

(1955) defines hypothetical bias as bias resulting from people not having an incentive to reveal their true willingness to pay and rather hoping to free-ride off others. Carson and Groves (2007) use the concepts of consequential and inconsequential, instead of hypothetical bias. They suggest that researchers who use a survey can only make a conjecture about counterfactual conditions that are contingent upon a specific concrete scenario, but they cannot identify a hypothetical thing that is imaginary and inconsequential. In contrast, a consequential survey can yield implications for the reality. If the respondents in a survey care about the outcome and think that they can influence it then the implications are identical to rational and utility-maximizing agents behaving in a real situation.

Loomis (2014) defines the bias as the difference between what people indicate they would pay in a survey or an interview and what they would actually pay, the so-called, "true" willingness to pay. He emphasises both directions of the bias (i.e. overstatement and understatement), even though hypothetical bias is in general considered to be an overstatement of willingness to pay. Many methods can be used to for mitigate hypothetical bias. This research uses two methods: cheap talk and honest priming task. Therefore, in this subsection, the two approaches are explored.

3.3.2 Cheap Talk

Cheap talk is defined as a script that explicitly highlights the hypothetical bias problem before participants make any decisions with the aim of generating unbiased responses in a survey questionnaire (Murphy et al., 2005). Cummings and Taylor (1999) introduced a cheap talk script to mitigate hypothetical bias (Murphy et al., 2005; Bosworth and Taylor, 2012). They also include a budget constraint reminder in the original version of the cheap talk script of their questionnaire. Table 3.1 shows the example that Cummings and Taylor (1999) use in their study.

Table 3. 1 Example of the cheap talk script by Cummings and Taylor (1999)

... in a recent study, several different groups of people voted on a referendum. Payment was hypothetical for these groups, as it will be for you. No one had to pay money if the referendum passed. The results of these studies were that on average, across the groups, 38 percent of them voted "yes." With another set of groups with similar people voting on the same referendum as you will vote on here, but where payment was real and people really did have to pay money if the referendum passed, the results on average across the groups were that 25 percent voted yes. That's quite a difference, isn't it? We call this a "hypothetical bias". Hypothetical bias is the difference that we continually see in the way people respond to hypothetical referenda as compared to real referenda... … I think that when we hear about a referendum that involves doing something that is basically good-helping people in need, improving environmental quality or anything else- our basic reaction in a hypothetical situation is to think: sure, I would do this. I really would vote "yes" to spend the money... … we vote in a way that takes into account the limited amount of money we have.... This is just my opinion, of course, but it's what I think may be going on in hypothetical referenda. So if I were in your shoes ... In any case, I ask you to vote just exactly as you would vote if you were really going to face the consequences of your vote: which is to pay money if the proposition passes. Please keep this in mind in our referendum.

Since the first use of the method, many studies have reported cheap talk as effective in reducing hypothetical bias (Carlsson et al., 2005; Landry and List, 2007; Tonsor and Shupp, 2011; Silva et al., 2011). On the other hand, others argue that the method may have limitations (List, 2001; Brown et al., 2003; Murphy et al., 2005; Aadland and Caplan, 2006).

List (2001) claims that the method might be restricted when the respondents have considerable experience in consuming the commodity tested. Brown et al. (2003) and Murphy et al. (2005) argue that the cheap talk may evoke a limitation when respondents face small payments. Aadland and Caplan (2006) assert that a shortened and more neutral script can cause the method to be ineffective.

Furthermore, no consensus exists on the effects of the method even where the previously mentioned conditions are met. For instance, Lusk et al. (2003) report no difference in the estimated WTPs between the hypothetical responses with cheap talk and the responses without cheap talk. Brummett et al. (2007) note that no differences in the WTP estimates with or without cheap talk. Jacquemet et al. (2009) also support the view that cheap talk does not affect sincere bidding. Therefore, caution is needed in preparing the cheap talk script, such as including the budget constraint reminder. Many stated preference valuation studies include a short reminder or discussion of hypothetical bias or budget constraint. However, there is no consistency in these reminders across studies regarding their efficacy.

3.3.3 Honesty Priming Task

The honesty priming task can be traced back to the social psychology study of Bargh and Pietromonaco (1982) which shows the effect when people are subconsciously primed with semantic words with respect to hostility: “the more hostile the words presented earlier, the more negative the impression of the stimulus person became”. Many social psychologists have demonstrated that unconscious priming can influence people’s choice and behaviour (De-Magistris et al., 2013). Maxwell et al. (1999) argue that participants primed with fairness showed more cooperative behaviour than those who are not primed. Chartland et al. (2008) demonstrate that some words in an independent task may unconsciously influence people’s subsequent decisions. Drouvelis et al. (2010) show that the priming task method can initiate cooperative behaviour among the participants in a social dilemma game. More recently, De-Magistris et al. (2013) show that honesty priming task can be effective in mitigating hypothetical bias in choice experiments.

Many studies in social psychology have also used the method to reduce hypothetical bias. Among them, some papers have stated that priming effects trigger cognitive and perceptual changes (Schvaneveldt and McDonald, 1981; Johnston and Hale, 1984). Others report that the priming tasks have failed when using notional duplications of these wider types of priming effects. Rasinkin et al. (2005) show that the priming tasks do not have an effect on cheating questions (e.g. alcohol drinking behaviour of respondents). Doyen et al. (2012) report no effect when they examine the walking speed of their participants exposed to conceptual words like “old age”. Pashler et al. (2012) experiment with the differences in distances when two participant groups are asked to plot a single pair of points on a piece of graph paper. The groups are presented with different notional words like “close, intermediate and far” and conclude that there is no difference in the distances between the two groups. Shanks et al. (2013) examine whether the priming effects of intelligence-related concepts such as professor and soccer hooligan can influence people in answering general knowledge questions, and report that they do not find such kind of effect in their experiments. As shown, many studies have been conducted to detect the priming effects and in some cases their failure, even though many reviewed studies are specifically implemented in the psychological field (Shanks et al., 2013). Therefore, caution should be used when interpreting the result of this research.

Apart from the two methods for mitigating hypothetical bias, strategic bias is also mentioned as an important factor regarding the supply of public goods and services. When answering a questionnaire about public goods, for example, people tend to understate their willingness to pay because they want to become free-riders. In this regard, the possibility of understatement also seems to exist. This research follows the conventional approach to hypothetical bias, so methods are used to mitigate both over and under-statement bias.

3.3.4 Hypothetical Bias Treatments

In this research, the four blocks are split to seek the strongest mitigating measure of willingness to pay by comparing the performances of the two chosen methods, cheap talk and honest priming task. Table 3.2 shows the details of organising the methods in blocks.

Table 3. 2 *Blocks for organizing the methods*

Method	Block 1	Block 2	Block 3	Block 4
Cheap talk	√	√	not	not
Honest priming task	√	not	√	not

Each block can be described by using dummy variables for testing the significance of its coefficient. In addition, this research will explore the interaction effect by using the interaction variables between the dummies and the price variable.

3.4 Random Utility Theory

As discussed above, CE has been used to measure the WTP of some attributes in many environmental goods and services. To calculate the WTP, it is necessary to estimate the coefficients of a utility function form set by a researcher. For evaluation of the values of attributes, several econometric models have been developed. Random utility theory is a starting point to introduce logit models. Let's assume that there is a sample of respondents, labelled i $(i=1,...,I)$, facing a choice among J $(j=1,...,J)$ alternatives in each of T $(t=1,...,T)$ choices; the utility regarding each alternative j measured by each respondent i in choice situation t can be expressed as follows,

$$U_{ijt} = bx_{ijt} + \varepsilon_{ijt} \quad (3.28).$$

x_{ijt} is a vector of observable independent variables that includes attributes of the alternatives, and socio-economic characteristics of the respondent (here, let $x_{ijt} = (x_{ijt1}, x_{ijt2,\cdots,}x_{ijtK})'$, i.e. x_{ijt} has K observable variables). b is the coefficient vector of the ideal representative consumer that should be estimated, and ε_{ijt} is the error term with stochastic distribution. Both are unobservable. One thing to consider is the form of the utility functions. Usually, a utility function is considered to be under the law of diminishing marginal utility. However, the utility function has a simple additive linear expression in many discrete choice models, which can be a drawback in these model.

For more flexibility, the error term is thought to have two parts (Hensher et al., 2001). One is an unspecified distributed error term and the other is independently identically distributed with Gumbell (type I) extreme value distribution. The two error terms can be assumed to be uncorrelated because one can set up the possibility that the error term, regardless of being unobserved, can be full of information to fade out the correlation among the alternatives in and across each consumer choice time. Then, the second error term acts as white noise. In this case, the utility can be written as follows,

$$U_{ijt} = bx_{ijt} + \eta_{ijt} + \varepsilon_{ijt} \qquad (3.29).$$

In Equation (3.29), η_{ijt} is one part of the error term and means random taste variation with any probability density form. Adding the error term of random taste variation can play a role in approximating any kind of random utility models. In Equation (3.29), η_{ijt} might be changed to other forms related to independent variables, $s_{ij}\tilde{\eta}_{ijt}x_{ijt}$. Here, s_{ij} is a vector of standard deviations having k^{th} scalars and $\tilde{\eta}_{ijt}$ is a vector of any density regarding individual *i* with mean zero and standard deviation one. Then, Equation (3.29) can be written as follows,

$$U_{ijt} = bx_{ijt} + \eta_{ijt} + \varepsilon_{ijt} = bx_{ijt} + s_{ij}\tilde{\eta}_{ijt}\, x_{ijt} + \varepsilon_{ijt}$$

$$= \left(b + s_{ij}\tilde{\eta}_{ijt}\right) x_{ijt} + \varepsilon_{ijt} \quad = \beta_{ij}\, x_{ijt} + \varepsilon_{ijt} \qquad (3.30).$$

In Equation (3.30), it is not necessary to assume that $\tilde{\eta}_{ijt}$ has a normal distribution. β_{ij} is a parameter vector of population distribution which has its own distribution, $f(b|\theta)$, with mean b, and standard deviation, s_{ij}. θ is parameters that provide information about the probability density of β_{ij}, and b is the mean taste of the population. The existence of $\tilde{\eta}_{ijt}$ provides the model with a place to accept preference heterogeneity (Hensher et al., 2001). β_{ij} can accommodate a number of meanings because it includes all observable independent variables, including alternative generic, specific and individual specific variables. Here, alternative generic coefficients car vary across individuals (j is not needed like β_i). Assuming the coefficients of socioeconomic factors have fixed values across individuals, *i* is not needed like β_j. This deriving of Equation (3.30) begins with an error component. On the other hand, Equation (3.30) can be derived from a random-coefficient interpretation. However, error-components and random-coefficient specifications are formally equivalent (Train, 2009, p. 140).

In this paper, random parameter logit (RPL) and latent class logit models (LCM) are used to analyse data. Random parameter logit can be used for deriving the formula of latent class logit because both have common elements. Random parameter logit, also called mixed logit, has three main advantages over standard logit: random taste variation, unrestricted substitution patterns and correlation in unobserved factors over time (Train, 2009, p. 134).

3.5 Random Parameter Logit Model

In economics, it is usually assumed that reasonable consumers choose the alternative with the largest utility. Individual i chooses alternative j at choice situation t, if and only if $U_{ijt} > U_{ikt}, \forall j \neq k$. However, each utility of consumers is unobservable and it is only possible to observe the levels of some attributes and socio-economic factors, $x_{ijt},\ \forall j$. The first part of the right side in the utility function is called representative utility because researchers can observe the explanatory variables and estimate the coefficients. If it is changed to V_{ijt}, then Equation (3.30) can be written as follows,

$$U_{ijt} = \beta_{ij}\, x_{ijt} + \varepsilon_{ijt} \;=\; V_{ijt} + \varepsilon_{ijt} \qquad (3.31).$$

If the independent variables of socio-economic factors are divided and expressed, z_{ijt}, V_{ijt} can be defined as the function of x_{ijt} and z_{ijt} like $V_{ijt} = V(x_{ijt}, z_{ijt})$. When individual *i* chooses alternative *j* at choice situation *t*, the probability can be expressed as below,

$$\begin{aligned} p_{ijt} &= Prob(V_{ijt} + \varepsilon_{ijt} > V_{ikt} + \varepsilon_{ikt}, \forall j \neq k) \\ &= Prob(\varepsilon_{ikt} < \varepsilon_{ijt} + V_{ijt} - V_{ikt}, \forall j \neq k) \qquad (3.32). \end{aligned}$$

In Equation (3.32), the error term, ε_{ijt} is a stochastic variable with Gumbell (type I) extreme value distribution (Train, 2009, p. 34). Because ε_{ijt} is independent, the cumulative distribution of when individual *i* chooses alternative *j* at choice situation *t* is the product of each cumulative distribution as follows,

$$p_{ijt}|\varepsilon_{ijt} = \prod_{j\neq k} e^{-e^{-(\varepsilon_{ijt}+V_{ijt}-V_{ikt})}} \qquad (3.33).$$

Even if ε_{ijt} is unknown, the expectation value of choice probability P_{ijt} can be calculated by the integral of the cumulative distribution over all values of ε_{ijt} multiplied by its density as below,

$$p_{ijt} = \int_{\varepsilon_{ijt}=-\infty}^{\infty} \left(\prod_{j\neq k} e^{-e^{-(\varepsilon_{ijt}+V_{ijt}-V_{ikt})}}\right) e^{-\varepsilon_{ijt}}\, e^{-e^{-\varepsilon_{ijt}}}\, d\varepsilon_{ijt} \qquad (3.34).$$

For a simple form of the expectation value, p_{ijt}, let ε_{ijt} ε and Equation (3.34) be manipulated as below (Train, 2009, p. 74-75),

$$p_{ijt} = \int_{\varepsilon=-\infty}^{\infty} (e^{e^{-\varepsilon}\sum_k -e^{-(V_{ijt}-V_{ikt})}}) e^{-\varepsilon} \, d\varepsilon = \frac{e^{\beta_{ij} x_{ijt}}}{\sum_k e^{\beta_{ik} x_{ikt}}} \qquad (3.35).$$

The representative utility V_{ijt} is assumed to have a parameter vector that has its own distribution, $f(\beta)$. Here, β_{ij} can become β because every β_{ij} can be congregated on β having the mean parameter of the sample population with its own density, $f(b|\theta)$. Then, p_{ijt} can be the probability when β is fixed like a standard logit model. However, in a mixed logit model, β is not a given and is a variable parameter vector with probability density function, $f(b|\theta)$. Thus, p_{ijt} should be integrated over all values of β multiplied by its density as below,

$$P_{ijt} = \int (\frac{e^{\beta x_{ijt}}}{\sum_k e^{\beta x_{ikt}}}) f(\beta) \, d\beta \qquad (3.36).$$

Equation (3.36) is the probability reflecting the densities of the entire error term, divided into two parts. The probability density function $f(\beta)$ can also have any form that researchers assume. This is a strong point of the mixed model. McFadden and Train (2001) prove that RPM can approximate any choice model such as any probit model. In contrast, the probit model cannot approximate any RPM because the error term of the probit model is based on normal distribution. This is the main reason the probit model cannot approximate an RPM.

3.6 Latent Class Logit

Latent class logit models also provide an alternative approach to mitigate the limitations of standard logit, fixed taste variation and restricted substitution patterns, as mentioned in Section 3.4, like RPM (Hensher et al., 2015). In other words, LCM has more flexibility than standard logit models. Another advantage of LCMs is that the model can explain which socio-economic factor of respondents will influence the division of sub-groups that have different coefficients. This advantage might allow for investigating the heterogeneity in a class or segment and the heterogeneity between two classes. Going forward, LCM will be explored in comparison with RPM.

With respect to the distribution of coefficient β, another distribution can be considered. If assuming that the distribution of coefficients, $f(\beta) = f(b|\theta)$ has a discrete form (i.e. β takes a finite set of distinct values like $b_1, b_2, \cdots, b_C$, with probability π_c that $\beta = b_c$), then the mixed logit model becomes a latent class model. In this case, the choice probability has changed somewhat as shown below (Greene, 2012, p. N-436),

$$P_{ijt} = \sum_{c=1}^{C} \pi_c \cdot \left(\frac{e^{b_c x_{ijt}}}{\sum_k e^{b_c x_{ikt}}}\right) \quad (3.37).$$

In Equation (3.37), π_c denotes the probability that individual i is a member of class=c. π_c actually has diverse formulations, but the most convenient form can be rewritten using the familiar logit formula as below (Greene, 2012, p. N-445),

$$\pi_c = \frac{e^{\theta'_c z_i}}{\sum_c e^{\theta'_c z_i}} \quad (3.38).$$

In Equation (3.38), z_i denotes a set of observable characteristics like socioeconomic factors, which are fixed across individuals, and θ' is the coefficients of z_i. β_{ij} seems to divide into two parts. Thus, Equation (3.38) can be changed as below (Greene, 2012, p. N-450),

$$P_{ijt} = \sum_{c=1}^{C} \frac{e^{\theta'_c z_i}}{\sum_c e^{\theta'_c z_i}} \cdot \left(\frac{e^{b_c x_{ijt}}}{\sum_k e^{b_c x_{ikt}}}\right) \quad (3.39).$$

In many choice experiments, respondents are given several choice cards (in this research, all respondents chose eight choice cards so T_i=8). Even though the unobserved parts of random utilities can be strongly supposed to auto-correlate, the latent class model usually assumes that the T_i events are independent. This point is one weakness of the model. Therefore, the unconditioned probability for the sequence of choices over classes can be expressed as below (Greene, 2012, p. N-450),

$$P_{ij} = \prod_{t=1}^{T} \sum_{c=1}^{C} \frac{e^{\theta'_c z_i}}{\sum_c e^{\theta'_c z_i}} \cdot \left(\frac{e^{b_c x_{ijt}}}{\sum_k e^{b_c x_{ikt}}}\right) = \sum_{c=1}^{C} \frac{e^{\theta'_c z_i}}{\sum_c e^{\theta'_c z_i}} \cdot \prod_{t=1}^{T} \frac{e^{b_c x_{ijt}}}{\sum_k e^{b_c x_{ikt}}} \quad (3.40).$$

In practice, an attribute non-attendance problem is often reported, which means that a substantial group of the respondents ignore one or more attributes when making their decision (Hole, 2011). In these cases, it is assumed that respondents use simple strategies or heuristics to make their decision, instead of assuming that consumers are rational and have complete, transient, and continuous preferences. Lagarde (2013) proposes that a latent class model can be used in which each class is assumed to have a specific non-attendance decision rule, and the parameter of the attribute with non-attendance is assumed to be zero.

3.7 Maximum Likelihood Method

3.7.1 Maximization of the Likelihood in Random Parameter Logit

To estimate the coefficients of the random parameter logit model, it is necessary to maximise the likelihood P_{ijt} from Equation (3.36) which represents the probability of when individual *i* will choose alternative *j* at choice situation *t*. To estimate the coefficient for representing a sample, it is necessary to multiply all individuals' choice probabilities over all alternatives *j* as below,

$$L_{ijt} = \prod_{i=1}^{I} \prod_{j=1}^{J} d_{ijt} P_{ijt}(\beta|\theta, x_{ikt}) \quad (3.41).$$

Equation (3.41) is called a likelihood function, where $d_{ijt} = 1$ if individual *i* chooses alternative *j* at choice situation *t* and zero otherwise. To calculate the coefficient, it is necessary to maximise the expression. However, maximization becomes much easier using the expression in logarithm form because the logarithm form is a monotone increasing function. This is called the log-likelihood function as below (Hensher et al. 2015, p. 121),

$$LL_{ijt} = ln(\prod_{i=1}^{I} \prod_{j=1}^{J} d_{ijt} P_{ijt}(\beta|\theta, x_{ikt})) = \sum_{i=1}^{I} \sum_{j=1}^{J} d_{ijt} lnP_{ijt}(\beta|\theta, x_{ikt}) \quad (3.42).$$

Maximising Equation (3.42) about β is shown as follows,

$$\max_{\beta\in\mathbb{R}} \sum_{i=1}^{I}\sum_{j=1}^{J} d_{ijt} lnP_{ijt}(\beta|\theta, x_{ikt}) \quad (3.43).$$

Because Equation (3.43) does not have a closed form Equation (3.36) should be simulated to estimate the coefficient, β. The mixed logit models became available after the introduction of simulation, even though the model had been introduced earlier. Therefore, one can say that simulation is one of the most important elements in using the model. A maximum simulated likelihood estimator can be used for the maximum likelihood function of the RPM. The probability P_{ijt} can be simulated as below (Train, 2009, p. 144),

$$\check{P}_{ijt} = \frac{1}{R}\sum_{r=1}^{R} p_{ijt}(\beta^r) \quad (3.44).$$

The simulated probability $\check{P}_{ijt}$ of β with information θ about its own distribution can be inserted into the log-likelihood function $LL_{ijt}(\beta)$ as below (Train, 2009, p.144),

$$\mathrm{S}LL_{ijt}(\beta^r) = \sum_{i=1}^{I}\sum_{j=1}^{J} d_{ijt} ln\check{P}_{ijt} \quad (3.45).$$

Equation (3.45) is a simulated log-likelihood function about the parameter, β. When $SLL_{ijt}(\beta^r)$ is maximised, the value of θ is the maximum simulated-likelihood estimator.

3.7.2 Maximization of the Likelihood in Latent Class Logit

Equation (3.42) can be the starting point for estimating the coefficients of the latent class logit models. The log-likelihood of the latent class logit (LL_{ijt}) can be expressed as below (Greene, et al. 2009, p. N-450),

$$LL_{ijt} = \sum_{i=1}^{I} ln\left[\sum_{c=1}^{C} \frac{e^{\theta_c' z_i}}{\sum_c e^{\theta_c' z_i}} \cdot \prod_{t=1}^{T} \frac{e^{b_c x_{ijt}}}{\sum_k e^{b_c x_{ikt}}}\right] \quad (3.46).$$

Here, C is the number of class = c, b_c is the structural parameter vector and θ_c is the latent class parameter vectors. Maximising Equation (3.46) can be shown as below,

$$\max_{b_c,\theta_c \in \mathbb{R}} \sum_{i=1}^{I} ln\left[\sum_{c=1}^{C} \frac{e^{\theta'_c z_i}}{\sum_c e^{\theta'_c z_i}} \cdot \prod_{t=1}^{T} \frac{e^{b_c x_{ijt}}}{\sum_k e^{b_c x_{ikt}}}\right] \quad (3.47).$$

There are two main simulation methods for maximizing the log-likelihood of latent class logit; conventional gradient methods and the expectation-maximization (EM) algorithm known as the most effective way to manage missing data. The EM algorithm can be expressed as below,

$$LL_{ij}\Big|E = \sum_{c=1}^{C} \sum_{i=1}^{I} E(b_c|j_i,\pi) \cdot ln\left[\prod_{t=1}^{T} \frac{e^{b_c x_{ijt}}}{\sum_k e^{b_c x_{ikt}}}\right] \quad (3.48).$$

Equation (3.48) is called weighted log-likelihood. Because C is assumed to be set in advance as discussed above, Equation (3.48) can be separated into C partitions and maximized separately as below (Green et al., 2009, p. 195),

$$LL_{ij}\Big|E, \mathrm{c} = \sum_{i=1}^{I} E(b_c|j_i,\pi) \cdot ln\left[\prod_{t=1}^{T} \frac{e^{b_c x_{ijt}}}{\sum_k e^{b_c x_{ikt}}}\right], c = 1, \cdots, C \quad (3.49).$$

The expectation-maximization algorithm for latent class logit can be conducted by using Equation (3.49).

3.8 Willingness to Pay

One of the main goals of this research is to estimate the benefits of introducing the new advanced water treatment system in one chosen waterworks in South Korea. To estimate the benefits, it is necessary to measure the willingness to pay for the water treatment systems. In this subsection, how to calculate the MWTP will be explored.

3.8.1 Marginal Willingness to Pay (MWTP)

MWTP can be derived from the consumers' utility maximization (Nechyba, 2011). Using the estimated parameters and Equation (3.31), the indirect utility function can be expressed as below,

$$V_{ijt} = b_1 x_1 + b_2 x_2 + \cdots + b_K x_K \qquad (3.50).$$

Applying Roy's identity to Equation (3.50), MWTP for each attribute can be obtained. If Equation (3.50) is total-differentiated and β_K is the parameter for cost, then Equation (3.50) is changed as below,

$$\Delta V_{ijt} = b_1 \Delta x_1 + b_2 \Delta x_2 + \cdots + b_{cost} \Delta cost_j \qquad (3.51).$$

If the utility is unchanged while an attribute is improved a unit, the price should rise. If the difference in indirect utility comes to be zero, $\Delta V_{ijt} = 0$, then Equation (3.51) changes as below,

$$b_1 \Delta x_1 + b_2 \Delta x_2 + \cdots + b_{cost} \Delta cost_j = 0 \qquad (3.52).$$

From Equation (3.52), MWTP can be calculated as below,

$$\begin{aligned} \mathrm{MWTP}_{x_1} &= \frac{\Delta c_j}{\Delta x_1} &&= -\frac{b_1}{b_{cost}} \\ &\vdots \\ \mathrm{MWTP}_{x_{K-1}} &= \frac{\Delta c_j}{\Delta x_{K-1}} &&= -\frac{b_{K-1}}{b_{cost}} \qquad (3.53). \end{aligned}$$

In many discrete choice methods, a simple additive form is used for the reason of convenience in simulation (Train, 2009, p. 34). For more complicated forms of utility functions, the simulations would take more time and effort.

3.8.2 MWTP of Random Parameter Logit

When estimating MWTP using the random parameter logit model, two methods exist; the first is using all information in the distribution of the estimated coefficient, β, and the second is using the mean and standard deviation of the coefficient β (Hensher and Greene, 2001). It is impossible to calculate the ratio between two parameters including the parameter of price which would have zero value. In those cases, the ratio cannot be calculated, and just becomes indeterminate or impossible in terms of mathematical terminology although the distribution of the parameters is assumed to be normal.

Simulation can be used for calculating the former ratio even though it is more complicated. If cost parameter b_{cost} is fixed and one parameter of an attribute j, β_j is normally distributed with mean b_j and standard deviation, s_j, then the willingness to pay for the attribute j is also normally distributed with mean $\frac{b_j}{b_{cost}}$ and standard deviation $\frac{s_j}{b_{cost}}$. In this case, the point estimators, b_{cost}, b_j, and s_j can be used to calculate the willingness to pay. However, this method ignores the variances in the estimated parameters.

To reflect the interference of the covariance between several distributions, it is necessary to calculate a covariance matrix for all the estimated parameters. If there are four parameters (e.g. β_1, β_2, β_3, β_4), there is also a four-by-four symmetric matrix M about their covariances as below,

$$M = \begin{bmatrix} & \beta_1 & \beta_2 & \beta_3 & \beta_4 \\ \beta_1 & 1 & \Omega_{12} & \Omega_{13} & \Omega_{14} \\ \beta_2 & & 1 & \Omega_{23} & \Omega_{24} \\ \beta_3 & & & 1 & \Omega_{34} \\ \beta_4 & & & & 1 \end{bmatrix} \quad (3.54).$$

From the covariance matrix, M, a Cholesky factor of M, defined as a lower-triangular matrix L like $LL' = M$, can be obtained as follows,

$$L = \begin{bmatrix} & \beta_1 & \beta_2 & \beta_3 & \beta_4 \\ \beta_1 & s_{11} & & & \\ \beta_2 & s_{21} & s_{22} & & \\ \beta_3 & s_{31} & s_{32} & s_{33} & \\ \beta_4 & s_{41} & s_{42} & s_{43} & s_{44} \end{bmatrix} \quad (3.55).$$

Because setting β_j is normally distributed with mean, b_j, it is possible to express error terms like $\varepsilon_j = b_j + L\eta_j$ ($\eta = (\eta_1, \eta_2, \cdots, \eta_k)'$) as follows,

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \end{bmatrix} = \begin{bmatrix} s_{11} & & & \\ s_{21} & s_{22} & & \\ s_{31} & s_{32} & s_{33} & \\ s_{41} & s_{42} & s_{43} & s_{44} \end{bmatrix} \begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \\ \eta_4 \end{bmatrix} \qquad (3.56).$$

Equation (3.56) allows the drawing up of each β with the independent and identically distributed (IID) standard normal distribution, η_j. After repeating many times for βs, (let β_4 be the estimated parameter of price), calculating each of the ratios of $\frac{\beta_j}{\beta_4}$ from the results provides the mean of the MWTP of each attribute and the standard deviation. The second version of MWTP can be estimated in this way.

3.8.3 MWTP of Latent Class Logit

Like the random parameter logit, latent class logit can also calculate the values of MWTP in the sample, based on the previously estimated parameters in the model. To estimate the individual MWTP within the sample, it is necessary to estimate individual specific estimates of the coefficients. In Equation (3.38), π_c denotes the probability that individual i is a member of class, c and $P_{ijt}|c$ the conditional choice probabilities. The conditional probability for person *i* choosing the series of choices can be written as below (Greene, 2012, p. N-436),

$$P_{ij}|c = \prod_{t=1}^{T_i} P_{ijt}|c \qquad (3.57).$$

In Equation (3.57), T_i denotes the number of choice situations for individual i (in this research, T_i is 8, because every respondent is given 8 choice cards). The unconditional probability for the series of choices can be expressed by the expected value as below,

$$P_{ij} = \sum_{c=1}^{C} \frac{e^{\theta_c' z_i}}{\sum_c e^{\theta_c' z_i}} \cdot \prod_{t=1}^{T} \frac{e^{b_c x_{ijt}}}{\sum_k e^{b_c x_{ikt}}} = \sum_{c=1}^{C} \pi_c \cdot \prod_{t=1}^{T} P_{ijt}|c \qquad (3.58).$$

If j meant the actually observed choice by individual i in Equation (3.40), a "posterior" estimate of the individual specific class probabilities can be written once again using Bayes' theorem in Equation (3.58), as follows,

$$Pro(choices|c, data) = \frac{\pi_c \cdot \prod_{t=1}^{T} P_{ijt}|c}{\sum_{c=1}^{C} \pi_c \cdot \prod_{t=1}^{T} P_{ijt}|c} \quad (3.59).$$

The posterior class probability $\hat{\pi}_{ic}^{*}$ can be calculated. Using $\hat{\pi}_{ic}^{*}$, an individual specific set of conditional posterior estimates of the class probabilities can be expressed as below,

$$\hat{\beta}_i = \sum_{c=1}^{C} \hat{\pi}_{ic}^{*} \hat{\beta}_c \quad (3.60).$$

Equation (3.60) means the conditional posterior estimate vector of individual i, so it is possible to measure the individual specific MWTP, $\widehat{WTP}_i$ using Equation (3.60) as below,

$$\widehat{WTP}_{i,m} = -\frac{\hat{\beta}_{im}}{\hat{\beta}_{i,cost}} \quad (3.61).$$

Where, $\hat{\beta}_{i,m}$ is the coefficient of m attribute and $\hat{\beta}_i, cost$ is the coefficient of price.

3.9 Goodness of Fit

To choose the best version of utility function forms, it is necessary to test the model's goodness of fit. Goodness of fit is defined as a measurement of how well the model fits the data. This part will describe how to test a model's goodness of fit.

3.9.1 Likelihood and Log-likelihood Functions

The likelihood function (L_{ij}) and the log-likelihood function (LL_{ij}) can be used to test a model's goodness of fit because they can show the extent of probability that the model can explain respondents' choices. The likelihood function (L_{ij}) is defined as the probability of individual *i* choosing alternative *j* at choice situation *t*. The log-likelihood function (LL_{ij}) is the logarithm value of the likelihood function (L_{ij}). The likelihood function falls between zero and one by definition as below,

$$0 \leq L_{ij} \leq 1 \qquad (3.62).$$

When $L_{ij} = 1$, the model can explain the probability of which alternative a respondent will choose among options with a 100% rate. From Equation (3.36), the log-likelihood function runs from negative infinite to zero as below,

$$-\infty \leq LL_{ij} \leq 1 \qquad (3.63).$$

The greater the value of the log-likelihood, the better the explanation power of the model.

3.9.2 Pseudo-R squared

The most used statistic with discrete choice models is the likelihood ratio index. The likelihood ratio index was once called the pseudo-R squared for a choice model and can be expressed as follows (Train, 2009, p. 68),

$$R^2_{pseudo} = 1 - \frac{LL(\hat{\beta})}{LL(0)} \qquad (3.64).$$

$LL(\hat{\beta})$ is the value of the log-likelihood function with the estimated parameters and $LL(0)$ is the value when all parameters are set to zero, which has the same meaning as if there is no model at all. However, it is necessary to compare the goodness of fit when the number of the coefficients is different. In this case, adjusted pseudo R-squared can be considered as below,

$$R^2_{adj\ pseudo} = 1 - k\frac{LL(\hat{\beta})}{LL(0)},\ k = \frac{sample\ size}{sample\ size - \#\ of\ coefficients} \qquad (3.65).$$

Hensher et al. (2015) report that a pseudo-R squared of 0.3 represents adequate goodness of fit for a discrete choice model and pseudo-R squared values between 0.3 and 0.4 can be considered an R -squared of between 0.6 and 0.8 for a linear regression model.

3.9.3 Akaike's Information Criterion (AIC)

To determine the number of classes in latent class logit models, it is necessary to consider how to choose the number of classes. Since there is no rigorous method of selecting the right the number of classes of a latent class logit model (Louviere et al., 2000). Akaike (1974) suggests Akaike's information criterion (AIC), as follows (Greene, 2012, p N-67),

$$AIC = -2(LL(b) - k)/N \quad (3.66).$$

Here, *LL(b)* implies the log-likelihood value of one latent class logit model, k is the model dimension (size), and N is the number in the sample. Equation (3.66) shows the AIC normalised by the number in the sample.

3.9.4 Bayesian Information Criterion (BIC)

Another criterion for testing the goodness of fit of the latent class logit models is the Bayesian information criterion (BIC). Schwarz (1978) suggests BIC as below,

$$BIC = -2\,LL(b) + k \cdot \ln(N) \quad (3.67).$$

The lower value of Equation (3.67) means a better choice of the number of classes. The BIC is used to look for the appropriate number of classes of the latent class logit models.

Chapter 4. Survey Instrument and Data

4.1 Three Alternatives

One evident property of the drinking tap water supply industry in South Korea is that it is provided by a monopoly. Only one supplier provides drinking tap water to an area because local governments and Korea-Water have been allowed to manage the drinking water supply industry by law in South Korea. Often, the water supply industry is considered a part of the public sector. Therefore, all people living in one area are provided with the same quality of drinking tap water by the one supplier. In other words, no competition exists in the sector.

Many problems have arisen in drinking water quality, so the Korean government wants to resolve the problems by installing new advanced water treatment systems. As discussed in Section 1.1, the rapid sand filtration system is the main process for purifying water in South Korea, which is comparable to a status quo option. The status quo describes the current situation in which all of the people use drinking water. Therefore, it is not necessary to set up a "no choice" option, because status quo means that people do not want any change in the drinking water quality if it means paying more money. As a result, "no choice" comes to have the same meaning as the status quo option.

GAC and ozone plus GAC treatments are the most popular advanced water treatment systems in South Korea, accounting for 90.5% ($\frac{5,366,000\ \mathrm{m^3/day}}{5,931,000\ \mathrm{m^3/day}}$) of the already installed advanced treatment systems (Ministry of Environment South Korea[a], 2015). Therefore, it is possible to establish three alternatives; one is status quo, another is GAC, and the other is ozone plus GAC treatment system. In this regard, Louviere et al. (2000) stated that three alternatives are the minimum for multiple choice experiments.

4.2 Process of Choice Experiments

It is complex to evaluate the contribution to citizen welfare of improving drinking water quality because there is no market for transacting it. Choice experiments have many merits in measuring several attributes of goods or services. Bateman et al. (2009) suggest five phases for CE as shown in Table 4.1.

Table 4. 1 *Design phases for choice modelling*

Phase	Description
1. Selection of attributes	Selection of relevant attributes of the good to be valued. This is usually done through literature reviews, focus group discussions or direct questioning. Sometimes they may be self-evident because of the nature of the problem. A monetary cost should be one of the attribute, to allow the estimation of WTP.
2. Assignment of levels	The attribute levels should be realistic and span the range over which we expect respondents to have preferences, and/or should be practically-achievable.
3. Choice of experiment design	Statistical design theory is used to combine the levels of the attributes into a number of alternative environmental scenarios or profiles to be presented to respondents. Complete factorial designs allow the estimation of the full effects of the attributes upon choices: that includes the effects of each of the individual attributes presented ('main effect') and the extent to which behaviour is connected with variations in the combination of different attributes offered ('interaction'). These designs often produce an impracticably large number of combinations to be evaluated. Fractional factorial designs are able to reduce the number of scenario combinations presented, with a concomitant loss in estimating power, i.e. some or all of the interactions will not be detected.
4. Construction of choice sets	The profiles identified by the experimental design are then grouped into choice sets to be presented to respondents. Profiles can be presented individually, in pairs or in groups according to the technique being used.
5. Measurement of choice sets	Choice of survey procedure, and conduct of survey.

This research follows the five stages described in Table 4.1 for conducting the CE.

4.3 Selection of Key Attributes

Regarding the number of attributes, Caussade et al. (2005) argued that the number of attributes has an explicit negative effect on the ability to choose, increasing the error variance. Bateman et al. (2009) suggest that the number of attributes be restricted to a relatively small number (e.g. 4, 5 or 6) because the minimum required sample size will increase exponentially with the number of attributes. This research is undertaken because many South Koreans are not satisfied with the drinking water quality. Hence, the proportion of Korean people drinking tap water is small (Beaumais et al. 2010). The Ministry of Environment, South Korea[c] (2013) surveyed the satisfaction level among South Koreans with drinking water quality and reported on the main reasons why Korean people were not satisfied with it; Table 4.2 shows the reasons.

Table 4. 2 *Reasons why Koreans were unsatisfied with drinking water*

unit: %	2009	2010	2011	2012
Vague anxiety	35.3	31.0	30.2	31.9
Distrust of old water tanks, pipelines	16.5	17.6	17.7	18.3
Distrust of water supply source	15.5	16.7	18.1	15.0
Bad taste and odour	9.3	13.3	14.3	14.6
Rust	9.8	13.5	11.6	10.2
Negative media reports	-	2.0	2.1	2.1
Others	12.1	5.9	6.1	8.2

Note. Ministry of Environment, South Korea[c], 2013.

Based on the results of the survey, there are several reasons why most Koreans are not satisfied with the quality of their drinking water. The reasons can be divided into three groups according to the solutions. One group links to the waterworks system. The three reasons, "vague anxiety[11]", "bad taste and odour", and "rust", can be included in the first group. It is

[11] With respect to vague anxiety, people answered that they worry about the safety of drinking water without any particular reason.

assumed that “vague anxiety” is linked to the safety of drinking water. Another group relates to public relations. “Distrust of old water tanks, pipelines, and water supply sources” and “negative media reports” are included in this group. The other group includes the rest, “preference of purifier”, “other” and “no answer”. In these cases, there seems to be no particular solution for water suppliers.

This research focuses on the feasibility of a public investment in waterworks for improving drinking water quality. Therefore, the attributes must be related to the waterworks system. Three reasons relate to the waterworks system; “vague anxiety”, “bad taste and odour”, and “rust”. In the case of rust, this can be applied to the colour. Also, it is necessary to select one essential attribute to measure the benefits of installing new water treatment systems. The price should be one attribute, for valuing the willingness to pay. Consequently, five attributes; safety, taste, odour, colour, and price are chosen for this research.

4.4 Assignment of Levels

In this subsection, the assignment of levels for the five attributes is explored, in the order mentioned, safety, taste, odour, colour, and cost. The standards for drinking water quality in some countries are first reviewed to support in the assignment of attribute levels.

4.4.1 Drinking Water Quality Standard

Each nation has its own legal drinking water quality standards for providing safe drinking water to the public. Table 4.3 shows the number of items for some countries.

Table 4. 3 *Number of items for standards of drinking water*

Organisation	U.S	WHO	Canada	South Korea	E.U	Japan	U.K
Number of items	97	92	85	58	52	50	41

Note. Source from http://www.wabis.or.kr/government/4862. National Institute of Environmental Research, South Korea, 2012.

The number of items differs because of the various conditions that each nation faces. For more information, Table 4.4 shows a comparison for the 58 items in the Korean standards.

Table 4. 4 *National standard of drinking water, South Korea*

No	Contaminants	Unit	WHO	US	EU	Japan	South Korea
1	Total colony counts	CFU/mL				100	100
2	Total coliforms	CFU/100mL					0
3	E.coli	CFU/100mL			0	0	0
4	Lead	mg/L	0.01	0.015	0.010	0.01	0.01
5	Fluoride	mg/L	1.5	4.0	1.5	0.8	1.5
6	Arsenic	mg/L	0.01	0.010	0.01	0.01	0.01
7	Selenium	mg/L	0.01	0.05	0.01	0.01	0.01
8	Mercury	mg/L	0.006	0.002	0.001	0.0005	0.001
9	Cyanide	mg/L	0.07	0.2	0.05	0.01	0.01
10	Chromium	mg/L	0.05	0.1	0.05	0.05	0.05
11	Ammonia	mg/L			0.5		0.5
12	Nitrate(NO3-)	mg/L	50	10	50	10	10
13	Boron	mg/L	0.5		1	1.0	1
14	Cadmium	mg/L	0.003	0.005	0.005	0.003	0.005
15	Phenols	mg/L				0.005	0.005
16	1,1,1-Trichloroethane	mg/L		0.2			0.1
17	Tetrachloroethylene	mg/L	0.04	0.005		0.01	0.01
18	Trichloroethylene	mg/L	0.02	0.005		0.03	0.03
19	Dichloromethane	mg/L	0.02	0.005		0.02	0.02
20	Benzene	mg/L	0.01	0.005	0.001	0.01	0.01
21	Toluene	mg/L	0.7	1			0.7
22	Ethylbenzene	mg/L	0.3	0.7			0.3
23	Xylenes	mg/L	0.5	10			0.5
24	1,1-Dichloroethylene	mg/L		0.007			0.03
25	Carbon tetrachloride	mg/L	0.004	0.005		0.002	0.002
26	Diazinon	mg/L					0.02
27	Parathion	mg/L					0.06
28	Fenitrothion	mg/L					0.04
29	Cabaryl	mg/L					0.07
30	1,2-Dibromo-3-chloropropane	mg/L	0.001	0.0002			0.003
31	Residual chlorine	mg/L					4
32	Total Trihalomethanes	mg/L		0.080	0.1	0.1	0.1

33	Chloroform	mg/L	0.3			0.06	0.08
34	Chloral hydrate	mg/L					0.03
35	Dibromoacetonitrile	mg/L	0.07				0.1
36	Dichloroacetonitrile	mg/L	0.02				0.09
37	Trichloroacetonitrile	mg/L					0.004
38	Haloacetic acids	mg/L					0.1
39	Hardness as CaCO3	mg/L				300	300
40	Consumption of KMnO4	mg/L					10
41	Odour	-				adequate	no odour
42	Taste	-				adequate	no taste
43	Copper	mg/L	2	1	2	1.0	1
44	Colour	TCU		15		5	5
45	Foaming agents	mg/L		0.5		0.2	0.5
46	pH	-		6.5-8.5	6.5-9.5	5.8-8.6	5.8-8.5
47	Zinc	mg/L		5		1.0	3
48	Chloride	mg/L		250	250	200	250
49	Total solids(TS)	mg/L		500		500	500
50	Iron	mg/L		0.3	0.2	0.3	0.3
51	Manganese	mg/L	0.4	0.05	0.05	0.05	0.05
52	Turbidity	NTU			1	2	0.5
53	Sulfate	mg/L		250	250		200
54	Aluminium	mg/L		0.05	0.2	0.2	0.2
55	Dibromochloromethane	mg/L	0.1			0.1	0.1
56	Bromodichloromethane	mg/L	0.06			0.03	0.03
57	1,4-Dioxane	mg/L	0.05			0.05	0.05
58	Formaldehyde	mg/L				0.08	0.5

Note. Source from http://www.wabis.or.kr/government/4862.

Since many items regulate drinking water quality, it would be ineffective and inefficient to select all items to depict the attributes of drinking water quality. Therefore, it is necessary to choose items that are most strongly related to the chosen four attributes. For the latter four attributes (taste, odour, colour and cost), it is relatively straightforward to select the standards from the criteria. Three items from the standards listed are directly related to the attributes (i.e. Nos. 41, 42 and 44).

In the case of colour, the true colour unit (TCU) measures the state of colour, as explained in more detail later. For the taste and odour of drinking water, no common standard exists. Some countries like Japan and South Korea have a standard for taste and odour, but the content mention only that the water must be "inoffensive". In other words, no objective criterion exists for the two items. The taste and odour of drinking water cannot be objectively measured because there is considerable variation among consumers as to what is acceptable. The cost attribute is not shown in Table 4.4. However, it is simple to select the additional water bill for the cost attribute, because drinking water charges must be collected by law in South Korea. Last, for safety, it is more difficult to select one among the many items for standards and to assign the levels. This will be explored in the following subsection.

4.4.2 Safety of Drinking Water

With respect to the safety of drinking water, chlorine disinfection cannot remove many risk factors. These risk factors include, deactivating pathogenic protozoa acquiring resistance to insecticides, sterilising viruses and bacteria, removing tiny organic substances in raw water, oxidizing and removing several synthetic organic chemicals, deactivating manganese and iron, colour removal and disintegrating and removing trihalomethanes (Cho, 2007). Ozone can resolve the problems with strong oxidizing power. Also, pharmaceutical and personal care products remaining in drinking tap water have recently become a social issue. No conclusive proof has been offered that these products harm human health with the present level of usage, but doubts persist. However, advanced water treatment systems can remove almost all of them, so the systems can protect public safety in relation to drinking water.

To help respondents to understand the concept of safety, it is necessary to narrow down the levels of cancer risk resulting from drinking tap water. Trihalomethanes are related to cancer risk, the probability of how many people are diagnosed with cancer from drinking water when they have drunk water with certain levels of trihalomethanes during their lives (Mitchell and Carson, 1986, Eom, 2008). Cho (2007) also analyses the relationships between three types of treatment systems and the levels of trihalomethanes. Table 4.5 shows these relationships.

Table 4. 5 *Relationships between treatments, levels of trihalomethans and cancer risk*

Technical treatment	Level	Cancer risk (Per 10 million)	Water quality criteria
Status quo	0.1 mg/L	40	South Korea, US, EU, Japan
GAC	0.75mg/L	6	-
GAC plus Ozone	0.05mg/L	1	-

Note. Mitchell and Carson, 1986. Eom, 2008. Cho, 2007.

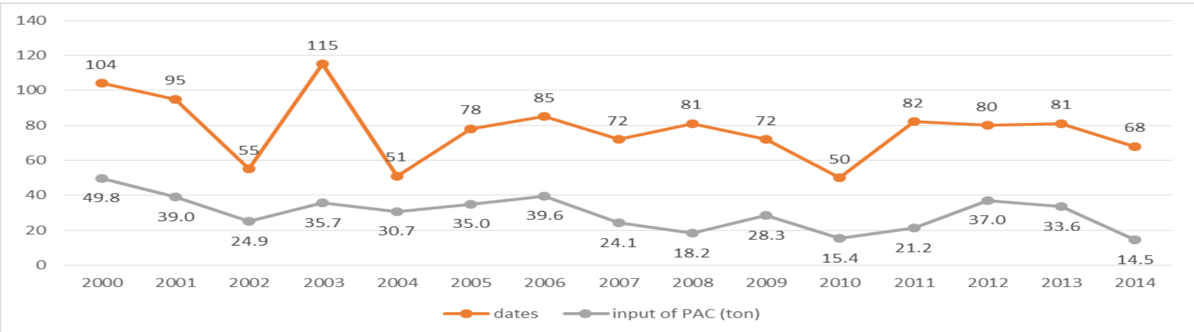
In this research, cancer risk will be used to depict three levels of the first attribute, safety of drinking water quality. According to the three studies, the first level is 40 people per 10 million (Mitchell and Carson, 1986). This links to the status quo, which means the current level of drinking water quality for all people in the target area. The second level, six people per 10 million links to GAC treatment system (Eom, 2008). The last level is one person per 10 million related to ozone plus GAC system (Cho, 2007).

4.4.3 Taste and Odour of Drinking Water

The starting point for this subsection is discussing the cause of unpleasant taste and odour in drinking water. Because of industrialisation, the environment has been contaminated for a long time. Pollutants are threatening human lives. In particular, the water environment faces severe pollution. Economic activities have given rise to eutrophication of many rivers and lakes which made blue-green algae rampant in South Korea. Algae, particularly blue-green algae (cyanobacteria) produce geosmin and 2-methylisoborneol, the substances responsible for the earthy taste and strong musty scent in water. In some cases, cyanobacteria can also produce chemical toxins harmful to consumers of drinking water.

Geosmin is an organic compound with chemical formula C12H22O, a derivative of decalin. 2-methylisoborneol (2-MIB) is also an organic chemical with molecular formula C11H20O, a derivate of borneol. The two substances give rise to unpleasant taste and odour in water. The taste and odour detection thresholds are very low, 4ng/L for geosmin, 9ng/L for 2-MIB. These are the major influences on taste and odour in drinking water. Almost all rivers in South Korea are rampant with green algae. Figure 4.1 illustrates the green algae problem for an average 78 days at the water-intake points for Cheongju City over the last 10 years.

Figure 4. 1 *Dates of green algae breakouts in Lake Daecheong and the input amount of powder activated carbon at waterworks in Cheongju City*



Note. Source from Cheongju City Government, South Korea, 2014.

To control the taste and odour of drinking water, Cheongju City has added an amount of powdered activated carbon. Many problems have been reported with the taste and odour of drinking water due to blue-green algae, which were caused by severe eutrophication in the Lake located in the upper Gum-Gang River starting in the 1980s (Cho, 2007). The number of dates depends on the amount of annual rainfall and the inflow of nutrients, which are mainly derived from the untreated livestock manure in the basin, as discussed in Section 1.3 (Kim, Ji-Won., et al., 2013).

However, according to research conducted by the American Water Works Research Foundation, there are limitations in removing the bad taste and odour from drinking water when using powder activated carbon. In 23 waterworks near the Great Lakes, only the Central Lake County Joint Action Waterworks (140,000m^3 per day) which installed an ozone plus GAC treatment system totally solved the problem (Nerenberg et al., 2000). Therefore, a permanent solution is needed to remove the bad taste and odour. The advanced treatments can be considered to supply good quality water. The levels of taste and odour need to be considered according to the systems. Table 4.6 shows the relationships among the treatments, the levels of geosmin and 2-MIB and people's perception.

Table 4. 6 *Relationships among treatments, levels of the substances and the perceptions*

Technical treatment	Level	Degree of perception	Water quality criteria
Status quo	20 ng/L	10% happy	South Korea, US, EU
Granular Activated Carbon (GAC)	10 ng/L	90% happy	Japan
Ozone plus GAC	4 ng/L	99.9% happy	Detection threshold

Note. Pirbazari et al., 1993, Ho et al., 2004, Cho, Woohyun., 2007, Korea-Water, 2015.

One problem is how to connect the levels of the substances with the degree of people's perception. Human detection abilities are different across the nations of the world (Piriou et al., 2004). Davies et al. (2004) report that the human odour threshold of Geosmin and 2-MIB are 4 to 20 nano-grams (ng) per litre and 6 to 42 ng per litre, respectively. At the level of 20 ng per litre of the two substances, most people can detect the taste and odour (Joe et al., 2006). Thus, it is assumed for the status quo that 90% of people can detect the taste and odour; that is, only 10% is likely to be satisfied with the taste and odour of drinking water.

Second, at the level of 10 ng per litre, most humans cannot detect the taste and odour (Joe et al., 2006). Even though the South Korean national standards for the two compounds, geosmin and 2-MIB, are 20 ng per litre, Korea-Water has self-regulated the levels of the two compounds at 10 ng per litre to satisfy as many consumers as possible. Across the world, the Japanese government first regulated the standards of the two substances at the same level, 10 ng per litre in 2003 (Cho, 2007). Thus, it is assumed that 10% of people would detect the taste and odour at that level; that is, 90% would probably be happy.

Third, the level of four ng per litre is reported as the human-detection-limit. Thus, no one can detect the taste and odour in drinking water at that level of the substances (Pirbazari et al., 1993, Ho et al., 2004). Therefore, it is assumed with caution that the ozone plus GAC treatment is linked to a satisfaction level of 99.9% rather than 100%.

Finally, a point to be noted is the citizen-consumer gap (or duality). The citizen-consumer gap is defined as people's tendency to give answers that can create a favourable image for them with others (Vanhonacker et al., 2007). On the one hand, Bauman (2009) describes consumers as the enemy of the citizen. He introduces an explicit distinction between the citizen and consumer. On the other hand, De-Bakker et al. (2012) argue for a more hopeful perspective of harmonising the two sides, citizens and consumers. They review papers revealing that the sides are interlinked and claimed that "egoistic consumers" considering price, enjoyment, and utility and "altruistic citizens" looking at principles, ideals and public interests, cannot be separated. However, the gap in behaviour between citizens and consumers might be prevalent in the real world (Alphonce et al., 2014). If someone is included in the 10% of people who are satisfied with the taste and odour of drinking water, he or she would not want to pay more to improve drinking water, which means that the person would not care about the welfare of others, which can be called an "egoistic consumers". However, this treatment might prompt respondents to choose the advanced alternatives as if they were asked to play the role of citizen, which can be described as an "altruistic citizens". If some people have experienced bad taste and odour of drinking water, they are likely to choose the advanced options. This type of behaviour would be good as customers. There may be concern about the others who have not had the bad experience. They might act as citizens rather than customers. In this case, the benefit can be overestimated by the choices of the respondents who might choose the advanced options even though they don't want to pay any more as customers.

To lessen the misguided effect, the questionnaire explains the levels of chemical compounds that give rise to the bad taste and odour in drinking water before the choice cards are presented. Every choice card in the questionnaire also shows the actual level of the compounds that trigger the bad taste and odour with the perception levels. From the information, the respondent can understand to what extent the advanced water treatment systems can purify the drinking water. In this respect, one should be careful in interpreting the results of estimation of the attribute in terms of overestimation. To reduce overestimation, three treatments for mitigating hypothetical bias are included in developing the questionnaire, as discussed in Section 3.3. Also, this point of view can be addressed in conducting sensitivity analyses.

4.4.4 Colour of Drinking Water

The third attribute of drinking tap water is colour linked to the concept of true colour unit (TCU[12]). Figure 4.2 shows samples of TCU for reference.

Figure 4. 2 *Samples of TCU*

Note. Source from Korea-Water, 2015.

The current standard for the colour of drinking water in South Korea is 5 TCU. In this research, the attribute levels are arranged according to the two water treatments. Table 4.7 shows the relationships among the water treatments, TCU levels and the perceptions.

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

Table 4. 7 *Relationships between treatments, levels of TCU, and perceptions*

Technical treatment	Level	Perception treatment	Water quality criteria
Conventional	5 TCU	90% happy	South Korea, US, EU, Japan
GAC	4 TCU	99% happy	-
Ozone plus GAC	3 TCU	99.9% happy	Detection Threshold

Note. Tap Water Public Relations Association, South Korea, 2013. Cho, 2007. Bean, 1962.

Seven per cent of people complained about the colour of drinking water in South Korea (Tap Water Public Relations Association, South Korea, 2013). Thus, it is assumed that about 10% of people are likely not satisfied with the colour of drinking water. The GAC system can reduce the colour of drinking water to less than 4 TCU and the ozone plus GAC system can remove the colour of drinking water to less than 3 TCU (Cho, 2007). Bean (1962) reported that the three TCU level of drinking water colour is the human detection limit. Thus, it was assumed that the Ozone plus GAC is linked to a satisfaction level of 99.9% with the colour of drinking water rather than 100%. In the case of four TCU, it is assumed that 99% of people would be satisfied with the colour because its level is very close to the human detection limit, 3 TCU.

Hypothetically, it is doubtful that most people can identify small differences between the TCU levels. The willingness to pay for improvements in the colour of drinking water might be less than the willingness to pay for other factors. Some people may ask why the colour attribute should be chosen for one of the main attributes of drinking tap water. The colour attribute ranks as the fifth factor for people's dissatisfaction with drinking tap water quality in South Korea. Although the colour attribute may be valueless in estimating the WTP for each attribute, it is one attempt of this research. In addition, the same viewpoint of a citizen survey can be noted because the treatment of colour also uses the levels of people's perception as discussed in Subsection 4.4.3. Thus, it is necessary to interpret the estimation of the benefits and the choices of the respondents.

4.4.5 Prices for Additional Monthly Water Bills

No indicative prices inform about the benefits from improved attributes of drinking water quality. However, some contingent valuation studies calculate the willingness to pay for improvements in drinking water quality. Therefore, it is necessary to borrow prices from other previous contingent valuation studies in South Korea. Table 4.8 shows the prices for additional monthly water bills that other researchers have measured.

Table 4. 8 *Prices for additional monthly water bills*

Author	Year	Region	WTP(KRW)	Levels of prices (KRW)
Um et al	2002	Pusan	3,994 - 5801	4,000 (USD 3.40)
Park et al	2007	Seoul and 6 cities	1,183 - 3,011	1,000 (USD 0.85), 3,000 (USD 2.55)
Eom, YS[13]	2008	Jeonju	465	500 (USD 0.42)
Kwak et al	2013	Seoul	2,124	2,000 (USD 1.70)
Average			2,276	2,100 (USD 1.78)

Note. The exchange rate is based on KRW/USD at the end of 2015.

Six levels of costs in the last column are chosen for additional monthly water bills including zero for the status quo. For reference, the level of the average of the six prices was calculated at about KRW 2,100 (USD 1.78), which seems low compared to the average monthly income per household in South Korea, at about 0.05%. This point will be discussed in Section 5.2.1.

4.4.6 Questionnaire Using Graphics

Many stated preference surveys have been conducted by using graphics to explain the levels of attributes visually and explicitly. Many stated choice surveys often contain highly technical and unfamiliar information that respondents find difficult to understand. Phaneuf et al. (2013) mention that graphic and pictures can play a complementary role in a survey with

[13] Eom. (2008) estimated the WTP for a reduction of trihalomethans by using laboratory experiments in Jeonju City, South Korea, which is why this thesis has not been discussed in literature reviews.

text. The U.S. National Oceanic and Atmospheric Administration panel (1993) recommend that visual displays be included with text. Mathews et al. (2007) also underline the practicality of visual aids like pictures and graphics, in explaining information. Therefore, all attributes in this research are expressed with graphics and explanations to help respondents understand the choice task.

Appendix 1 contains the graphics and explanations used in the questionnaire. Regarding the safety (cancer risk) graphic, one thing to notice is the size of the pixels, 10,000 pixels (100 by 100). The larger pixel might influence the respondents to overestimate the risk. The size of the presented pixel is 1,000 times larger than the one that present the actual probability (1/10,000,000). However, if a pixel is made up of 1,000,000 (1,000 by 1,000), one pixel would be invisible. In that case, the size of the presented pixel will become 100 times smaller, and nobody could recognise any differences between the three graphics. Therefore, enlarged pixels are displayed to present the risk despite concerns that people might overestimate the cancer risk. Thus, caution should be exercised when interpreting the measurement of the coefficient of the attribute.

4.5 Experimental Design

This part will explore the treatment combinations. As discussed in Section 3.2, D-efficiency is used for generating the experimental design. D_0-error of (3.25) is used for building the experimental design, and D_p-error of (3.26) is used for justifying the practicality of the design. A prior b vector of an MNL model is chosen for ex-post testing the efficiency of design. This point will be explored in Subsections 4.5.5 and 4.5.6.

4.5.1 Number of Choice Sets

Before discussing the treatment combination, it is useful to explore how many choice sets are presented to each respondent. Researchers cannot ask the respondents to answer too many choice cards, because the respondents would likely decline to participate in the survey. In this regard, Bateman et al. (2009) argues that respondents should not be asked to complete too many choices because they will become tired and either the quality of responses will fall, or they may terminate the interview before completion. Smith and Desvousges (1987) argue that it is complex for most respondents to handle more than eight choices. Thus, eight choice sets are chosen for each respondent in this research. Also, four blocks were built for this research, so 32 choice sets are made in total.

4.5.2 Hypothetical Bias

As discussed in Section 3.3, this research uses two methods for mitigating hypothetical bias. The cheap talk which is used in the questionnaire is shown in Appendix 1. Cheap talk is used to communicate the problem of hypothetical bias explicitly, particularly the case of overstatement, and to emphasise the consequentiality of the survey and respondents' choices. Second, the honest priming task is included in the questionnaire to induce respondents to answer truthfully in choosing the preferred option in line with the general questions. Many scholars have used the treatment and reported its effectiveness (Maxwell et al, 1999; Chartland et al, 2008; Drouvelis et al, 2010, De-Magistris, 2013). An example of the honest priming used in the questionnaire is shown in Appendix 1. In practice, each method is distributed to the four blocks, which are split to seek the strongest mitigating measure of willingness to pay by comparing the performances of the combination of the two methods. Table 4.9 shows the details of organizing the methods in blocks.

Table 4. 9 *Blocks for organizing the methods*

Method	Block 1	Block 2	Block 3	Block 4
Cheap talk	√	√	not	not
Honest priming task	√	not	√	not

4.5.3 Fractional Factorial Design

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 4.10.

Table 4. 10 *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 4.11.

Table 4. 11 *Profile of price*

KRW	Alternative 1	Alternative 2	Alternative 3
Treatment 1	0	500 (USD 0.42)	1000 (USD 0.85)
Treatment 2	0	500	2000 (USD 1.71)
Treatment 3	0	500	3000 (USD 2.56)
Treatment 4	0	500	4000 (USD 3.41)
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

Note. The exchange rate is based on KRW/USD at the end of 2015.

Therefore, the total number of profiles reflecting all the cases of the four attribute is 2,160 (= 6×6×6×10). However, it would be impossible to present that number of choice cards to respondent. Therefore, it is necessary to build efficient profiles of the choice cards. To choose the most efficient set of profiles, D_0-error is used with a statistical program[14]. The restrictions for reflecting the assumption discussed above are set in using the program. Table 4.12 shows the first version of the experimental design. However, five cases of the treatment combinations provide preferable options between the three alternatives, Choice cards 8, 9, 10, 26, and 31. For example, Choice cards 8 and 10 provided the same levels for the three attributes and different price levels for the two advanced alternatives. In those cases, reasonable consumers would not choose the ozone plus GAC option because they can enjoy the same levels of the three attributes at a cheaper cost.

[14] Ngene program was used for generating the experimental design. Professor Iain Fraser at University of Kent, helped in building the experimental design. He gave plenty of advice for the experimental design. For example, he suggested some attribute levels could be changed when there were preferred options as discussed later.

Table 4. 12 *Thirty two choice sets*

Card number	Granular activated carbon (GAC)				Ozone plus GAC				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	**1**	**1**	**0**	4	1
9	0	**0**	0	0.5	0	1	1	1	3
10	1	0	1	0.5	**1**	**0**	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	**0**	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	**0**	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.

In the cases of Choice cards 9, 26 and 31, the levels of the three attributes are zero but people must pay the additional cost for the GAC options. Reasonable consumers would not choose GAC because the status quo can provide the same levels without the additional cost. After replacement of the irrational cases, the final version of the choice sets is shown in Table 4.13.

Table 4. 13 *Final version of 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.

4.5.4 Interaction Effects

Before developing the experimental design, researchers must decide whether interaction effects are included or not. Louviere (1988) suggests that in practice more than 80 % of respondent behaviour can be explained as main effects. Bateman et al. (2009) argues that interaction effects are often not examined for a practical reason; the size of the questionnaire would increase steeply in order to detect the effects. If it is plausible to believe that there is no significant interaction effect, then a main-effect-only design can be used in practice.

This research focused on the main effects of the attributes because there seems to be no substantial interaction effects among the attributes of drinking water quality. There is no obvious relationship between the safety of water and its taste and odour. Colour has already reached a high level of clarity with which most citizens are satisfied. Thus, the interactive terms of the attributes are excluded in the utility function.

4.5.5 Pre-Test

To build the experimental design, a pre-test was undertaken from April to May 2015 for three groups. The first group consisted of 10 citizens in the target area. They were asked to answer the questionnaire and to suggest any ideas they had related to the questionnaire. The second group was composed of 12 staff members who work for Korea-Water. Some academic faculty members at the School of Economics, University of Kent comprised the last group. They were also asked to answer the same questions and to make suggestions.

As a result of the pre-test, it was possible to reflect on opinions for the questionnaire such as changing some sentences and graphics. For example, the graphics describing the level of cancer risk and colour was changed following a suggestion by a staff member. An academic faculty helped to improve the debriefing question by suggesting adding the ranking of the attributes, later used in the attribute non-attendance analyses.

4.5.6 Design Practicality

The practicality of experimental design can be influenced not only by choice sets but also by sample size and (or) the number of choice cards for each respondent. If the sample size and the number of the choice cards for each respondent are larger, the experimental design can be complemented by both of them. However, usually time and cost restrictions exist with regard to conducting surveys. Thus, it is important to build the most efficient experimental design.

As mentioned in Section 4.5.3, the D_0-error is used to generate the first version of the experimental design. However, the D_p-error of the final version of the choice sets is measured for ex-post testing the efficiency of the experimental design. The parameters from the pre-test data are not used to generate the experimental design[15]. For calculating the D_p-error, the coefficients estimated from the sample of 21 pre-test respondents are used as shown in Table 4.14. For reference, one sample is removed because it appeared to be a potential label heuristic (the person chose the same alternatives in every choice card).

Table 4. 14 Preliminary coefficients estimated from the pre-test data

Attribute	Safety	Taste and odour	Colour	Cost
Coefficient (P-value)	-0.1224 (0.0028)	0.0371 (0.0033)	0.2470 (0.0027)	-0.9745 (0.0065)

The D_p-error of the final version of the choice sets is calculated at 9.314. Compared to the value of the first version, 10.2707, D_p-error slightly decreased by 0.0547 (5.32 %). For reference, A-error for the two versions is calculated. The efficiency decreases by 0.16 % from 5.7961 for the first version to 5.7345 for the second version of choice sets.

4.6 Other Questions

4.6.1 Socioeconomic Factors

Questions regarding socio-economic factors are included in the questionnaire for multiple purposes. The questions about socio-economic factors used in the questionnaire are shown in

[15] As acknowledged above, Professor Ian Fraser suggested that presumed parameters could be used for generating an experimental design. Therefore, the parameters from the pre-test data were used for testing the validity (ex-post), according to his suggestion.

Appendix 1. The socio-economic questions are used to verify the sample representativeness, and as alternative-specific variables of the utility function, as discussed in Section 6.2.

4.6.2 Debriefing Question

The first type of debriefing question involves asking about the preference for the attributes of drinking water quality and which attributes the consumers ignore when they chose the preferred alternative in the choice sets. This question can help to identify which attributes are associated with non-attendance. As discussed in Section 3, many studies report an attribute non-attendance problem; a substantial group of respondents ignores one or more attributes in stated preference surveys. This type of questions is shown in Appendix 1.

The second type of debriefing question is used for choosing reliable data. This question is used as the tool to select effective data from the whole dataset and to eliminate ineffective data. The questions are shown in Appendix 1. All respondents are asked to choose the pictures that they cannot see among the 10 pictures on the choice cards. The aim of the question was to verify how much the respondents are concentrating on answering and choosing the best options for the choice cards.

The last debriefing questions try to elicit how people think about issues of the environment and the importance of drinking water quality, using seven Likert scale questions. The questions are shown in Appendix 1.

4.7 Data Collection

4.7.1 Sampling Frame

This research focuses on a city in South Korea, Cheongju City. Therefore, when conducting the survey, it is important to think about how to ensure the representativeness of the sample. In this research, the survey is distributed to respondents in the target area according to the proportions of age as far as possible. The population of the city was 679,301 in 2013. The survey was conducted for those aged between 20 to 65 years old. The population between those ages is 452,217. The proportions according to age and gender are shown in Table 4.15.

Table 4. 15 *Proportions according to age and gender in Cheongju City, 2013*

Age	Sum		Male		Female	
20~29	94,414	20.9%	49,733	21.9%	44,681	19.9%
30~39	108,371	24.0%	54,091	23.8%	54,280	24.1%
40~49	121,034	26.8%	59,490	26.2%	61,544	27.4%
50~59	98,011	21.7%	49,018	21.6%	48,993	21.8%
60~65	30,387	6.7%	14,865	6.5%	15,522	6.9%
Sum	452,217	100%	227,197	100%	225,020	100%

Note. Cheongju City Government, 2014.

Respondents should reflect the proportions in the age range and by gender, as far as possible. Table 4.16 shows the target distribution for the sample of 500.

Table 4. 16 *Target distribution for the 500 sample*

Age	Sum		Male		Female	
20~29	104	20.9%	56	21.9%	49	19.9%
30~39	120	24.0%	60	23.8%	60	24.1%
40~49	134	26.8%	66	26.2%	68	27.4%
50~59	108	21.7%	54	21.6%	54	21.8%
60~65	34	6.7%	16	6.5%	17	6.9%
Sum	500	100%	252	100%	248	100%

4.7.2 Collection Method

Two methods are used to collect data. One is web-based survey and the other a face-to-face survey. NOAA recommends the face-to-face survey for all major contingent valuation studies

(Arrow et al., 1993). However, recent use of web-based surveys in choice experiments has steeply increased because of the lower cost compared to face-to-face survey (Sills and Song, 2002). Also, Lindhjem and Navrud (2008) report no significant biases when comparing the results between the two methods, in a controlled field experiment with the same respondents.

Interviewer bias is mentioned in the case of the face-to-face survey. Interviewer bias is defined as the bias that arises because the interviewer may stimulate the interviewees to respond with the favoured answer. Sometimes the interviewers show a negative reaction to interviewees when they give an unfavourable response. Online surveys have many advantages including speed, low cost and the removal of interviewer bias (Evans and Mathur, 2005). Therefore, the two methods for conducting surveys are used for this research. To compare the results of the sub-four blocks, each of the two methods are applied to each of the two blocks. Table 4.17 shows the details of the methods for mitigating hypothetical bias and collecting data in planning the survey.

Table 4. 17 *Methods for mitigating hypothetical bias and of collecting data*

block	Target sample	Survey method	Tools for hypothetical bias
1	125	web-based	budget constraint, cheap talk, honest priming
2	125	face-to-face	budget constraint, cheap talk
3	125	face-to-face	honest priming
4	125	web-based	none

Four types of questionnaires are created for the two types of survey methods. Each block contains the same kind of eight choice cards. Therefore, the 32 choice cards are divided into eight cards for each block. The first questionnaire contains as tools for mitigating hypothetical bias, budget constraint reminder, cheap talk and honest priming task. The second contained the budget constraint reminder and cheap talk. The third includes the honest priming task, and the last contains none of them. Blocks 1 and 4 used the web-based survey method, and Blocks 2 and 3 are carried out by face-to-face survey. Three different companies[16] independently conduct the survey.

Another point to note is the orthogonality between the hypothetical bias treatments and the survey modes of data collection. First, two survey methods are used for collecting the data, as mentioned above. Therefore, one dummy can be included for separating the effect. Let D_f be the dummy for indicating 1 if the face-to-face survey mode is used and 0 otherwise. Second, this research divides four blocks to compare the effectiveness of the two treatments for mitigating hypothetical bias. Thus, it is possible to establish three dummies to discriminate between the blocks because one chosen block can serve as a base group. Table 4.18 shows the effect coding (Hensher et al., 2015) of the case.

Table 4. 18 *Effect coding of dummies for hypothetical bias treatment and survey modes*

Block	Hypothetical bias treatment	Survey mode	D_{both}	D_{cheap}	D_{honest}	D_f
1	cheap talk, honest priming	web-based	1	-1	-1	-1
2	cheap talk	face-to-face	-1	1	-1	1
3	honest priming	face-to-face	-1	-1	1	1
4	none	web-based	-1	-1	-1	-1

Orthogonality is defined as when the inner product between any two chosen vectors is zero. For example, the inner product between D_{both} and D_{cheap} is zero, but the inner product between D_{both} and D_{f} is not zero. Actually, the inner products between any dummies of the hypothetical bias and the dummy of the survey method are not zero. As a result, it is not possible to distinguish the effects of hypothetical bias or the survey methods and therefore only the effect of hypothetical bias treatments will be studied in what follows.

[16]The companies were Macromill Embrain, Research Panel Asia and Korea Survey in South Korea.

4.7.3 Outcome of Survey

The survey was conducted in July/August 2015 in the target areas by the three survey companies. Table 4.19 shows the responses to the survey.

Table 4. 19 *Result of the survey*

Block	Target sample	Total	Hypothetical bias treatment	Survey mode
1	125	161	cheap talk, honest priming	web-based
2	125	125	cheap talk	face-to-face
3	125	125	honest priming	face-to-face
4	125	162	none	web-based
Sum	500	573		

In total, 573 questionnaires are obtained. This sample of 573 respondents is the starting point for analysis in this research. Table 4.20 shows the summary of statistics of the sample of 573 respondents.

Table 4. 20 *Summary of statistics*

Mean (S.D)	Male*	Age* (year)	Household income (KRW million)	Education* (year)	Monthly water bill per household (KRW)
Population	0.515	41.00 (12.52)	4.304** -	13.25 (9.27)	11,429** -
Sample	0.518	40.41 (11.80)	4.364 (2.08)	14.74 (2.35)	12,447 (10.50)

Note. Source from the database of Cheongju City in 2015. *means the statistics were calculated the data of people between 20 and 65 years old. ** means the statistics were the nationwide average values.

As shown in Table 4.20, the proportion of male for the population is estimated at 0.515 but the proportion for the sample is 0.518. This difference means that more male respondents answered the questionnaire. However, the difference is marginal. The average age of the population is estimated at 40.4 years old but one of the sample population at 41.0. This result shows that younger people participate in the survey. The average monthly income per household of the population is slightly less than the one of the sample. The value of the population is reported at KRW 4.304 million but the one of the sample was estimated at KRW 4,364 million. The average years of education for the population was estimated at 13.25 years but the average of the sample is at 14.74. This result means that more educated people participate in the survey. Last, the average monthly water bill per household is slightly larger than the nationwide value for South Korea. The average monthly water bill per household is reported at KRW 11,429 but the one for the sample is estimated at KRW 12,447.

These statistics are chosen because the mean values (and their standard deviations) could be obtained. As a result, the statistics will be used to test the representativeness of the sample after refinement of the dataset in the next chapter, Chapter 5.

Chapter 5. Representativeness of the Sample

5.1 Refinement of the Sample

This section will explore the representativeness of the sample. First, the data are refined in terms of ineffectiveness and potential label heuristics. Second, for testing the sample representativeness, five socio-economic factors are used (water-bill, gender, age, income, and education year) for which relevant statistics can be obtained. The statistics are mainly from Cheongju City Government and the Korea National Statistical Office.

5.1.1 Ineffective Data

In total, 573 respondents took part in the survey. Each respondent is asked to answer the debriefing questions, where all respondents are asked to choose the picture that they could not see in the choice cards among the 10 pictures in the figure of Question 2 (as shown in Appendix 1). This question aimed to verify how much they are concentrating on answering and choosing the best options in the choice cards. Table 5.1 shows the result of the survey.

Table 5. 1 *Result of the survey*

Block	Target sample	Total	Ineffective response	Effective response
1	125	161	27	134
2	125	125	-	125
3	125	125	-	125
4	125	162	41	121
Sum	500	573	68	505

There are 68 cases in which the respondents reply incorrectly to the debriefing question for testing how carefully they answered the survey questions. For testing whether removing the ineffective data could be justified, homogeneity test is conducted to determine whether different subgroups exist within one group. In analysing maximum likelihood estimations, Green (2012) introduces the test -statistic for homogeneity defined as below,

$$\chi^2 = 2\left(\sum_{g=1}^{G} LL_g - LL_p\right) \qquad (5.1).$$

Here, χ^2 is a chi-squared statistic, and G is the number of subgroups (g=1, 2, ⋯, G). LL_g is the log-likelihood of the subgroups and LL_p is the log-likelihood of the pooled sample. In Equation (5.1), the degrees of freedom is G-1 times the number of coefficients in the model. It is possible to calculate the p-value by using the chi -squared distribution as below,

$$p - value = 1 - Chi(\chi^2, df) \qquad (5.2).$$

Here, χ^2 is the cumulative distribution function of the chi -squared statistic and df is the degree of freedom. The chi-squared statistic and p-value to test for homogeneity between the subgroups (68 ineffective and 505 data) and all the data using a multinomial logit model with the four generic variables and one alternative specific constant (ASC) are as follows,

$$\chi^2 = 28.5098, \qquad p - value = 0.0047.$$

The test shows that the homogeneity between the two groups and all the data should be rejected at the 1.0% significance level. These 68 responses can be excluded in terms of the homogeneity test and the remaining 505 samples are used for the next step.

5.1.2 Potential Label Heuristics

In conducting choice experiments, some respondents might choose the alternative just following the new advanced treatment -label. Therefore, each data item is tested regardless of whether the respondents choose the same alternatives in the eight choice cards independently of the different information on the cards. Table 5.2 shows the potential label heuristics. As shown in Table 5.2, 98 people chose the same alternatives in the eight choice cards given to them.

Table 5. 2 *Potential Label Heuristics*

Block	Total	Ineffective response	Label Heuristics				Outlier of water-bill	Final Sample
			sum	S.Q	GAC	Ozone		
1	161	27	34	8	19	7	1	99
2	125	-	17	5	4	8	-	108
3	125	-	22	16	2	4	-	103
4	162	41	25	2	17	6	-	96
Sum	573	68	98	31	42	25	1	406

Note. The outlier of water-bill will be discussed in Subsection 5.2.1.

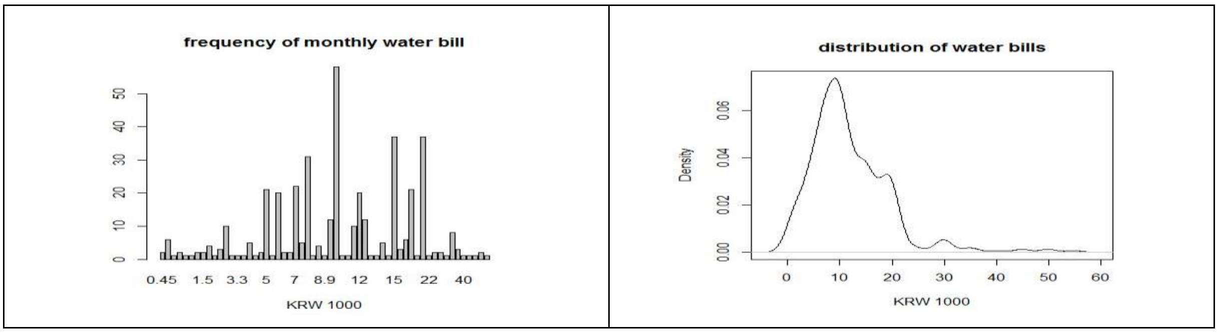
It is doubtful that they have chosen the options on the choice card considering substitution effects between the attributes and price. These respondents might just tick the options chasing the new advanced treatment-label. These cases are called "label heuristics". Therefore, it is necessary to consider how to deal with such data. One simple way is to exclude the data from analysis because the data do not provide information about people's real preferences. In this respect, this research will basically analyse the data without the potential label heuristics (407 respondents). However, the sample of 407 respondents is reduced to 406 because an additional outlier in terms of water-bill has been removed. This reduction will be discussed in the next subsection.

5.2 Sample Representativeness

5.2.1 Water-Bill

The monthly water bill per household is the first socio-economic factor to be discussed. There are two outliers; KRW 70,000 (USD 59.7) and 150,000 (USD 127.9). These values are much higher than the average monthly water bill of KRW 11,429 (USD 9.8, Ministry of Land, Infrastructure and Transport, South Korea, 2013) so they are removed hereafter. However, one of the two outliers also has a potential problem of label heuristics so it was previously removed. Thus, only one additional respondent has been removed and the sample is reduced to 406. Figure 5.1 shows the distribution of monthly water bills among the sample.

Figure 5. 1 *Distribution of water bill data*

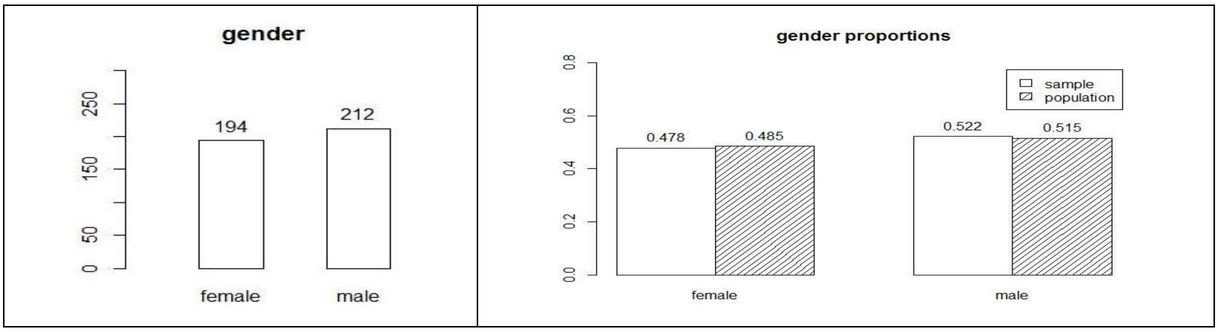


The average monthly water bill of the sample is KRW 11,820 (USD 10.08), which is slightly higher than the nationwide average monthly water bill per household. The sample standard deviation is 7.7689. In this case, the t-statistic is calculated as 0.6488. With 405 (406-1) degrees of freedom and a 1.0% significance level, the rejection region is $t \geq 2.576$. Therefore, there is no discrepancy between the sample and the population according to the distribution of the average monthly water bill per household at a 99% confidence level.

5.2.2 Gender

Figure 5.2 shows the gender proportions of the sample of 406 respondents.

Figure 5. 2 *Gender proportions of the sample of 406 respondents*

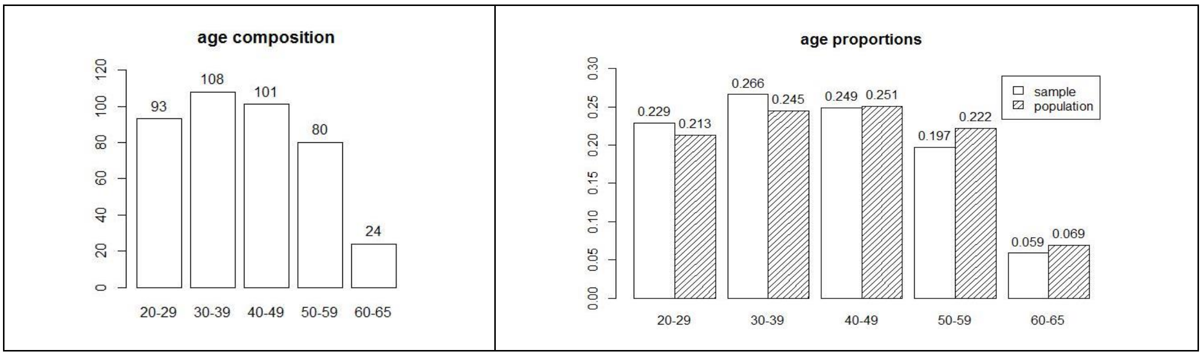


Among the 406 respondents, 212 people are male (51.5%), and 194 are female (47.8%). There is less than a 1.0% difference in the proportions between the sample and the population. The Z statistic is -0.284 (>-2.575). Thus, the sample is representative at the 1.0% significance level. Regarding all the data before removing the ineffective and potential label heuristic data, the gender ratios are similar to those of the population; 297 men (51.8%) and 276 women (48.2%) of 573 participate in the survey.

5.2.3 Age

Regarding age, Figure 5.3 shows the age composition and the differences between the sample of 406 respondents and the population.

Figure 5. 3 *Age compositions and proportions*

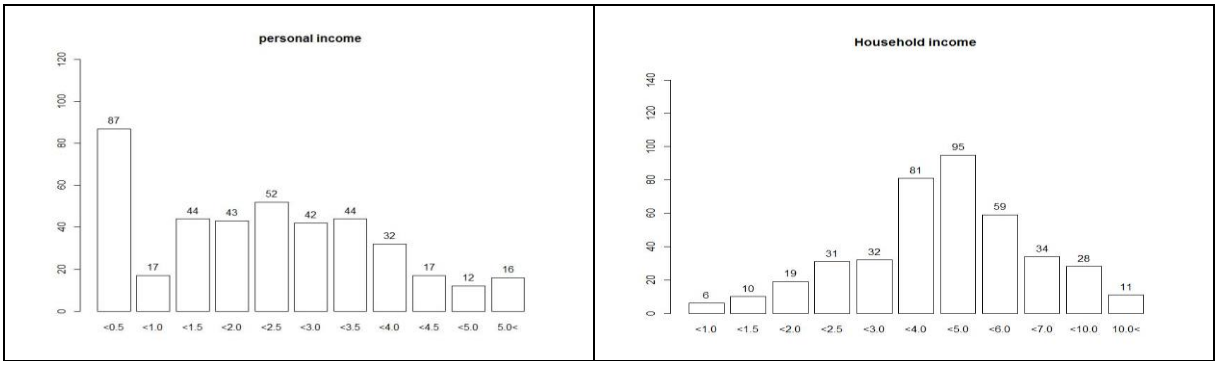


People younger than 40 years old are more likely to take part in the survey, while those older than 39 years old are less likely to do so. The chi -squared statistic is 0.0014. For four degrees of freedom and a 5.0% significance level, the rejection region is $\chi^2 \geq 9.49$. Therefore, there is no significant discrepancy between the sample and the population.

5.2.4 Income

Figure 5.4 shows the distributions of personal and household income of the 406 respondents.

Figure 5. 4 *Distribution of income data*



The distribution of household income is more similar to the normal distribution and both the lowest groups; less than KRW 500,000(USD 426) for monthly income and the highest group; more than KRW 5 million (USD 4,264), are larger than the normal distribution. Therefore, underestimation should also be considered when estimating the willingness to pay in the same senses as above. According to the Korean Statistical Information Service, the average monthly income per household in the whole of South Korea is KRW 4.304 million (USD 3,671) in the second quarter of 2015. The average monthly income per household of the sample is KRW 4.46 million (USD 3,805) and the standard deviation of it was KRW 2.02 million (USD 1,725). In this case, the t-statistic of it was calculated as 1.56. With 405 (406-1) degrees of freedom, and α = 5 % level of significance, the rejection region is $t \geq 1.645$. Therefore, there is no discrepancy between the sample and the population according to the distribution of the average monthly income per household at a 95 % level of confidence.

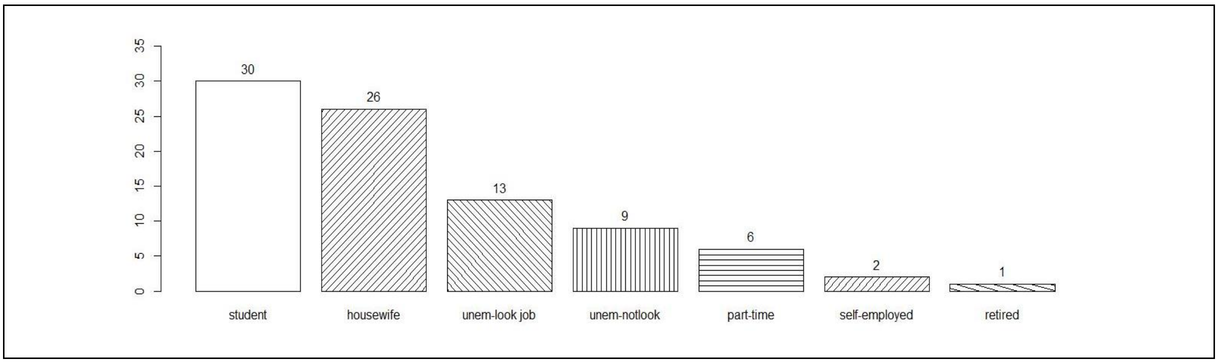
Eighty-seven people (21.4%) of the 406 do not earn sufficient money to make a decision about the additional water bills. However, the homogeneity test discussed in 5.1 can be used regarding the personal income of respondents. The chi-squared statistic and p-value to test the homogeneity between the subgroups (87 of the lowest personal income and the rest of them; 319=406-87) and all the data (406) using the same MNL model, are as follows,

$$\chi^2 = 24.126, \qquad p - value = 0.0196.$$

The result of the test shows that the homogeneity between the two groups and all the data cannot be rejected at a 1.0% significance level and therefore, the 87 responses can be included in the sample which leaves 406 people for further analysis.

Two points can be considered regarding the results. First, there is no restriction when taking part in the survey regarding personal income. If restricting the sample only to earning people, it would be impossible to obtain information about public projects from those without income about public projects. An unrestricted sample would be more similar to the distribution of the population. Also, restricting participation only to people earning would have entailed additional survey costs. Another point is related to the composition of the respondents who chose the lowest category for personal income. Figure 5.5 shows the composition of the lowest income group.

Figure 5. 5 *Compositions of respondents who answered 'less than KRW 500,000 per month*

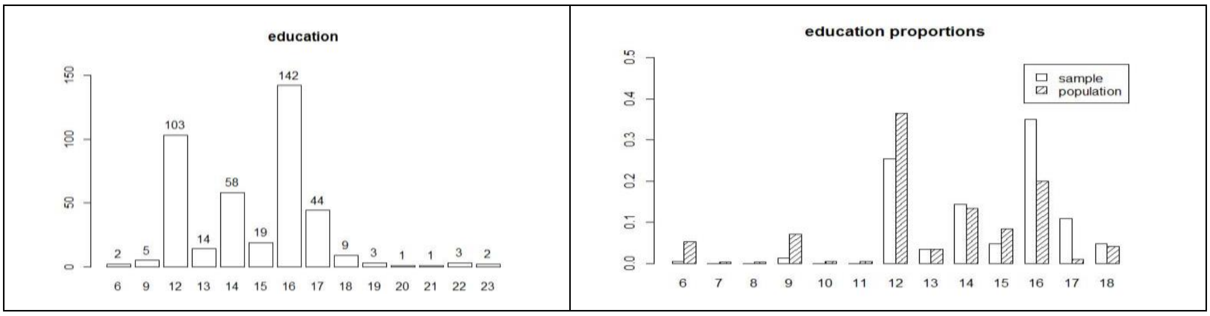


Among them, 87 choose the lowest personal income category (less than KRW 500,000). Regarding their job, 30 people answer they are students and 26 say they are housewives. Thirteen people reply they are unemployed and looking for a job, while nine people are unemployed but not looking for a job. Eight people say that they make money but only a little (part-time or self-employed). One person says that he is retired. The question remains as to whether they are in charge of responding to the additional cost. In the case of housewives, it might be too early to jump to the conclusion that they do not have the right status in their household. It is certain that housewives are in the firm position of determining many kinds of housekeeping decisions in South Korea, although difficult to prove. They, rather than their husband, usually allocate items of living cost, and often have the final word in economic decisions. Thus, housewives are qualified to decide on the willingness to pay. Regarding the unemployed, it would be more complicated to understand how their answers affect the outcome. If they were temporarily unemployed and looking for a job, it is not difficult to say that they are in a sufficient position to state their willingness to pay. However, if they have given up looking for a job, they are likely to overstate the willingness to pay. Last, concerning students and the retired person, it is natural to think that they are not in charge of deciding on the willingness to pay. It also can be suspected that comparatively more students take part in the survey. The proportion of students in the survey is about 7.3% (30/406), but the actual proportion of students living in the target area is estimated at 9.9%; 67,201 (students) / 679,301 (population) in 2013 (Cheongju City Government, 2014). Thus, fewer students participate the survey. Moreover, the average monthly water bill per household in South Korea is KRW 11,940 (USD 10.14) and its proportion of personal income is 0.2%. Considering the relative proportion of water bills to personal income, the non-earning group can afford the additional water-bill.

5.2.5 Education

Figure 5.6 shows the distribution of years of education of the 406 respondents and the differences between the sample and the population.

Figure 5. 6 *Distribution of years in education*



The chi -squared test is also used to verify the representativeness. Table 5.3 shows the calculation of the chi -squared statistic of the sample of 406 respondents. The chi -squared statistic is calculated as 587.6. For 17 degrees of freedom and α = 5% level of significance, the rejection region is larger than 27.59 and for α = 1% level of significance the rejection region is larger than 33.41. Therefore, there are large discrepancies between the sample and the population.

Table 5. 3 *Differences of years in education*

Year	6	7	8	9	10	11	12	13	14	15	16	17	18
population (1,000)	23	1	1	30	2	2	156	15	58	36	86	4	17
Expected	21	1	1	29	2	2	148	14	55	34	81	3	16
Observed	2	0	0	5	0	0	103	14	58	19	142	44	19
χ2	17.6	1.1	1.1	19.6	1.6	1.6	13.7	0.0	0.2	6.6	45.9	478	0.7

From the result, the respondents might be comparatively highly educated. Highly educated people who graduated from universities are more likely to take part in the survey, while low educated people are less likely to take part. Higher education is usually assumed to influence the possibility of overestimating the willingness to pay in stated preference analyses (Catalano et al., 2016). This is going to be taken into consideration in the further analysis.

5.2.6 Descriptive Statistics of five factors

So far, the representativeness of the sample was discussed with respect to the five socio-economic factors. Table 5.4 shows the descriptive statistics of the sample for the five socio-economic factors.

Table 5. 4 *Descriptive statistics of five socio-economic factors*

Factor	Water-bill (KRW)	Gender (proportion of male)	Age	Income per household (KRW million)	Education
Average	11,820 (USD 10.08)	0.5222	40.68	4.46 (USD 3,804)	14.69
Standard deviation	7.7689 (UD 0.007)	0.5001	12.08	2.02 (USD 1,725)	2.29
Method	t-test	z-test	χ^2 test	χ^2 test	χ^2 test
Result	H_0 not rejected	H_0 not rejected	H_0 not rejected	H_0 not rejected	H_0 rejected

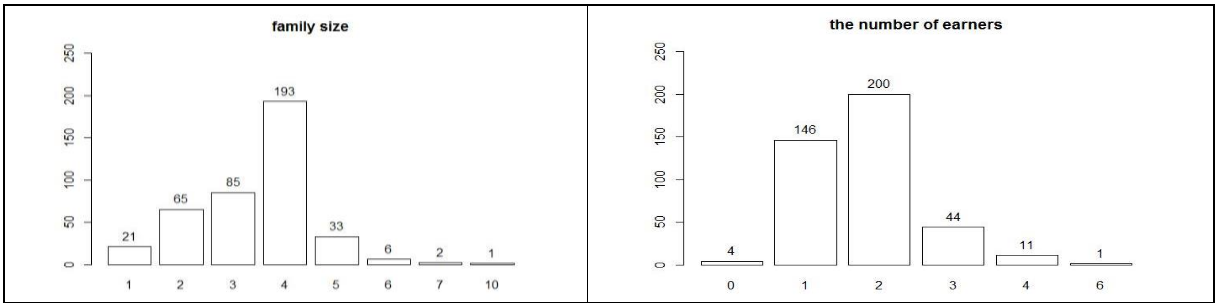
Note. H_0 means the null hypothesis that there is no discrepancy of average between the population and sample.

The four factors; water-bill, gender, age, and income per household fail to reject the null hypothesis; there is no discrepancy of average between the population and sample. However, the last factor, year of education is rejected for the null hypothesis, as discussed above.

5.3 Other Descriptive Statistics

Other observed data are described without testing the representativeness of the sample. First, the family sizes and number of earners per household are as shown in Figure 5.7.

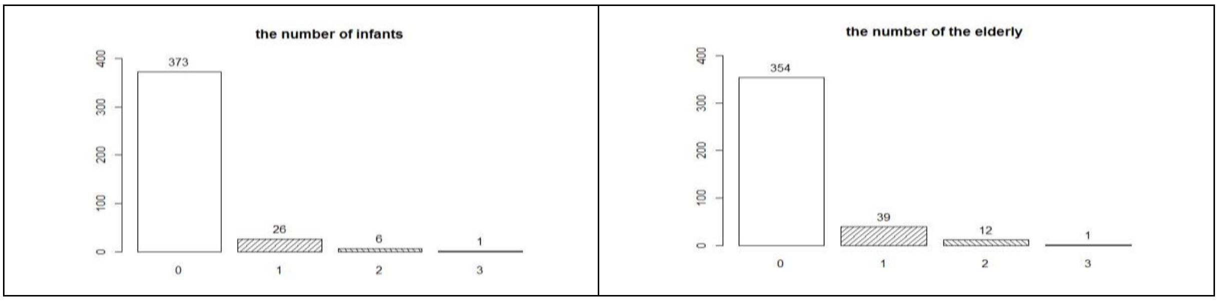
Figure 5. 7 *Family size and number of earners per household*



The average family size is 3.46, which is higher than the average family size of the population, 2.51. The family size of the sample might cause a bias of underestimating the willingness to pay because many empirical studies have reported that family size negatively influences the stated willingness to pay (Ahlheim and Schneider, 2004, Chambers et al. 1998). Thus, family size may be one factor that counterbalances positive factors like education and personal income. The average number of earners per household of the sample is 1.793.

Figure 5.8 shows the number of infants (younger than 4 years) and elderly (older than 59 years) per household.

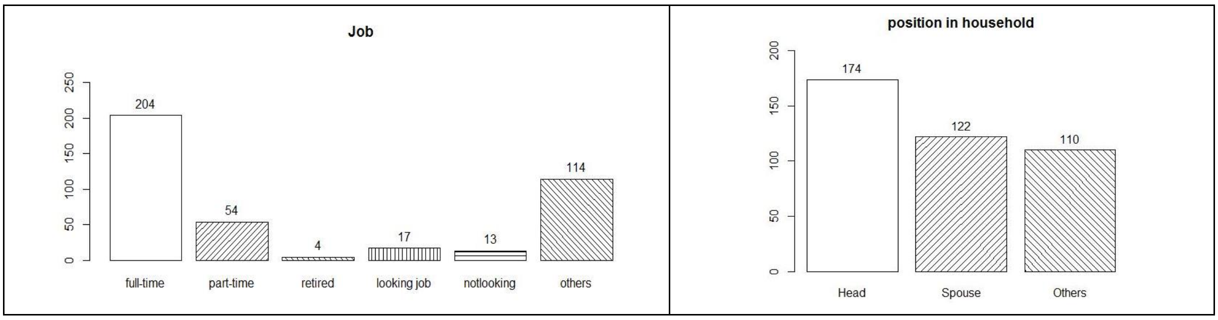
Figure 5. 8 *Number of infants and elderly per household*



The vast majority of the respondents answers that they have no infant or elderly person. Only a few respondents answered that they have infants and (or) live with the elderly.

Third are the employment status and the position in the household of the respondents. Figure 5.9 shows the types of employment and the position of the respondents in the household.

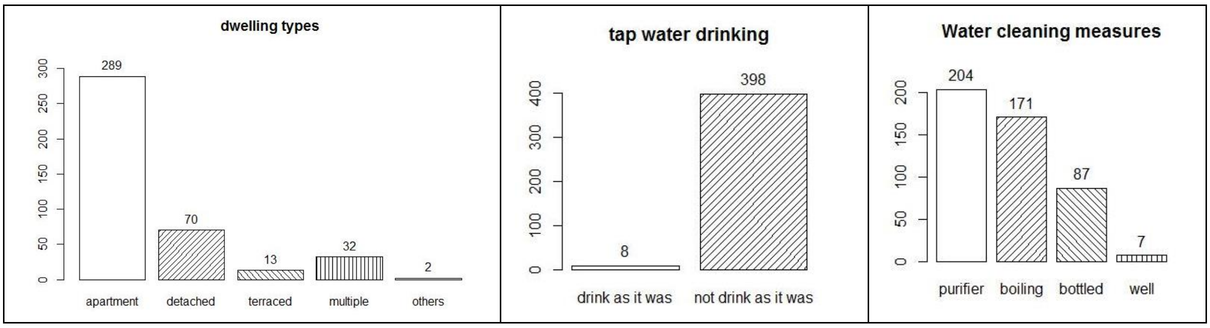
Figure 5. 9 *Employment type*



Two hundred and four respondents answered they have full-time jobs and 54 reply that they have part-time jobs. Seventeen people are looking for a job and 13 are not looking for a job even, though they are unemployed. Four people are retired but 114 answer they are engaged in different work, like students and housewives. One hundred and seventy four people replied that they are in charge of the household, and 122 reply they are spouses of the head of household. One can assume that the rest, 110, lived with their parents.

Figure 5.10 shows the type of dwelling and water drinking behaviour of the respondents.

Figure 5. 10 *Dwelling types and water drinking behaviours*



Two hundred and eighty nine respondents answer that they live in apartments and 70 lived in detached houses. Eight people say they do drink tap water as it is. This result is consistent with several reports indicating that almost all Koreans do not drink tap water as it is, as discussed in Section 1. Most respondents say that they use in-line filters (purifiers), boil water for drinking, purchased bottled water or drink from a well. For reference, the respondents could choose the options that they use for drinking water as alternatives.

So far, the socio-economic factors were discussed by using the descriptive statistics. Table 5.5 shows the descriptive statistics for nineteen socio-economic factors of the sample.

Table 5. 5 *Descriptive statistics for nineteen socio-economic factors of the sample*

Factor	Mean	Median	Standard deviation	Maximum	Minimum
Gender	0.5222	1	0.5001	1	0
Age	40.68	40.0	12.079	65	20
Education (year)	14.69	16	2.2916	23	6
Personal income per month (KRW million)	2.152 (USD 1,835)	2.25 (USD 1,919)	1.449	5.25	0.25
Household income per month (KRW million)	4.46 (USD 3,804)	4.5 (USD 3,838)	2.02	10	0.50
Water bill (KRW)	11,820 (USD 10.08)	10.0 (USD 8.53)	7.769	55,000	1,000
Family size	3.46	4	1.1382	10	1
Earners	1.79	2	0.7835	6	0
Infant	0.10	0	0.3680	3	0
Elderly	0.16	0	0.4589	3	0
Head of household	0.4286	0	0.4955	1	0
Spouse	0.3005	0	0.4590	1	0
Boil	0.4212	0	0.4944	1	0
Purify	0.5025	1	0.5006	1	0
Bottled	0.2143	0	0.4108	1	0
Apart	0.7118	1	0.4535	1	0
Multi	0.0788	0	0.2698	1	0
Full time	0.5025	1	0.5006	1	0

5.4 Debriefing Questions

For choosing effective data and testing the feasibility of data, three types of questions are used for debriefing. The first type asks about the preference for the attributes of drinking water quality and which attributes they ignore when they choose the preferred alternative in the choice sets. This might help in identifying which attributes are associated with non-attendance. As mentioned in Chapter 3, many studies report the attribute non-attendance problem, which means that a substantial group of respondents ignores one or more attributes within a stated preference survey. To avoid the biases caused by the attribute non-attendance, three methods can be considered. One is to take account of overestimation in the willingness to pay. Another is to use the median of willingness to pay instead of the mean. The third is to use a latent class logit model to overcome the problem. The second question type asks about the rank of preference between the four attributes. The third question group is used to test the attitude of the respondents with respect to environmental issues regarding drinking water. The last part of debriefing questions is aimed at finding out how much each respondent focussed on answering the questionnaire. This is discussed as the tool for selecting effective data from the whole dataset in Section 5.1.

As discussed in Chapter 4, four attributes are chosen for measuring the benefits of improving drinking tap water quality in this research, because they appeared to be the main causes for why people do not drink tap water as it is. In this respect, the first debriefing question to be explored is “Which of the following attributes did you ignore when completing the choice task?” The result is shown in Table 5.4.

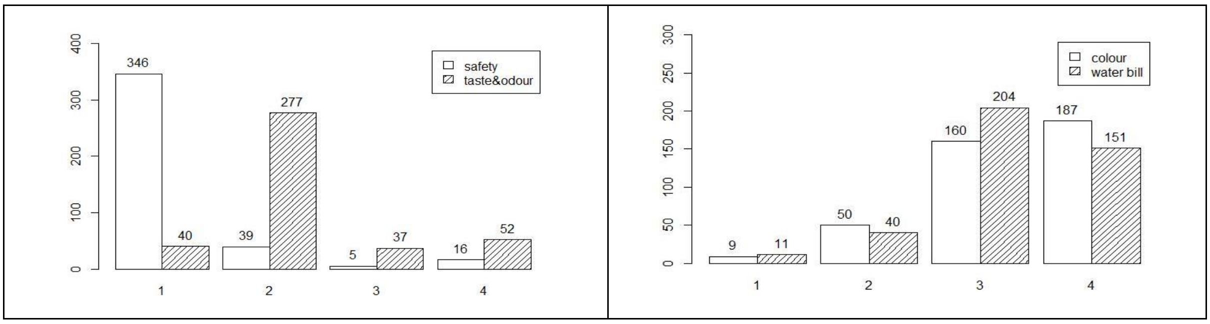
Table 5. 6 *Result of the first debriefing question*

Attribute	Safety	Taste and odour	Colour	Price
Number (Proportion)	33 (8.1 %)	39 (9.6 %)	133 (32.8 %)	34 (8.4 %)

The most ignored attribute is the colour; 32.8% of respondents answers that they ignore the colour of drinking water. This result is expected because people cannot detect the differences between 5 TCU and 3 TCU for clarity of drinking water. Around 10% of respondents answer they ignored the other attributes except colour. It is surprising that a few people (8.4%) in the sample ignored water bills when they considered the choice. However, given that the water bill is such a small proportion (0.21%) of monthly income, this is understandable.

The second question is about the preferences between the attributes. The question is, "Please rank which of the attributes you most considered when making your choices". The results are shown in Figure 5.11.

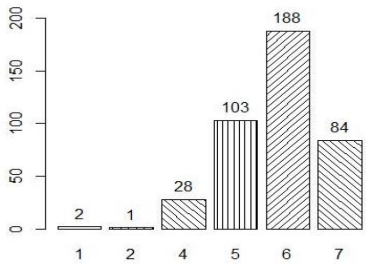
Figure 5. 11 *Result of debriefing questions asking the preference ranks between the attributes*



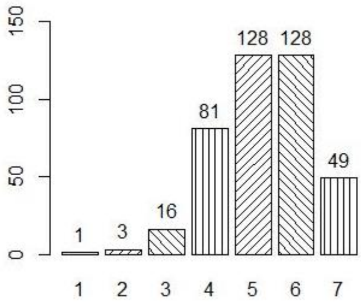
Many respondents answer that they prefer safety first and taste and odour second; in total, 346 respondents of 406 choose safety as the first attribute and 277 taste and odour as the second attribute. In the case of colour and water bill, respondents answer that they are the less preferred two attributes. How this preference order is related to the estimates of the magnitudes of the willingness to pay for the attributes, will be tested when estimating the parameters of the attributes.

The last debriefing questions ask how people think about issues of the environment and the importance of drinking water quality by using seven Likert-scale questions as shown in Appendix 1. Figure 5.12 shows the questions and results.

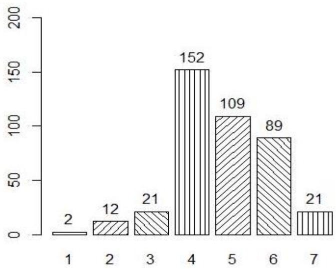
Figure 5. 12 *Debriefing Questions and the result*



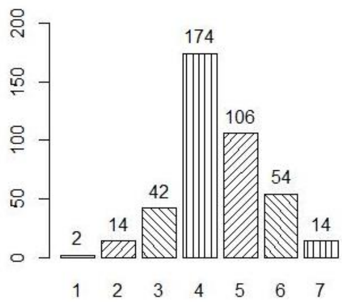
Q1. I prefer that water resource policies aiming to prevent contamination of the water environment, should be enhanced.



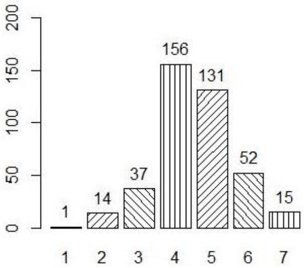
Q2. I want more information about the safety of drinking water.



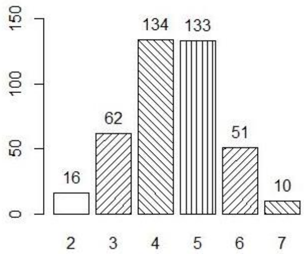
Q3. I am interested in looking for information on the taste and odour of drinking water.



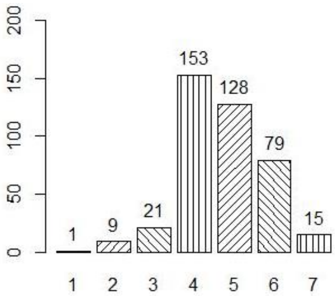
Q4. I usually pay attention to the colour of drinking water.



Q5. I don’t spend much time reading about the safety problems of drinking water.



Q6. I read about the taste and odour problem of drinking water in newspapers and on air.



Q7. I would like to receive additional information about drinking water.

Likert scale questions

	mean	percentage
Q1	5.78	82.6%
Q2	5.25	74.9%
Q3	4.74	67.7%
Q4	4.44	63.5%
Q5	4.52	64.6%
Q6	4.42	63.2%
Q7	4.71	67.3%

Question 1 shows that most respondents are in favour of more environmentally -friendly policies, which is the highest score among the answers. Questions 2 to 4 ask about the extent to which the respondents are interested in the problems of each attribute of drinking water. Safety is the highest scored attribute with a mean of 5.25. Taste and odour is the second highest scored attribute with a mean of 4.74, and colour is the lowest scored attribute with a mean of 4.44. These results show a consistency with the preference order, as discussed in Section 5.3.

To test the significance of the differences between the results of answers, the t-test is used. Table 5.5 shows the t-values of answers to the questions.

Table 5. 7 *T-values of answers to the debriefing questions*

Question	Q2	Q3	Q4	Q5	Q6	Q7
Q1	7.51 (0.0000)	14.39 (0.0000)	18.83 (0.0000)	17.92 (0.0000)	19.18 (0.0000)	15.47 (0.0000)
Q2		6.51 (0.0000)	10.45 (0.0000)	9.51 (0.0000)	10.75 (0.0000)	7.12 (0.0000)
Q3			3.79 (0.0002)	2.77 (0.0058)	4.04 (0.0000)	0.322 (0.7473)
Q4				1.04 (0.2999)	0.2893 (0.7724)	3.5824 (0.0004)
Q5					1.3312 (0.1835)	2.557 (0.0107)
Q6						3.885 (0.0001)

Note. The parenthesis means the P-values.

As shown in Table 5.5, the p-values for the mean differences between Q1 – and all other questions and Q2 – and all the other questions are close to zero, which means that the null hypothesis that there is no difference between the two means can be rejected. Therefore, the differences between them are statistically significant at the 99% confidence level. Thus, the means for these two questions ae significantly higher than for the other questions meaning that measures to prevent the contamination of the water environment (Q1) and information about the safety attribute (Q2) are the most relevant issues to the respondents.

Question 5 is a negative statement so it has an inverse relationship with Question 2. The result of Question 5 shows the third lowest score so it is consistent with the result of Question 2. Question 6 can be interpreted as how much the respondents are interested in the taste and odour problem of drinking water. Thus, it can also be interpreted as the likelihood of coming across articles about the taste and odour problems of drinking water in the mass media. The result shows a lower score than the one for safety. This might mean that many respondents are not willing to pay attention to the taste and odour problem of drinking water. Last, Question 7 asks how much the respondents are willing to pay attention to drinking water problems. The result shows that respondents want to spend more time finding more information about drinking water, which is also consistent with the outcome of Question 1. The difference of the results between Q1 and Q7 is statistically significant at the 99% confidence level.

Chapter 6. Results of Measuring Benefits

In Chapter 5, the sample is refined by excluding some parts of the sample, such as ineffective responses, label heuristics and outliers. As a result, the sample of 406 respondents remains. This sample will be used for analysis.

6.1 Assumptions about the Parameters

6.1.1 Direction of the Parameters

To measure the benefit reflected in the utility of consumers, it is necessary to establish assumptions about the parameters of the attributes in the utility function form. Assumptions can be made about the parameters of the four attributes of drinking tap water. The sign of the coefficients is the first conceivable aspect. For the assumption about the direction of coefficients, it is helpful to establish the units and ranges of attribute levels. Table 6.1 shows the definitions, units, and ranges of the attributes for this research.

Table 6. 1 *Unit and range of the attributes*

Attribute	Definition	Unit	Range
Safety	Probability of how many people are diagnosed with cancer from drinking tap water all one's life due to the amount of Trihalomethanes	1 person per 10 million	40 – 1
Taste and Odour	Proportions of how many people can be satisfied with taste and odour with respect to the amount of Geosmin and 2-Methyisoborneol	1 %	10 – 99.9
Colour	Proportions of how many people can be satisfied with the colour of tap water	1%	90 – 99.9
Cost	Additional monthly water bill per household	KRW 1,000 (USD 0.85)	0 – 4

A reduction in the level of safety and cost is more beneficial for people. In the cases of taste and odour, and colour, an increase in the attribute level can be regarded as beneficial. In this sense, improvements in the attribute levels are shown as in Table 6.2.

Table 6. 2 *Improvement in the attribute levels*

Attribute	Alternative 1 Status quo	Alternative 2 Granular Activated Carbon	Alternative 3 Ozone plus GAC
Safety (cancer risk)	40 per 10 million	6 per 10 million	1 per 10 million
Taste and Odour	10 %	90 %	99.9 %
Colour	90 %	99 %	99.9 %
Cost (KRW)	0	500, 1000, 2000, 3000 (USD 0.42, 0.85, 1.71, 2.56)	1000, 2000, 3000, 4000 (USD 0.85, 1.71, 2.56, 3.41)

Assuming that the utility functions for the three alternatives for this research are simple additive forms and there are only three options with four attributes, the functions can be written for person *i*, with four attributes (β_{ik}; a vector for coefficients of k^{th} attribute variables,x_{kj}, $i = (1, \cdots, I), j = (1, \cdots, J), k = (1, \cdots, K)$) as below,

$$U_{i1} = \beta_1 x_{1k} + \beta_2 x_{21} + \beta_3 x_{31} + \beta_4 x_{41} + \varepsilon_{i1}$$

$$U_{i2} = \beta_1 x_{12} + \beta_2 x_{22} + \beta_3 x_{32} + \beta_4 x_{42} + \varepsilon_{i2}$$

$$U_{i3} = \beta_1 x_{13} + \beta_2 x_{23} + \beta_3 x_{33} + \beta_4 x_{43} + \varepsilon_{i3} \qquad (6.1).$$

To discuss the signs of coefficients, it is advantageous to think of the statement: "Only differences in utility matter" (Train, 2009, p. 19). For example, Equation (6.2) can be written as the choice probability of choosing alternative 3 versus alternative 1 as below,

$$prob(U_{i3} - U_{i1} > 0) = prob(\beta_1(x_{13} - x_{11}) + \beta_2(x_{23} - x_{21})$$

$$+\beta_3(x_{33} - x_{31}) + \beta_4(x_{43} - x_{41}) + \varepsilon_{i3} - \varepsilon_{i1} > 0)$$

$$= prob(\beta_1 \Delta x_{131} + \beta_2 \Delta x_{231} + \beta_3 \Delta x_{331} + \beta_4 \Delta x_{431} + \varepsilon_{i3} - \varepsilon_{i1} > 0) \qquad (6.2).$$

Alternative 3 would be chosen by people on condition that the alternative provides more utility than alternative 1. Assuming alternative 1 is the status quo and alternative 3 is the ozone plus GAC treatment, the ozone plus GAC would be chosen if it provide more utility. Therefore, the direction of the coefficients depends on the signs of the differences between the two levels of each attribute. In the cases of safety and cost, the differences (Δx_{131}, Δx_{431}) are negative so the directions of coefficients should also be negative to increase the utility of the ozone plus GAC treatment. In the cases of taste and odour, and colour, the differences (Δx_{231}, Δx_{331}) are positive so the directions of coefficients should also be positive.

If two attributes, taste and odour and colour, improved, (i.e. people are satisfied with an increase in the quality of the attributes), then the utility for consumers will increase. It is difficult to imagine that some people would think negatively about an improvement in drinking water quality compared to the status quo. Therefore, these two parameters are expected to be positive. For example, in the status quo option, safety is related to the possibility of cancer; 40 people per 10 million, in option 2; where a GAC treatment system is installed, safety (cancer risk) is expressed as 6 people per 10 million. In option 3 where the ozone plus GAC treatment system is installed, safety is expressed as 1 person per 10 million being diagnosed with cancer from drinking water when they have drunk water with certain levels of trihalomethanes during their life. The additional monthly water bill can be interpreted as a cost for improving the service. The sign would be negative because, other things being equal, utility would decrease as the cost increases.

6.1.2 Alternative-Specific Constants

Utility function forms can use alternative specific constants (ASCs) to reflect the average effect on utility of all factors that are not included in the model as in (6.1) as below,

$$U_{ij} = \alpha_j + \beta_k x_{kj} + \varepsilon_{ij} \qquad (6.3).$$

If the utility function includes ASCs, the error term, ε_{ij}, has zero mean (Train, 2009). Only differences in the ASCs matter as only differences in utility do. In this respect, it is impossible to estimate the ASCs because a number of two pair values of the ASCs can have the same difference, and the choice probabilities can also have the same result. To avoid this, it is necessary to normalise the absolute levels of the ASCs. The typical method for normalising the ASCs is to drop one of the ASCs. Actually, any of the ASCs can be normalized to zero. One of the alternative specific constants; α_3, can be removed as below,

$$U_{i1} = \alpha_1 + \beta_1 x_{11} + \beta_2 x_{21} + \beta_3 x_{31} + \beta_4 x_{41} + \varepsilon_{i1}$$

$$U_{i2} = \alpha_2 + \beta_1 x_{12} + \beta_2 x_{22} + \beta_3 x_{32} + \beta_4 x_{42} + \varepsilon_{i2}$$

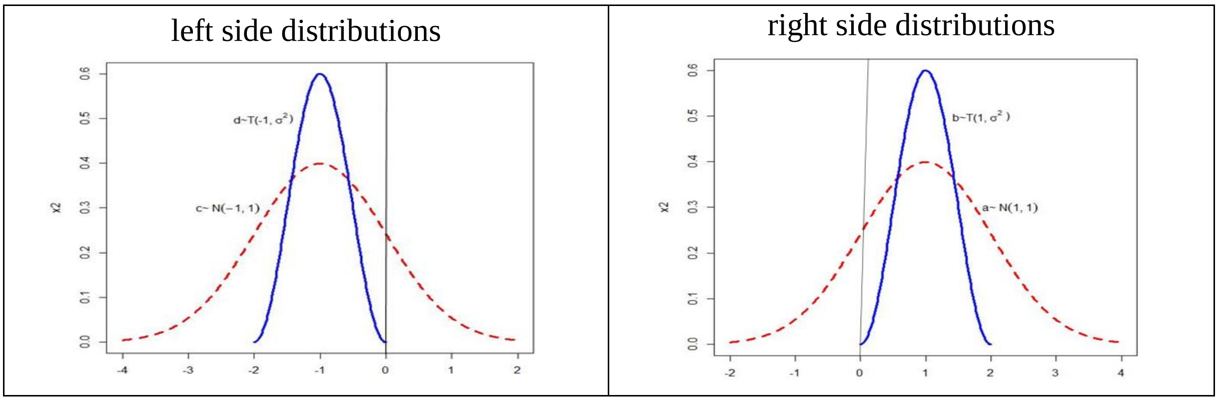
$$U_{i3} = \qquad \beta_1 x_{13} + \beta_2 x_{23} + \beta_3 x_{33} + \beta_4 x_{43} + \varepsilon_{i3} \qquad (6.4).$$

The error terms, ε_{i1} , ε_{i2} , ε_{i3} have zero mean by adding the ASCs; α_1 , α_2 , and the normalisation of the ASCs is achieved. The two constants, α_1, α_2, can be interpreted as the average effect of unaccommodated factors on the utility of alternative 1, and 2 relative to alternative 3. In this research, the alternative -specific constant of the status quo is set to zero for the normalisation.

6.1.3 Distribution of Generic Parameters

The random parameter and latent class logit models can calculate the parameters of each individual. Assumptions can be made in relation to the distributions of the estimated parameters. Figure 6.1 shows four kinds of distribution for some parameters.

Figure 6. 1 *Distributions of random parameters*



As above, the reasons that the two parameters, safety and cost, would be negative, and the other two parameters would be positive, are explained. For example, there may be two distributions for negative parameters as shown on the left in Figure 6.1. "c" is a normal distribution with negative one mean and standard deviation one. This assumption of the parameter distribution allows the coefficient of some respondents to be positive, which means that a person's utility falls when cancer risk and the water-bill decreases, contrary to common sense. On the right in Figure 6.1, "a" is a normal distribution with mean one and standard deviation one. This assumption allows for the case that the coefficient of some respondents might be estimated to be negative, which means that a person's utility decreases when taste and odour and the colour of tap water are improved. Regarding the distribution, the attribute non-attendance (ANA) can be applied to the models. If an estimation of coefficients shows a negative sign for taste and odour, or colour attribute, the person ignores the attribute. In this case, the willingness to pay can be regarded as zero. More specifically, when using random parameter logit models, many types of coefficient distributions can be used such as normal, lognormal, truncated normal and triangular. However, this research presumes the normal distribution for coefficients of the three generic attributes, safety, taste and odour, and colour.

6.2 Establishment of Utility Function

Before estimating the coefficients, it is necessary to establish the utility function form. The discussion starts with the basic forms of the utility function including the four generic attribute variables and the two constant terms for the three alternatives as below,

$$U_{i,Oz} = \alpha_{Oz} + \beta_{i,safe}X_{i,safe} + \beta_{i,taste}X_{i,taste} + \beta_{i,col}X_{i,col} + \beta_{i,p}X_{i,p} + \varepsilon_{i,Oz}$$

$$U_{i,GAC} = \alpha_{GAC} + \beta_{i,safe}X_{i,safe} + \beta_{i,taste}X_{i,taste} + \beta_{i,col}X_{i,col} + \beta_{i,p}X_{i,p} + \varepsilon_{i,GAC}$$

$$U_{i,SQ} = \beta_{i,safe}X_{i,safe} + \beta_{i,taste}X_{i,taste} + \beta_{i,col}X_{i,col} + \beta_{i,p}X_{i,p} + \varepsilon_{i,SQ}$$

Thus, $U_{ij} = \alpha_j + \beta_{i,k}X_{ijk} + \varepsilon_{ij},\ j = 1, \cdots, 3, k = 1, \cdots, 4,$ (6.5).

Here, SQ stands for the alternative status quo, GAC for the alternative granular activated carbon, and Oz for ozone plus GAC treatment, safe, $taste$, and col stand for the safety, taste and odour, and colour, respectively. In Equation (6.5), $p\ at\ \beta_p\ and\ X_p$ represent the coefficients and variables for cost. The simple additive (linear) utility function forms used for analysis in this research are shown in Equation (6.5).

6.2.1 Socioeconomic Factors

This subsection explores which individual-specific independent variables should be included in the utility function. Table 6.3 shows all of the individual specific variables.

Table 6. 3 *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

In total, 28 individual specific variables are included as variables for analysis of the parameters. All collected variables are included and the coefficients are estimated to choose all statistically significant variables at a 95% confidence level. Before proceeding to the analysis, the correlations between the variables are analysed.

If correlated variables are included within one model, then the problem of multicollinearity may occur. More specifically, if correlated dummies are included in one model, the result of analysis would not be meaningful. Barker and Brown (2001) suggest that logistic regression can produce estimates with large mean square error when independent dummy variables are correlated. Thus, it is necessary to test the correlations between the variables. Table 6.4 shows the correlation coefficients between 19 individual specific variables.

The most strongly correlated variables are between whether or not using a purifier and whether or not boiling water to drink (p-value; -0.65). Regarding the behaviour with regard to drinking tap water, three dummy variables are correlated with each other, as below,

Purify;	-0.65^{***}
Bottle;	-0.44^{***}.

This looks reasonable because a person using a purifier, is less likely to boil water and also less likely to purchase the bottled water.

The head of household dummy is highly related with six variables as below,

Spouse;	-0.64^{***}
Gender;	0.60^{***}
Personal income;	0.52^{***}
Age;	0.37^{***}
House income;	0.33^{***}
Fulltime;	0.33^{***}.

Table 6. 4 *Correlation coefficients between nineteen individual specific variables*

	gender	age	edu	pinc	hinc	bill	family	earner	infant	elderly	Head	spouse	boil	purify	bottle	apart	Multi	Full	environ
gender	1.00	0.06 (0.16)	0.19 (0.00)	**0.33 (0.00)**	-0.01 (0.87)	0.07 (0.14)	-0.01 (0.91)	-0.09 (0.04)	0.00 (0.93)	0.06 (0.19)	**0.60 (0.00)**	**-0.64 (0.00)**	-0.03 (0.47)	-0.02 (0.64)	0.07 (0.14)	0.04 (0.31)	0.03 (0.50)	0.22 (0.00)	-0.08 (0.09)
age		1.00	-0.23 (0.00)	**0.26 (0.00)**	-0.09 (0.05)	0.06 (0.19)	-0.19 (0.00)	**-0.29 (0.00)**	-0.12 (0.01)	0.14 (0.00)	**0.37 (0.00)**	0.24 (0.00)	-0.04 (0.32)	0.11 (0.01)	-0.15 (0.00)	-0.02 (0.65)	-0.14 (0.00)	-0.08 (0.06)	-0.01 (0.78)
edu			1.00	**0.35 (0.00)**	0.13 (0.00)	0.03 (0.53)	0.02 (0.74)	0.00 (0.98)	0.16 (0.00)	-0.12 (0.01)	0.19 (0.00)	-0.22 (0.00)	-0.03 (0.47)	-0.02 (0.60)	0.18 (0.00)	0.17 (0.00)	0.08 (0.09)	**0.25 (0.00)**	0.02 (0.59)
pinc				1.00	**0.36 (0.00)**	0.04 (0.39)	0.07 (0.10)	0.04 (0.35)	0.02 (0.63)	-0.10 (0.02)	**0.52 (0.00)**	-0.23 (0.00)	-0.03 (0.51)	-0.00 (0.93)	0.05 (0.24)	0.12 (0.01)	-0.01 (0.78)	**0.52 (0.00)**	0.04 (0.35)
hinc					1.00	-0.02 (0.67)	**0.44 (0.00)**	**0.51 (0.00)**	-0.09 (0.05)	-0.09 (0.04)	-0.10 (0.03)	-0.01 (0.89)	-0.04 (0.33)	0.09 (0.03)	-0.05 (0.31)	0.13 (0.00)	-0.08 (0.08)	0.19 (0.00)	0.08 (0.09)
bill						1.00	-0.09 (0.05)	-0.02 (0.61)	-0.07 (0.09)	-0.02 (0.69)	0.05 (0.27)	-0.04 (0.32)	0.07 (0.10)	-0.00 (0.99)	0.03 (0.48)	-0.05 (0.23)	-0.07 (0.12)	-0.01 (0.86)	0.10 (0.03)
family							1.00	**0.42 (0.00)**	0.06 (0.16)	0.02 (0.64)	-0.19 (0.00)	0.00 (0.96)	-0.02 (0.63)	0.08 (0.06)	-0.09 (0.05)	0.11 (0.01)	-0.18 (0.00)	-0.01 (0.87)	-0.01 (0.89)
earner								1.00	-0.09 (0.04)	-0.01 (0.90)	**-0.30 (0.00)**	-0.05 (0.30)	0.03 (0.50)	-0.00 (0.94)	0.01 (0.79)	0.03 (0.48)	-0.02 (0.63)	0.07 (0.10)	0.14 (0.00)
infant									1.00	-0.02 (0.58)	0.03 (0.51)	0.12 (0.01)	0.04 (0.40)	0.00 (0.99)	0.08 (0.07)	0.12 (0.01)	-0.02 (0.73)	0.05 (0.24)	0.04 (0.40)
elderly										1.00	-0.10 (0.03)	-0.02 (0.64)	0.07 (0.12)	-0.07 (0.12)	-0.07 (0.13)	-0.19 (0.00)	-0.11 (0.02)	-0.05 (0.28)	0.11 (0.01)
head											1.00	**-0.57 (0.00)**	-0.10 (0.03)	0.02 (0.67)	0.03 (0.44)	0.01 (0.84)	0.11 (0.01)	**0.33 (0.00)**	-0.08 (0.07)
spouse												1.00	0.01 (0.90)	0.08 (0.06)	-0.04 (0.35)	0.01 (0.84)	-0.09 (0.04)	-0.19 (0.00)	0.10 (0.02)
Boil													1.00	**-0.65 (0.00)**	0.06 (0.20)	0.02 (0.71)	-0.01 (0.83)	-0.02 (0.63)	0.02 (0.69)
purify														1.00	**-0.44 (0.00)**	0.04 (0.34)	-0.11 (0.01)	-0.02 (0.70)	-0.06 (0.20)
bottle															1.00	-0.06 (0.21)	0.13 (0.01)	0.01 (0.75)	0.12 (0.01)
apart																1.00	**-0.45 (0.00)**	0.12 (0.01)	-0.09 (0.05)
multi																	1.00	-0.03	-0.01 (0.83)
full																		1.00	0.03 (0.53)
environ																			1.00

Note. Numbers in parenthesises 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.

If someone is the head of a household, the person is highly likely to be a man. The personal income is higher with the head of the house. Also, the older he or she is, the more probable it is that he or she is the head of household. If someone is the head of household, then he or she is more likely to have a full-time job.

The number of earners is also correlated with socio-economic factors as below,

Household income;	0.51^{***}
Family size;	0.42^{***}
Head of household;	-0.30^{***}
Age;	-0.29^{***}.

From the results, earner numbers are likely to be explained by family size and household income. The relationship between the number of earners and head of household is also predictable. If one respondent is a head of a house, the number of earners may be smaller, with high probability. The older a respondent is, the more likely fewer people have a job, which means that the number of earners in the household is smaller. The relationship between earners and age implies that a younger respondent is likely to live alone as a single-person household.

There are other correlated socio-economic factors as below,

Personal and Household income;	0.36^{***}
Personal income and Education;	0.35^{***}
Personal income and Gender;	0.33^{***}
Personal income and Age;	0.26^{***}
Family size and Household income;	0.44^{***}
Education and Full time;	0.25^{***}.

It is understandable why personal income and household income are correlated. It can be expected that the more educated, older, men would make more income than the less educated and younger do, and that a larger family can mean more household income. Also, the family size is likely to be correlated with the household income, and the years of education can mean people are more likely to have a full-time job.

From Table 6.4, it is notable that four factors seem not to be correlated with others: water bill, number of infants (younger than three years old), number of elders (older than 59 years old), and the dummy whether a respondent lives in an apartment. These variables can be included in a utility function form without worrying about multicollinearity.

Before starting the analysis, the general form of the utility function can be expressed as below,

$$U_{ijt} = \alpha_j + \beta_{ik} X_{ijk} + \gamma_{il} \cdot Z_l + \varepsilon_{ijt} \quad (6.6).$$

Here, Z_l is a vector of the socioeconomic factors and $j = 1, \cdots, 3,\ k = 1, \cdots, 4, l = 1, \cdots, L$. Including the individual specific variables for analysis step by step, only significant and uncorrelated variables are selected and included in the models through the procedure that aims to provide a succinct utility function insofar as possible.

6.2.2 Dummies for Mitigating Hypothetical Bias as Independent Variables

In this subsection, dummy variables for mitigating hypothetical bias will be explored. The tools for mitigating hypothetical bias are cheap talk and the honest priming task. Regarding terminology, the two tools for minimizing hypothetical bias can be regarded as a treatment for mitigating the problem. However, it is notable that the word, 'treatment' is also used for making a choice experimental design, which stands for the unique levels of the attributes. This research uses four blocks to compare the effectiveness of the two treatments for mitigating hypothetical bias. Therefore, it is possible to set three dummies to discriminate between the blocks because a chosen block can serve as a base group. Table 6.5 shows the dummy setup for the four blocks.

Table 6. 5 *Example of the dummy coding*

Block	Tools against hypothetical bias	D_{both}	D_{cheap}	D_{honest}
1	cheap talk, honest priming	1	0	0
2	cheap talk	0	1	0
3	honest priming	0	0	1
4	none	0	0	0

The first dummy (D_{both}) represents Block 1 which uses both treatments for reducing the hypothetical bias. The second dummy (D_{cheap}) stands for Block 2 using the two treatments, budget constraints reminder, and cheap talk, and the third (D_{honest}) for Block 3 uses the honest priming task. Block 4 works as the base group, because all dummy variables are zero. When using the three dummies of hypothetical bias as independent variables, the utility functions can be set as below,

$$U_{ijt} \ = \ \alpha_j + \beta_{ik} \cdot X_{ijk} + \gamma_{il} \cdot Z_l + \ \theta_m \cdot D_m + \varepsilon_{ijt} \qquad (6.7).$$

Here, $D_m$is a vector of the dummies of hypothetical bias, θ_m is a vector of the dummies for mitigating hypothetical bias, X_{ijk} is a vector of attribute variables, β_{ik} is a vector for coefficients of attribute variables, and $j = 1, \cdots, 3,\ \ l = 1, \cdots, L,\ \ m = 1, \cdots, 3,\ \ k = 1, \cdots, 4$.

6.2.3 Interaction Terms between the Cost Variable and Dummies of Hypothetical Bias

Unlike Equation (6.7), a utility function can be set by using interaction terms between the cost variable and the three dummies for mitigating hypothetical bias. Assume a hypothetical bias in both directions like understatement or overstatement to understand the role of the dummy variables for hypothetical bias; then it will be possible to express the difference between the biased slope and the true slope of a variable as follows,

$$\beta_{biased} - \beta_{true} = \Delta\beta \quad (6.8).$$

Here, β_{true} means the true coefficient of respondents, and β_{biased} means the biased coefficient, which can also stand for a coefficient of "untreated". If the treatments are effective, the coefficient using the dummies for the tools can be expressed as below,

$$\beta_{biased} - \beta_{treated} = \Delta\check{\beta} \quad (6.9).$$

In Equation (6.9), $\beta_{treated}$ stands for the slope; the coefficient using the dummies of the tools for mitigating the hypothetical bias, $\Delta\check{\beta}$, represents the difference between the biased slope, β_{biased}, and the treated slope, $\beta_{treated}$, which is different with $\Delta\beta$ (the difference between the biased slope; β_{biased} and the true slope; β_{true}). It is uncertain whether the two differences are equal, which has the same meaning as the true slope, β_{true} being equal to the treated slope, $\beta_{treated}$. However, if the tools have at least some effect on moderating hypothetical bias, then the treated slope will be located between the biased slope and the actual slope as follows,

$$\beta_{biased} \leq \beta_{treated} \leq \beta_{true} \text{ or } \beta_{biased} \geq \beta_{treated} \geq \beta_{true} \quad (6.10).$$

Although it is impossible to find a true coefficient, the treated coefficient can play a role in minimizing the hypothetical bias. Using the dummies, Equation (6.10) can be changed as follows,

$$\beta_{treated} = \beta_{biased}(D_1, D_2, \cdots, D_K),\ D_k\text{; the } k^{th} \text{ dummy} \quad (6.11).$$

Then the coefficients reflecting the dummy can be shown by using Equation (6.11) as below,

$$\beta_{treated} = \beta_{biased}(D_{both}, D_{cheap}, D_{honest}) \quad (6.12).$$

For a version of the utility functions, the three dummies are included, as shown in Table 6.6. Therefore, a version of the utility functions for using interaction terms between cost and dummies for mitigating hypothetical bias is set as follows,

$$U_{OZ} = a_{OZ} + \gamma_{k,OZ}X_k + \beta_{safe}X_{safe} + \beta_{taste}X_{taste} + \beta_{color}X_{color}$$
$$+(\beta_p + \theta_{both}D_{both} + \theta_{cheap}D_{cheap} + \theta_{honest}D_{honest})X_p + \varepsilon_{OZ}$$
$$U_{GAC} = a_{GAC} + \gamma_{k,GAC}X_k + \beta_{safe}X_{safe} + \beta_{taste}X_{taste} + \beta_{color}X_{color}$$
$$+(\beta_p + \theta_{both}D_{both} + \theta_{cheap}D_{cheap} + \theta_{honest}D_{honest})X_p + \varepsilon_{GAC}$$
$$U_{SQ} = \beta_{safe}X_{safe} + \beta_{taste}X_{taste} + \beta_{color}X_{color}$$
$$+(\beta_p + \theta_{both}D_{both} + \theta_{cheap}D_{cheap} + \theta_{honest}D_{honest})X_p + \varepsilon_{SQ} \qquad (6.13).$$

Here, α is the constant term, $\beta, \gamma, \delta, \theta$ are the coefficients of the independent variables, and the index indicating the individual *i* is skipped for simplicity. The utility functions expressed in a simple form are as follows,

$$U_j = \alpha_j + \gamma_j X_{1;k-1} + \delta_{jl}D_l + \beta_{k;K}X_{k;K} + (\beta_p + \theta_m D_m)X_p + \varepsilon_j \qquad (6.14).$$

At this point, it is possible to assume the direction of the coefficients of the dummy variables. 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 people have a hypothetical bias of understatement and the treatments for mitigating the hypothetical bias are effective, the coefficients of the dummies will be positive. In this way, the directions of the treatment dummies allow for testing whether the hypothetical bias leads to overstatement or understatement. If the coefficients of dummies are negative, the size of the cost coefficient as a denominator will increase so the MWTP will decrease.

6.2.4 Dummy Variables of Survey Methods

Two survey methods are used to collect the data used in this research. Therefore, one dummy can be included in the utility function for separating the effect. Let D_f be the dummy variable indicating 1 if face-to-face interview survey is used and 0 otherwise. Then, the base group is the online survey group (Blocks 1 and 4). Table 6.6 shows the coding of the case.

Table 6. 6 *Coding of dummies for the survey methods*

Block	1	2	3	4
Survey method	online	face-to-face	face-to-face	online
D_f	0	1	1	0

Before using the dummies, it is necessary to test the correlation with others to avoid multicollinearity. Table 6.7 shows their correlations between the dummy variables.

Table 6. 7 *Correlations between the dummy variables*

	D_{cheap}	D_{honest}	D_{both}
D_f (p-value)	0.5785 (0.000)	0.5785 (0.000)	-0.5929 (0.000)

The correlations between the dummies of the hypothetical bias treatments and the one of the survey mode are all larger than ±0.57 and highly significant. In this research, two types of dummies are included in models for analysis. As a result, the dummies of the survey mode are not significant but the dummies of the hypothetical bias are significant. Hence, only the dummies of hypothetical bias treatment are chosen for analysis.

6.3 Estimation of Multinomial Logit Models

This part will explore two types of multinomial logit models; MNL 1 uses the dummies of the hypothetical bias treatments as alternative specific constants and MNL 2 used them as the interaction terms with the cost variable. Table 6.8 shows the estimations of MNL 1 and MNL 2. The MNL 1 uses seven ASCs, one, elderly, bill, environ, D_{both}, D_{cheap} and D_{honest}, which are significant at the 95% significance level. Other factors are insignificant so that they are not included. The coefficients of safety, taste and odour, and cost are significant at the 99% significance level and the coefficient of colour is significant at a 95% significance level. This result suggests that the colour is less important than other attributes.

Table 6. 8 *Estimations of MNL 1 and 2 models*

Variable	MNL 1	MNL 2
x1 (safety; cancer risk)	-0.0367 (0.0000)	-0.0302 (0.0000)
x2 (Taste and odour)	0.0049 (0.0001)	0.0049 (0.0000)
x3 (Colour)	0.0213 (0.0166)	0.0187 (0.0290)
x4 (Cost)	-0.7046 (0.0000)	-0.4167 (0.0000)
$D_{both} \cdot x4$	-	-0.2074 (0.0000)
$D_{cheap} \cdot x4$	-	-0.3133 (0.0000)
$D_{honest} \cdot x4$	-	-0.4233 (0.0000)
ASC Of Ozone	-1.4312 (0.0006)	-1.7350 (0.0001)
Elderly	-0.4093 (0.0002)	-0.3565 (0.0014)
Bill	0.0410 (0.0000)	0.0372 (0.0000)
Environ	0.0426 (0.0000)	0.4362 (0.0000)
Age	-	-0.0108 (0.0139)
D_{both}	-0.8983 (0.0000)	-
D_{cheap}	-1.1993 (0.0000)	-
D_{honest}	-1.3843 (0.0000)	-
ASC Of GAC	0.8064 (0.0147)	0.4459 (0.2009)
Elderly	-0.3654 (0.0003)	-0.2725 (0.0062)
Bill	0.0217 (0.0032)	0.0183 (0.0103)
Environ	0.1127 (0.0283)	0.1291 (0.0106)
Age	-	-0.0108 (0.0067)
D_{both}	-0.4396 (0.0036)	-
D_{cheap}	-1.3748 (0.0000)	-
D_{honest}	-0.8966 (0.0000)	-
Sample size	406	406
Log Likelihood	-3037.9	-3055.9
AIC	6111.8	6145.8
BIC	6183.9	6213.9
Pseudo R^2_{adj}	0.0997	0.0945

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

Regarding the socio-economic factors, the coefficients of elderly are negative and significant at the 99% significance level. This result indicates that the households with more elderly people are less likely to prefer the two advanced alternatives. The coefficient of bill is positive and significant at the 99% significance level. This result predicts that people who consume more tap water are more likely to enjoy the improvement in drinking tap water.

They are more likely to accept the additional costs for improving tap water quality because the water bills are proportional to the amount of drinking tap water that people consume in their house. The charging system for water bills in the target area supports the assumption. The coefficient of environ is positive and significant at the 99% significance level. This result implies that people who prefer environmentally -friendly policies are more likely to choose the two advanced water treatment systems. The three dummies of the treatments for mitigating hypothetical bias are significant at the 99% significance level. All coefficients show a negative sign which would reduce the total utilities of the two advanced options. This result suggests that all treatments for mitigating hypothetical bias are successful in influencing the respondents of less utility from the two advanced water systems against the status quo and make them more likely to choose the status quo.

The MNL 2 model uses interaction terms between the dummies of the hypothetical bias treatments and the cost variable and employed five ASCs, one, age, earner, infant and elderly, which are significant at a 95% significance level. Other factors are insignificant so that they are not used. The coefficients of the four attribute variables (safety, taste and odour, cost) are significant at the 99% significance level. The coefficient of colour is significant at the 95% significance level. The signs for safety and cost are negative, and those for taste and odour and colour are positive. The three interaction terms with the cost variable are all significant at the 99% significance level and show negative signs. This result suggests that all treatments for mitigating hypothetical bias are successful in influencing the respondents of less utility from the two advanced water systems against the status quo and made them more likely to choose the status quo.

Regarding the socio-economic factors, the coefficients of elderly are negative and significant at the 99% significance level. This result suggests that the households with more elderly people are less likely to prefer the two advanced alternatives. The coefficient of bill is positive and significant at the 99% significance level in both models. This result predicts that people who consume more tap water are likely to enjoy the improvement in drinking tap water. The coefficient of environ is positive and significant at the 99% significance level, which implies that people who prefer environmentally -friendly policies are more likely to choose the two advanced water treatment systems. The coefficient of the age variable is negative and significant at the 95% significance level for the two advanced options. This result suggests that the older respondents are likely to prefer the status quo option compared to the two advanced options.

The results of the two MNL models are similar. However, the coefficient of the cost variable for MNL 1, -0.7046 is larger than the one for MNL 2, -0.4167. Considering the coefficients of the interaction terms between the cost and the dummies of the hypothetical bias treatment, the difference can be explained. MNL 1 shows a higher pseudo R^2 and log-likelihood function value and a lower AIC than the MNL 2.

6.4 Estimation of Random Parameter Logit Models

This part will explore random parameter logit models; RPL 1 uses the dummies of the hypothetical bias treatments as alternative specific constants, and RPL 2 uses them as the interaction terms with the cost variable. When using RPL models, it is necessary to specify the distributions of the coefficients of the variables. Many specifications of distributions can be used. Normal and lognormal distributions have worked as basic approaches in many studies (Train, 2009, p. 138). This research uses the normal distribution for the three attributes: safety, taste and odour and colour. In many studies using RPLs, the coefficient of the cost variable is used as a fixed parameter for convenience of simulation and interpretation of the result (King et al., 2016, Meijer and Rouwendal, 2006, Revelt and Train, 1998). In this research, the coefficient of the cost variable is assumed to be the same for all respondents.

When analysing RPL models, it is important to look into the significance of the standard deviation of random parameters. As discussed in Section 3.5, RPL models assume that the representative utility V_{ijt} has a parameter vector that has its own distribution, $f(\beta) = f(b|\theta)$. The RPL models estimate the mean parameter b and their density θ by maximizing the probability function as in Equation (3.36). This is one advantage of the RPL model because it can provide an individual parameter for each respondent; RPLs can accommodate the assumption that each individual has a different preference about some attributes. For reference, the number of initiations of the random draws is 1,000 which Bhat (2001) mentions as an appropriate value even though Train recommends several hundred times (Greene, 2012, p. N-552).

6.4.1 Estimation of Two Random Parameter Logit Models

Table 6.9 shows the estimation of the RPL 1 and RPL 2 models. With respect to the RPL 1 model, the coefficients of the three attributes (safety, taste and odour, cost) are significant at the 99% significance level but the coefficient of colour is insignificant. This result implies that colour is the attribute for which people's average preference is near zero. The signs for safety and cost are negative, and the one of taste and odour is positive. It is also important to look into the standard deviation of the random parameters in RPL models. The three coefficients of the standard deviations are significant at the 99% significance level. This result suggests that each respondent has a different preference about the three attributes.

Regarding the socio-economic factors, the ASCs are chosen when their coefficients are significant at least in one option at the 95% significance level. The coefficients of elderly, bill and environ are significant and show the same signs as in the MNL models. The coefficients of the three dummies of hypothetical bias treatments are negative and significant at the 99% significance level in the two advanced options.

Table 6. 9 *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)
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)	-1.0791 (0.0000)	-0.6511 (0.0000)
$D_{both} \cdot x4$	-	-0.2343 (0.0145)
$D_{cheap} \cdot x4$	-	-0.2730 (0.0027)
$D_{honest} \cdot x4$	-	-0.6582 (0.0000)
ASC Of Ozone	-1.1352 (0.1927)	-2.2388 (0.0092)
Elderly	-0.6303 (0.0224)	-0.6712 (0.0111)
Bill	0.0385 (0.0185)	0.0397 (0.0096)
Environ	0.6553 (0.0000)	0.6113 (0.0000)
Fulltime		-0.4936 (0.0488)
D_{both}	-2.1771 (0.0000)	-
D_{cheap}	-1.8695 (0.0000)	-
D_{honest}	-2.5258 (0.0000)	-
ASC Of GAC	1.7204 (0.0053)	0.5395 (0.3684)
Elderly	-0.5236 (0.0075)	-0.4764 (0.0112)
Bill	0.0137 (0.2999)	0.0138 (0.2414)
Environ	0.2205 (0.0292)	0.2241 (0.0277)
Fulltime	-	-0.4086 (0.0273)
D_{both}	-1.1580 (0.0000)	-
D_{cheap}	-2.2261 (0.0000)	-
D_{honest}	-1.6462 (0.0000)	-
Sample size	406	406
Log Likelihood	-2655.96	-2692.9
AIC	5353.9	5425.8
BIC	5438.1	5487.9
Pseudo R^2_{adj}	0.2533	0.2430

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

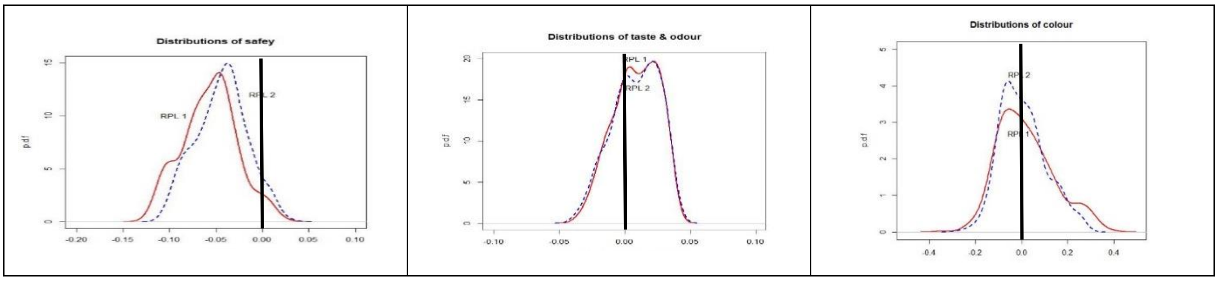
The negative signs of the coefficients reduced the level of utility of the two advanced options. This result implies that all treatments of hypothetical bias are successful in reducing hypothetical bias. The RPL 2 model uses interaction terms of hypothetical bias treatments. The coefficients of the four attribute variables show the expected direction of signs and are significant at the 99% significance level, but the one for colour is insignificant. All three random parameters show significant coefficients for standard deviations at the 99% significance level. This result implies that the three random parameters have significant variations, which may mean that the respondents have different marginal utilities for the attributes. The coefficients of the interaction terms of the hypothetical bias treatments ($D_{both} \cdot x4$, $D_{cheap} \cdot x4$, $D_{honest} \cdot x4$) are negative and significant at the 99% significance level, which suggests that the hypothetical bias treatments reduce the willingness to pays for improvement of the attributes. Among them, the coefficient of $D_{honest} \cdot x4$ has the largest value. This result predicts that the honest priming task might influence the slope of cost.

Regarding the socio-economic factors, the RPL 2 model uses four (elderly, fulltime, bill and environ). Other socio-economic factors are not significant so they are not included. The coefficients of elderly and fulltime are significant at the 95% significance level and negative in both options. This result implies that the factor negatively influences respondents' choice of two alternatives compared to the status quo option. That is, the respondents who live with more elderly people and have a full-time job prefer the status quo. The coefficient of the bill variable is significant at the 95% significance level and positive only for the ozone plus GAC option. This result suggests that people who consume more drinking water are likely to prefer the Ozone plus GAC option. The coefficient of environ is significant and positive at the 95% significance level in both options, which means that the people who are more interested in environmentally -friendly policies are more likely to choose the two advanced alternatives. With respect to the goodness of fit, the RPL 1 model shows lower log-likelihood and higher AIC, BIC, and pseudo R^2 than the RPL 2 model.

6.4.2 Distributions of the Coefficients of the Three Generic Attributes

In this research, one type of distribution for the three generic attributes is tested in the two RPL models. It uses the normal distribution, as discussed in Section 6.4. Figure 6.2 shows the distributions of the individual coefficients of the three attributes for the two RPL models.

Figure 6. 2 *Distributions of the individual random parameters of the three attributes*



The figures show the kernel density of the distributions of the three attributes for the two RPL models. The distributions of the three attributes are assumed to be normal. The two RPL models show similar shapes for the distributions. With respect to the safety attribute, the distribution shows that minus area is larger than the plus area. This result suggests that more people are likely to find more utility when the probability of cancer risk decreases. The estimated distribution of the taste and odour attribute shows that the plus area is larger than the minus. This result implies that more people find more utility when the taste and odour attribute improves. In particular, the distribution of the colour attribute is symmetric for the two parts. With this result, it would be difficult to assert that the mean of the coefficient of the attribute is not zero. In the same vein, the coefficients of the colour are not significant, as discussed earlier. However, the coefficient of the standard deviation of the coefficient of colour is significant. This result implies that the density of the individual coefficients is distributed. In other words, some people would like the improvement of the colour attribute and others would not. On the other hand, when the coefficient of the standard deviation is not significant, it would be difficult to assert that people have different preferences. In this case, everyone has a similar preference. If the coefficient of the attribute and the coefficient of the standard deviation are insignificant in RPL models, then it is possible to assert that everyone ignores the attribute.

6.5 Estimation of Latent Class Logit Models

This section explores two types of latent class models: full attribute attendance (FAA) LCMs and attribute non-attendance (ANA) LCM (Hensher et al., 2015). Four LCMs are analysed to detect the effectiveness of the treatments for moderating hypothetical bias. FAA 1 and ANA 1 use the dummies of hypothetical bias treatments as ASCs and FAA 2 and ANA 2 introduce the interaction terms between the dummies of hypothetical bias treatments and the cost variable.

6.5.1 Utility Function Forms of LCMs

Before starting the estimation of the LCMs, it is useful to identify the difference between the FAA and ANA models. An FAA model can be expressed as below,

$$U_{ij|1} = \alpha_{j|1} + \beta_{safe|1}X_{safe} + \beta_{t\&o|1}X_{t\&o} + \beta_{col|1}X_{col} + \beta_{p|1}X_p + \gamma_{mj|1}Z_m + \varepsilon_{ij|1}$$

$$U_{ij|2} = \alpha_{j|2} + \beta_{safe|2}X_{safe} + \beta_{t\&o|2}X_{t\&o} + \beta_{col|2}X_{col} + \beta_{p|2}X_p + \gamma_{mj|2}Z_m + \varepsilon_{ij|2}$$

$$\vdots$$

$$U_{ij|c} = \alpha_{j|c} + \beta_{safe|c}X_{safe} + \beta_{t\&o|c}X_{t\&o} + \beta_{col|c}X_{col} + \beta_{p|c}X_p + \gamma_{mj|c}Z_m + \varepsilon_{ij|c}$$

(6.15).

Here, $\gamma_{mj|c}$ stand for the coefficients of the individual specific variables, and c stands for class. The coefficients in Equation (6.15) have different values because the people in the different classes are assumed to have different preferences. The FAA models estimate the coefficients by maximizing the log-likelihood of the model. Thus, the FAA models might presume that the coefficients have zero estimations but this would be rare.

In addition, it is important to establish how to decide on the optimal number of classes. As discussed in Section 3.9, BIC values are used for choosing the number of classes of the FAA models. Table 6.10 shows the BICs of the four models from two classes to nine.

Table 6. 10 *BICs with three statistics of the 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

For reference, the AIC, log-likelihood function and pseudo -R squared of each model are presented together. To test the BIC values, the FAA 1 model uses four variables (one, D_{both}, D_{cheap}, D_{honest}) for the ASCs, because the dummies of the hypothetical bias treatment show the significant results in the MNL and RPL models. The FAA 2 uses one variable for the ASCs because it has already included the dummies in the interaction terms. The FAA 1 shows the lowest BIC value in a five -class model. The FAA 2 shows the lowest BIC in a four -class model.

As discussed in Section 3.6, the ANA problem can be applied in logit models. In this research, the ANA problem is explored in the LCMs[17]. The utility forms of the ANA models can be set by imposing constraints on the parameters. Assuming the three attributes except cost are zero, an ANA model can have eight latent classes. However, approximately, 10% of the respondents answered that they ignored the cost. Thus, to accommodate the attribute non-attendance of the cost attribute, the last case is added; all generic coefficients including the cost attribute are assumed to be zero as below,

$$U_{ij|1} = \alpha_{j|1} + \beta_{safe|1}X_{safe} + \beta_{t\&o|1}X_{t\&o} + \beta_{col|1}X_{col} + \beta_{p|1}X_p + \gamma_{mj|1}Z_m + \varepsilon_{ij|1}$$

$$U_{ij|2} = \alpha_{j|2} + \beta_{safe|2}X_{safe} + \beta_{t\&o|2}X_{tando} + 0 \cdot X_{col} + \beta_{p|2}X_p + \gamma_{mj|2}Z_m + \varepsilon_{ij|2}$$

$$U_{ij|3} = \alpha_{j|3} + \beta_{safe|3}X_{safe} + 0 \cdot X_{t\&o} + \beta_{col|3}X_{col} + \beta_{p|3}X_p + \gamma_{mj|3}Z_m + \varepsilon_{ij|3}$$

$$U_{ij|4} = \alpha_{j|4} + 0 \cdot X_{safe} + \beta_{t\&o|4}X_{t\&o} + \beta_{col|4}X_{col} + \beta_{p|4}X_p + \gamma_{mj|4}Z_m + \varepsilon_{ij|4}$$

$$U_{ij|5} = \alpha_{j|5} + \beta_{safe|5}X_{safe} + 0 \cdot X_{t\&o} + 0 \cdot X_{col} + \beta_{p|5}X_p + \gamma_{mj|5}Z_m + \varepsilon_{ij|5}$$

$$U_{ij|6} = \alpha_{j|6} + 0 \cdot X_{safe} + \beta_{t\&o|6}X_{t\&o} + 0 \cdot X_{col} + \beta_{p|6}X_p + \gamma_{mj|6}Z_m + \varepsilon_{ij|6}$$

$$U_{ij|7} = \alpha_{j|7} + 0 \cdot X_{safe} + 0 \cdot X_{t\&o} + \beta_{col|7}X_{col} + \beta_{p|7}X_p + \gamma_{mj|7}Z_m + \varepsilon_{ij|7}$$

[17]This research chooses the LCMs for the ANA problem even though ANA with MNL and RPL could be used. The LCMs are well -suited for the ANA problem and can identify classes of people who ignore a specific attribute. In the LCMs, it is not necessary to identify which attribute is not important to specific classes of people. The estimates of the LCMs reveal which coefficient of attribute is equal to zero or not in each class.

$$U_{ij|8} = \alpha_{j|8} + 0 \cdot X_{safe} \quad + 0 \cdot X_{t\&o} \quad + 0 \cdot X_{col} \quad + \beta_{p|8} X_p + \gamma_{mj|8} Z_m + \varepsilon_{ij|8}$$

$$U_{ij|9} = \alpha_{j|9} + 0 \cdot X_{safe} \quad + 0 \cdot X_{t\&o} \quad + 0 \cdot X_{col} \quad + 0 \cdot X_p \ + \gamma_{mj|9} Z_m + \varepsilon_{ij|9}$$

(6.16).

Equation (6.16) shows the different estimations for the coefficients in each class. The coefficients can be assumed to have a different parameter of each class or the same. An ANA model using the nine latent classes is used for analysis. However, some combinations of choice of some latent classes among them may reveal lower BIC values. Equation (6.10) can be used for a starting point to obtain a combination of the utility functions. Therefore, how to choose the best combination of utility functions is important. When establishing the form of the utility function by choosing some latent classes from the nine, the FAA models suggests establishing of the combinations. In this research, after exploring the FAA models, the ANA models will follow the establishment of the utility function form.

6.5.2 Full Attribute Attendance Latent Class Logit Models

This subsection will discuss two FAA models; FAA 1 used the dummies of the treatments for mitigating hypothetical bias as the ASCs, and FAA 2 uses three interaction terms between the dummies of hypothetical bias treatments and the cost variable. As shown in Table 6.8, the FAA of using the ASCs of HB with five classes shows the lowest BIC value. Therefore, the FAA 1 model uses five latent classes. When a socio-economic factor is significant at the 95% significance level in one or more class, it is included in the ASCs. Three factors are added: elderly, bill and environ. Table 6.11 shows the estimation of the coefficients of the FAA 1.

In Class 1, the coefficients of the four generic variables are significant at the 95% significance level. The coefficients of the safety and cost variables show a negative sign, and those of the taste and odour and colour variables show a positive sign, as expected in Section 6.1.

Table 6. 11 *Estimation of the coefficients of the FAA 1*

variable	Class 1	Class 2	Class 3	Class 4	Class 5
x1 (safety)	-0.0184 (0.0117)	-0.0536 (0.0001)	-0.0458 (0.0007)	-0.1050 (0.0000)	-0.0514 (0.0000)
x2 (t&o)	0.0174 (0.0005)	-0.0034 (0.4803)	-0.0120 (0.1405)	0.0071 (0.0302)	0.0161 (0.0000)
x3 (colour)	0.1323 (0.0000)	0.0140 (0.7186)	-0.1442 (0.0524)	-0.0490 (0.0761)	-0.0200 (0.3450)
X4 (cost)	-0.2978 (0.0323)	-1.0350 (0.0000)	-5.9996 (0.0000)	-0.7333 (0.0000)	-1.0946 (0.0000)
of Ozone, one	12.4173 (0.0749)	-9.4206 (0.0329)	-9.1435 (0.1995)	7.4132 (0.0001)	-2.7721 (0.0091)
Elderly	4.8736 (0.3190)	4.2605 (0.0055)	-0.7546 (0.5117)	-1.3352 (0.0016)	0.2247 (0.5416)
Bill	-0.1473 (0.0001)	-0.0510 (0.5588)	0.7065 (0.0000)	-0.1132 (0.0009)	0.0995 (0.0001)
environ	-1.4603 (0.1325)	1.2179 (0.0488)	1.7724 (0.0948)	0.0133 (0.9294)	0.7072 (0.0000)
D_{both}	-0.1192 (0.8737)	-3.6880 (0.0235)	-10.6261 (0.1269)	-7.4898 (0.0000)	-0.9470 (0.0862)
D_{cheap}	4.4445 (0.4152)	-5.6024 (0.0115)	2.6389 (0.2827)	-6.7878 (0.0000)	-0.7129 (0.1896)
D_{honest}	1.1198 (0.7615)	1.2622 (0.3493)	-1.1561 (0.6264)	-5.6710 (0.0000)	-1.9741 (0.0000)
of GAC, one	13.4911 (0.0500)	-0.3357 (0.7962)	4.6751 (0.0621)	6.6650 (0.0002)	-0.2940 (0.7000)
Elderly	5.1313 (0.2939)	-1.4085 (0.0027)	-0.7422 (0.2028)	-0.7727 (0.0506)	-0.1183 (0.7006)
Bill	-0.0985 (0.0074)	0.0993 (0.0005)	0.3844 (0.0000)	-0.1298 (0.0005)	0.0208 (0.3738)
environ	-1.7992 (0.0618)	-0.0472 (0.7924)	0.2141 (0.5380)	0.0601 (0.7108)	0.6069 (0.0000)
D_{both}	0.8349 (0.2624)	-0.5833 (0.3336)	-2.6318 (0.0218)	-5.8378 (0.0003)	-0.6680 (0.1279)
D_{cheap}	4.4646 (0.4136)	-0.8021 (0.1389)	-3.8261 (0.0017)	-7.2870 (0.0000)	-1.4785 (0.0007)
D_{honest}	2.3862 (0.5152)	-1.0909 (0.0630)	-2.3386 (0.0232)	-5.6070 (0.0000)	-2.4787 (0.0000)
Class probability	0.196 (0.0000)	0.118 (0.0000)	0.157 (0.0000)	0.192 (0.0000)	0.336 (0.0000)
Sample size; 406, BIC; 5408.2, Log-likelihood; -2421.8, AIC; 5031.6, Pseudo-R^2; 0.3113					

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

With respect to the socioeconomic factors, only the coefficient of bill is significant in both options. This result implies that people who pay more in monthly water -bills prefer the two advanced options in Class 1. The ASCs of hypothetical bias are not significant. As a result, assume that people who cared about the four attributes and are sensitive to the water -bills can be included in Class 1. The size of the first class is estimated at 80 people.

In the second class, the coefficients of the safety and cost variables are negative and significant at the 99 % significance level. The respondents of Class 2 do not care about the taste and odour and colour attributes. Regarding the socioeconomic factors, the coefficient of the elderly variable is significant in both advanced option at the 99 % significance level. The sign of the coefficient is positive for the ozone plus GAC option and negative for the GAC option. This result suggests that the respondents who live with more elderly people are more likely to prefer the ozone plus GAC option and to dislike the GAC option compared to the status quo option. The coefficient of the bill variable is positive and significant in the GAC option at the 99% significance level, which suggests that people who pay more in monthly water -bills prefer the GAC option over the other two options. The coefficient of the environ variable is positive and significant for the ozone plus GAC option at the 95% significance level. This result implies that people who are interested in environmentally -friendly policies prefer the ozone plus GAC option. Among the ASCs of the hypothetical bias treatments, the coefficients of D_{both} and D_{cheap} are negative and significant for the Ozone plus GAC option at a 95% significance level. This result means that the two treatments, cheap talk plus honest priming task and cheap talk alone, are successful in influencing the respondents to find less utility from the two advanced water systems and make them more likely to prefer the status quo. Thus, the respondents who cared about the safety and cost attributes, and are sensitive to the elderly, bill, environ, both, and cheap talk can be included in this class. The size of this class is estimated at 48.

In the third class, the coefficients of safety and cost are negative and significant at the 99% significance level. Among the socioeconomic factors, the coefficient of the bill variable is positive and significant at the 99% significance level in the both advanced options. Therefore, one can say that the respondents who pay more in monthly water -bills prefer the two advanced options. The coefficients of the hypothetical bias treatments are negative and significant at the 95% significance level in the GAC option, which suggests that the treatments for mitigating hypothetical bias influenced the decisions of people who choose the GAC option. Therefore, the respondents who are interested in safety and cost, and influenced by the bill and the three treatments of hypothetical bias can be included in Class 3. The size of the third class is estimated at 64.

In Class 4, the coefficients of safety and cost are negative and significant at the 99% significance level. The coefficient of taste and odour is positive and significant at the 95% significance level. Regarding the socioeconomic factors, the coefficient of the elderly variable is negative and significant at the 99% significance level for the ozone plus GAC option. This result suggests that the respondents who live with more elderly people are more likely to prefer the ozone plus GAC option. The coefficient of bill is negative and significant at the 99% significance level for the two advanced options. Unlike the previous outcome, this result implies that the respondents who pay more in monthly water -bills prefer the status quo option. The coefficients of the hypothetical bias are negative and significant at the 99% significance level, which means that the three treatments for moderating the hypothetical bias are likely to reduce it. As a result, this class includes the respondents who cared about the safety, taste and odour, and cost attributes, and are sensitive to the elderly variable and the treatments of hypothetical bias. In particular, people who are negatively influenced by the bill attribute are more likely to be included in this class. The size of the fourth class is estimated at 78.

In the last class, the coefficients of safety and cost are negative and significant at the 99% significance level, and the coefficient of taste and odour is positive and significant at the 99% significance level, as presumed earlier. Among the socioeconomic factors, the coefficient of the bill is positive and significant at the 99% significance level for the ozone plus GAC option. This result suggests that the respondents who pay more in monthly water -bills prefer the ozone plus GAC option. The coefficient of environ is positive and significant at the 99% significance level for the two advanced level, which means that the respondents who prefer the environment-friendly policies are more likely to have utility in the two advanced options. The coefficient of the dummy of the cheap talk treatment is negative and significant at the 99% significance level just for the ozone plus GAC option and the coefficient of the dummy of the honest priming task is negative and significant at the 99% significance level for the two advanced options. Therefore, the respondents who care about the safety, taste and odour, and cost attributes, and are sensitive to the water -bills, environmentally -friendly policies are likely to be included in Class 5. The size of the last class is estimated at 136.

From the estimation of the class probabilities, the most respondents (33.6%) are included in Class 5 and they seem to ignore the colour attribute in drinking water quality. In the case of the safety attribute, the coefficient is significant in all five classes. This result implies that every respondent would accept paying to improve the safety attribute. About 72.4% of the respondents who are included in Classes 1, 4 and 5 expresses a willingness to pay to improve the taste and odour attribute because the coefficients of the attribute in the three classes are significant. The coefficient of the colour attribute is significant only in Class 1. Thus, 19.6% of the respondents has the WTP to improve the colour attribute. With respect to the goodness of fit, the pseudo R^2 is 0.3113. From the result, one can say that most respondent ignored the colour attribute.

As shown in Table 6.10, four -class FAA using interaction terms shows the lowest BIC value, so the FAA 2 model with four classes will be explored. Table 6.12 shows the estimation of the FAA 2 model with four added socio-economic factors (elderly, earner, head, and environ) because they show significant coefficients in at least one class. Therefore, the socio-economic factors can be insignificant in some classes.

Table 6. 12 *Estimation of the coefficients of the FAA 2*

variable	Class 1	Class 2	Class 3	Class 4
x1 (safety)	-0.0964 (0.0000)	-0.0482 (0.0000)	-0.0442 (0.0000)	-0.0218 (0.0001)
x2 (t&o)	0.0091 (0.0291)	0.0141 (0.0000)	-0.0018 (0.6082)	0.0147 (0.0000)
x3 (colour)	-0.0227 (0.4829)	-0.0246 (0.2583)	-0.0106 (0.7077)	0.0954 (0.0000)
X4 (cost)	0.1031 (0.6279)	-0.3401 (0.0191)	-1.5445 (0.0000)	-0.6073 (0.0000)
D_{both}·X4	-0.1525 (0.4871)	-1.3588 (0.0000)	0.3822 (0.0478)	0.3197 (0.0144)
D_{cheap}·X4	-0.7850 (0.0001)	-0.1374 (0.2983)	-2.3754 (0.0000)	-1.4674 (0.0000)
D_{honest}·X4	-0.6763 (0.0009)	-1.5783 (0.0000)	-0.7179 (0.0113)	0.3129 (0.0000)
of Ozone, one	0.4781 (0.6877)	-2.2845 (0.0484)	-2.5102 (0.3613)	-9.8807 (0.0000)
Elderly	8.0349 (0.7128)	-2.3780 (0.0000)	0.7472 (0.0555)	0.9466 (0.1099)
Earner	-0.4316 (0.0707)	-0.9037 (0.0013)	0.9851 (0.0055)	-0.2550 (0.3012)
Head	-0.7559 (0.0521)	-0.6760 (0.0721)	-6.1543 (0.8263)	-2.0134 (0.0000)
Environ	-0.0031 (0.9832)	1.1324 (0.0000)	0.1185 (0.7924)	2.1698 (0.0000)
of GAC, one	-0.9627 (0.4129)	0.8429 (0.4083)	2.9662 (0.0005)	-5.3093 (0.0000)
Elderly	9.2546 (0.6716)	-2.8907 (0.0000)	0.1618 (0.4730)	0.9179 (0.1090)
Earner	0.3179 (0.2324)	-1.5882 (0.0000)	0.4599 (0.0014)	-0.3078 (0.1480)
Head	0.6471 (0.1367)	-1.1585 (0.0011)	0.8784 (0.0002)	-2.1542 (0.0000)
Environ	-0.1525 (0.3259)	0.7657 (0.0000)	-0.3680 (0.0077)	1.6120 (0.0000)
Class probability	0.175 (0.0000)	0.276 (0.0000)	0.257 (0.0000)	0.292 (0.0000)
Sample size; 406, BIC; 5420.8, Log-likelihood; -2497.2, AIC; 5136.3, Pseudo-R^2 ; 0.2924				

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

In the first class, the coefficients of the safety, and taste and odour attributes are significant at the 99% significance level, but the coefficients of colour and cost are insignificant. The coefficient of safety is negative and the one of taste and odour is positive. The coefficients of the three interaction terms and the cost variable are all negative. However, the coefficients of two interaction terms, $D_{cheap} \cdot x4$ and $D_{honest} \cdot x4$ are significant at the 99% significance level, which suggests that the respondents who are asked to answer the test for the treatments of hypothetical bias are affected by the decisions they made in choosing the preferred options in the choice cards. The four socio-economic factors are not significant in this class. This result may occur because some socio-economic factors are insignificant in one or more classes, as mentioned above. Therefore, the people who care about the safety and taste and odour and are influenced by the treatments of the hypothetical bias can be included in this class. The size of Class 1 is estimated at 71.

In the second class, the coefficient of safety is negative and the one of taste and odour is positive. They are all significant at the 99% significance level. The coefficient of cost is negative and significant at the 95% significance level. The coefficients of two interaction terms, $D_{both} \cdot x4$ and $D_{honest} \cdot x4$, are negative and significant at the 99% significance level. Among the socio-economic factors, the coefficients of elderly and earner are negative and significant at the 99% significance level in both advanced options. This result means that the respondents in this class who live with more elderly people and earners prefer the status quo. The coefficient of the head of household is negative and significant at the 99% significance level only in the GAC option. This result implies that respondent who are heads of household are likely to prefer the GAC option. The coefficient of environ is positive and significant at the 99% significance level. This result suggests that the people who are more interested in environmentally -friendly policies prefer the two advanced alternatives over the status quo. Therefore, the respondents who care about the safety, taste and odour and cost and are influenced by the honest priming task treatment are likely to be included in this class. The size of Class 2 is estimated at 112.

In the third class, the coefficients of the safety and cost variables are negative and significant at the 99% significance level, and the others are insignificant. This result implies that the respondents in this class are more likely to prefer the improvement in safety quality of drinking water. The coefficients of the interaction terms of hypothetical bias are significant at the 95% significance level or higher. However, the coefficients of the interaction terms of

$D_{cheap} \cdot x4$ and $D_{honest} \cdot x4$ show negative signs but the coefficient of the interaction term of $D_{both} \cdot x4$ shows a positive sign. Among the socio-economic factors, the coefficient of earner is positive and significant at the 99% significance level in the two advanced options. This result suggests that the respondents who live with more earners are more likely to prefer the two advanced options. The coefficient of the head of household variable is positive and significant at the 99% significance level in the GAC option. This result implies that if the respondents are the head of their household, they would likely prefer the GAC alternative. The coefficient of the environ variable is negative and significant at the 99% significance level, which suggests that the people who are more interested in environmentally -friendly policies would dislike the GAC option. Thus, the respondents who care about the safety attribute are more likely to be included in this class. The size of Class 3 is estimated at 104.

In the fourth class, the coefficients of the four generic attributes are all significant at the 99% significance level, and show the expected signs. The coefficients of the interaction terms of the hypothetical bias are significant at the 95% significance level or higher, and the coefficient of D_{cheap} shows a negative sign but the coefficients of D_{both} and D_{honest} show positive signs. Among the socioeconomic factors, the coefficient of head of household is negative and significant at the 99% significance level in the two advanced options. This result implies that if the respondents are heads of their household, they would likely prefer the status quo. The coefficient of the environ variable is positive and significant at the 99% significance level in the two advanced options, which suggests that the people who are more interested in environmentally -friendly policies would like to prefer the two advanced options. Hence, the respondent of Class 4 who care about the safety, taste and odour, and cost attributes are the head of the household and (or) do not prefer environmentally -friendly policies. The size of Class 4 is estimated at 119.

From the estimation of the class probabilities, the most respondents (29.2%) are included in Class 4 and they seem to care about the four generic attributes in drinking water quality. In the case of the safety attribute, the coefficient is significant in all four classes. This result might mean that every respondent would pay to improve the safety attribute. About 72.4% of the respondents included in Classes 1, 2 and 4 seems to have the willingness to pay to improve the taste and odour attribute because the coefficients of the attribute in the classes are significant. The coefficient of the colour attribute is significant in only Class 4. Thus, about 29.2% of the respondents has the WTP to improve the colour attribute. With respect to the goodness of fit, the FAA 2 model shows 0.2924 for the pseudo-R^2.

6.5.3 Attribute Non-Attendance LCMs Using the ASCs of Hypothetical Bias

This subsection will explore latent class models of the attribute non-attendance. The ANA models use the utility function form as expressed in Equation (6.16). However, it is necessary to choose the best combination of the utility function forms from Equation (6.16). In this research, the FAA 1 model is used in setting the utility function forms. The ANA 1 is derived from the FAA 1 model. The attribute non-attendance attributes are inferred in the FAA 1 model. As shown in Table 6.12, the FAA 1 model shows some insignificant coefficients for the generic variables. In the first class of the FAA 1, the coefficients of the four generic variables are significant at the 95% significance level. In the second and third classes, the coefficients of the safety and cost variables are significant at the 95% significance level. In the fourth and fifth classes, the coefficients of the safety, taste and odour, and cost are significant at the 95% significance level. Therefore, the utility functions can be expressed as follows,

$$U_{ij|1} = \alpha_{j|1} + \beta_{safe|1}X_{safe} + \beta_{t\&o|1}X_{t\&o} + \beta_{col|1}X_{col} + \beta_{p|1}X_p + \gamma_{mj|1}Z_m + \theta_{m|1} \cdot D_m + \varepsilon_{ij|1}$$

$$U_{ij|2} = \alpha_{j|2} + \beta_{safe|2}X_{safe} + 0 \cdot X_{t\&o} + 0 \cdot X_{col} + \beta_{p|2}X_p + \gamma_{mj|2}Z_m + \theta_{m|2} \cdot D_m + \varepsilon_{ij|2}$$

$$U_{ij|3} = \alpha_{j|3} + \beta_{safe|3}X_{safe} + 0 \cdot X_{t\&o} \quad + 0 \cdot X_{col} \quad + \beta_{p|3}X_p + \gamma_{mj|3}Z_m + \theta_{m|3} \cdot D_m + \varepsilon_{ij|3}$$

$$U_{ij|4} = \alpha_{j|4} + \beta_{safe|4}X_{safe} + \beta_{t\&o|4}X_{t\&o} + 0 \cdot X_{col} \quad + \beta_{p|4}X_p + \gamma_{mj|4}Z_m + \theta_{m|4} \cdot D_m + \varepsilon_{ij|4}$$

$$U_{ij|5} = \alpha_{j|5} + \beta_{safe|5}X_{safe} + \beta_{t\&o|5}X_{t\&o} + 0 \cdot X_{col} \quad + \beta_{p|5}X_p + \gamma_{mj|5}Z_m + \theta_{m|5} \cdot D_m + \varepsilon_{ij|5}$$

(6.17).

Here, D_m is a vector of the dummies of hypothetical bias, θ_m is a vector of the dummies for mitigating hypothetical bias. Each class in the ANA model display a different estimation for the coefficients of the variables because they are assumed to have different values. Also, some coefficients of the generic variables are set to zero because they are insignificant in the FAA 1. In particular, the utility functions of Classes 2 and 3 show the same structure, and also those of Classes 4 and 5 do. However, the coefficient of each class is assumed to have different values so they would give rise to displaying different values. In addition, the ANA 1 model uses four ASCs, gender, elderly, bill and environ, because they are significant at the 95% significance level in one or more option. Other socio-economic factors are insignificant so they are not used for the ASCs.

Table 6.13 shows the estimation of the coefficients of the ANA 1. In the first class, the coefficient of the safety attribute is insignificant. The coefficients of the other generic attributes are significant at the 95 % significance level. The taste and odour and colour attributes show positive coefficients and the cost variable show a negative one. There is no significant coefficient of the socio-economic factors. Among the dummies of the hypothetical bias treatments, the coefficient of $D_{both} \cdot x4$ is negative and significant in the ozone plus GAC option at the 95% significance level. This result suggests that the respondents who answer the questionnaire with the two treatments (cheap talk and honest priming task) would be affected by the treatments of the hypothetical bias. The sample size of this class is estimated at 75.

Table 6. 13 *Estimation of the coefficients of the ANA 1 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)	-1.8581 (0.0000)	-0.4291 (0.0084)	-1.2237 (0.0000)
of Ozone, one	3.9368 (0.4143)	-10.3007 (0.0001)	-18.6362 (0.2240)	1.6704 (0.5182)	-2.4698 (0.0445)
Elderly	-1.5635 (0.1843)	-0.8538 (0.1485)	-5.6905 (0.9938)	8.1582 (0.9840)	-0.1390 (0.7508)
Bill	-0.0546 (0.3322)	-0.1164 (0.0432)	0.3009 (0.0442)	0.1269 (0.0093)	0.0249 (0.2348)
Environ	0.0982 (0.8803)	2.6911 (0.0000)	2.4889 (0.2331)	0.0109 (0.9686)	0.7965 (0.0003)
D_{both}	-3.6684 (0.0472)	-4.2468 (0.0000)	-8.6509 (0.9438)	-1.9746 (0.2125)	-1.6949 (0.0136)
D_{cheap}	4.3111 (0.9981)	-2.1275 (0.0303)	-8.3258 (0.9792)	-5.2732 (0.0014)	-1.0262 (0.1561)
D_{honest}	5.2144 (0.9988)	-4.4826 (0.0000)	0.0695 (0.9661)	-4.9345 (0.0023)	-2.6401 (0.0000)
of GAC, one	4.5498 (0.3429)	-0.9715 (0.5377)	2.6276 (0.0002)	2.5140 (0.3604)	-0.6299 (0.6164)
Elderly	-0.4004 (0.7747)	-1.4895 (0.0001)	-0.5352 (0.0751)	8.0302 (0.9842)	-0.5649 (0.0825)
Bill	-0.0086 (0.8787)	-0.1341 (0.0018)	0.1134 (0.0000)	0.1071 (0.0359)	-0.0386 (0.1066)
Environ	-0.2475 (0.7083)	1.1416 (0.0000)	-0.2641 (0.0455)	-0.0863 (0.7796)	0.8243 (0.0003)
D_{both}	-1.8130 (0.3076)	-3.5534 (0.0000)	-0.6633 (0.0817)	-1.7025 (0.2631)	-1.3913 (0.0233)
D_{cheap}	4.7046 (0.9979)	-2.2884 (0.0000)	-1.4024 (0.0000)	-5.6954 (0.0005)	-1.8048 (0.0091)
D_{honest}	6.8215 (0.9984)	-3.1666 (0.0000)	0.2009 (0.6191)	-4.5187 (0.0051)	-3.1014 (0.0000)
Class probability	0.185 (0.0000)	0.167 (0.0000)	0.220 (0.0000)	0.181 (0.0000)	0.247 (0.0000)
Sample size; 406, Log-likelihood; -2439.1, AIC; 5054.2, BIC; 5406.7, Pseudo-R^2 ; 0.3071					

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

In the second class, the coefficients of taste and odour and colour are set to zero. The coefficients of safety and cost are negative and significant at the 99% significance level. Regarding the socio-economic factors, the coefficient of elderly is negative and significant in the GAC option at the 99% significance level, which implies that the respondents who live with more elderly people in their house are likely to dislike the GAC option. The coefficient of bill is negative and significant in the two advanced options at the 95% significance level.

This result means that the respondents who pay more monthly water -bills are likely to prefer the status quo option. The coefficient of environ is positive and significant in the two advanced options at the 99% significance level. This result implies that the respondent supporting environmentally -friendly policies would prefer the two advanced options. The coefficients of the hypothetical bias treatments are all negative and significant in the two advanced options at the 95% significance level. This result suggests that all treatments for hypothetical bias might influence the respondents to find less utility in the two advanced water systems versus the status quo and make them more likely to choose the status quo option. The sample size of Class 2 is estimated at 68.

In the third class, the coefficients of taste and odour and colour are also set to zero as in Class 2. The coefficients of safety and cost are negative and significant at the 99% significance level. Regarding the socio-economic factors, the coefficient of bill is positive and significant in the two advanced options at the 95% significance level, which means that the respondents who pay more in monthly waters -bills are likely to prefer the two advanced options. The coefficient of environ is negative and significant in the GAC option at the 95% significance level. This result implies that the respondents supporting environmentally -friendly policies are more likely to dislike the GAC option. With respect to the dummies of the hypothetical bias treatments, the coefficient of D_{cheap} is negative and significant in the GAC option at the 99% significance level. This result suggests that the respondents who answer the questionnaire with only the honest priming task are less likely to choose the GAC option. The size of the third class is estimated at 89.

In the fourth class, the coefficient of colour is set to zero. The coefficients of safety and cost are negative and significant at the 99% significance level but the one of taste and odour is insignificant. This result implies that the members of this class don’t want to pay to improve the colour attribute like Classes 2 and 3. In the case of socio-economic factors, the coefficient of bill is positive and significant in both advanced options at the 95% significance level. This result means that the respondents who pay more in monthly water -bills are likely to prefer the two advanced options. Among the hypothetical bias treatments, the coefficients of D_{cheap} and D_{honest} are negative and significant at the 99% significance level in both advanced options. This result suggests that when cheap talk and the honest priming task are used respectively, they might influence the respondents to find less utility for the two advanced options versus the status quo. The size of the fourth class is estimated at 73.

In the last class, the coefficient of colour is also set to zero. The coefficients of safety and cost are negative and significant at the 99% significance level. The coefficient of taste and odour is positive and significant at the 95% significance level. Unlike Class 3, the members of this class seem to pay to improve the colour attribute. Regarding the socio-economic factors, the coefficient of environ is positive and significant in both advanced options at the 99% significance level. This result means that the respondents supporting environmentally -friendly policies are likely to prefer the two advanced options. The coefficients of the hypothetical bias treatments are negative and significant at the 95% significance level in both advanced options except the one for D_{cheap} dummy in the ozone plus GAC option. This result suggests that the three treatments of hypothetical bias might influence the respondents to find less utility in the two advanced options versus the status quo option in their choice cards. The size of the last class is estimated at 100.

From the estimation of the class probabilities, the most respondents (24.7%) were included in Class 5 and they seem to ignore the colour attribute in drinking water quality. In the case of the safety attribute, the coefficient is significant in the four classes except Class 1. This result means that about 81.5% of the respondents would pay to improve the safety attribute in drinking water quality. The respondents included in Classes 1 and 5 seem to have the willingness to pay to improve the taste and odour attribute because the coefficient of the attribute is significant. Therefore, 40.1% of the respondent would have the WTP to improve the taste and odour attribute. The coefficient of the colour attribute is significant in Class 1 at the 99% significance level. Thus, about 18.5% of the respondents has the WTP to improve the colour attribute. With respect to the goodness of fit, the pseudo R^2 is 0.3115.

Going forward, the ANA 2 model will be explored, which uses the interaction terms between the dummies of hypothetical bias treatments and cost. Before starting, it is necessary to choose the best combination of utility function forms. As discussed above, the FAA 2 model is used in setting the utility function forms. The attribute non-attendance attributes of the ANA 2 are inferred in the FAA 2 model. As shown in Table 6.12, the FAA 2 model shows some insignificant coefficients of the generic variables. In the first class of the FAA 2, the coefficients of the safety and taste and odour variables are significant at the 95% significance level. The coefficients of the colour and cost are insignificant. Also, the coefficient of the interaction term of $D_{both} \cdot x4$ is insignificant. In the second class, the coefficients of colour and the interaction term of $D_{cheap} \cdot x4$ are insignificant at the 95% significance level. In the third class, the coefficients of taste and odour and colour are insignificant. In the fourth class, the coefficients of the four generic variables and the interaction terms of the hypothetical bias treatments are all significant at the 95% significance level or higher. In the case of the cost variable, its coefficient is insignificant in the first class. When the coefficient of the cost is zero, it is meaningless to calculate the willingness to pay. In this sense, the coefficient of cost won't be zero. An ANA model can be established as below,

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

$$U_{ij|3} = \alpha_{j|3} + \beta_{safe|3}X_{safe} + 0 \cdot X_{t\&o} \quad + 0 \cdot X_{col} \quad + \beta_{p|3}X_p + \theta_{1j|1}D_{both}X_p$$

$$+ \theta_{2j|1}D_{cheap}X_p + \theta_{3j|1}D_{honest}X_p + \gamma_{mj|3}Z_m + \varepsilon_{ij|3}$$

$$U_{ij|4} = \alpha_{j|4} + \beta_{safe|4}X_{safe} + \beta_{t\&o|4}X_{t\&o} + \beta_{col|4}X_{col} + \beta_{p|4}X_p + \theta_{1j|1}\,D_{both}X_p$$

$$+\theta_{2j|1}D_{cheap}X_p + \theta_{3j|1}D_{honest}X_p + \gamma_{mj|4}Z_m + \varepsilon_{ij|4}$$

(6.18).

Table 6.14 shows the estimation of the ANA 2 model which adds four socioeconomic factors (elderly, earner, head and environ) as the FAA 2 did.

Table 6. 14 *Estimation of the coefficients of the ANA 2*

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)
D_{both}·X4	0.0 (fixed)	-0.0157 (0.9041)	-0.4940 (0.0145)	0.1479 (0.3916)
D_{cheap}·X4	-1.9072 (0.0000)	0.0 (fixed)	-1.1236 (0.0000)	-1.1481 (0.0000)
D_{honest}·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 parenthesis represent P-values.

In Class 1, the coefficient of safety is negative and significant at the 99% significance level, but the coefficient of taste and odour attributes is insignificant even though it is not set to be zero. The coefficient of cost is significant at the 99% significance level unlike in the FAA 2. The coefficient of the interaction term of $D_{cheap} \cdot x4$ is significant at the 99% significance level, but the one of the interaction term of $D_{honest} \cdot x4$ is insignificant. With respect to the socio-economic factors, the coefficients of elderly and earner are positive and significant for the ozone plus GAC option at the 99 % significance level. This result implies that the respondents living with more elderly and earners would prefer the ozone plus GAC options. The coefficient of head of household is positive and significant for the GAC at the 95% significance level. This result suggests if a respondent is the head of household the person is likely to prefer the GAC. The coefficient of environ is negative and significant for the GAC. This result predicts that the respondents supporting environmentally -friendly policies would dislike the GAC. Thus, people who care about the safety and are influenced by the cheap talk are more likely to be included in this class. The size of Class 1 is estimated at 90.

In the second class, the coefficient of safety is negative and significant at the 99% significance level. The coefficient of taste and odour is positive and significant at the 99% significance level. However, the coefficient of cost is negative and significant at the 95% significance level. Only the coefficient of $D_{honest} \cdot x4$ is negative and significant at the 99% significance level. Among the socio-economic factors, the coefficient of elderly is positive and significant at the 99% significance level in the GAC option. This result implies that the respondents in this class who live with more elderly people and earners are likely to prefer the GAC option. Therefore, the respondents who care about the safety and taste and odour, and are influenced by the honest priming task treatment are likely to be included in this class. The size of Class 2 is estimated at 117.

In Class 3, the coefficients of the safety and cost variables are negative and significant at the 99% significance level. The coefficients of the interaction terms of the hypothetical bias treatments are negative and significant at the 95% significance level or higher. Among the socio-economic factors, the coefficients of elderly and head of household are negative and significant at the 99% significance level in the two advanced options. This result suggests that when the respondents live with more earners and (or) are heads of household, they are more likely to prefer the two advanced options. The coefficient of earner is positive and significant at the 95% significance level in the ozone plus GAC option. This result predicts that the respondents who live with more earners are likely to prefer the ozone plus GAC. The coefficient of environ is positive and significant at the 99% significance level in the two advanced options, which implies that the people supporting environmentally -friendly policies would prefer the two advanced options. Thus, the respondents who care about the safety attribute are likely to be included in this class. The size of Class 3 is estimated at 103.

In the fourth class, the coefficients of safety and cost are negative and significant at the 99% significance level. The coefficient of taste and odour is also positive and significant at the 99% significance level but the coefficient of colour is positive and significant at the 95% significance level. The coefficient of $D_{cheap} \cdot x4$ is negative and significant at the 99% significance level. Among the socio-economic factors, the coefficients of elderly and earner are negative and significant at the 95% significance level in the two advanced options. This result suggests that the respondents who live with more elderly people and earners are likely to prefer the two advanced options. Hence, the respondents of Class 4 care about the three sorts of drinking water quality. The size of Class 4 is estimated at 95.

From the estimation of the class probabilities, the most respondents (28.8%) are included in Class 2 and they seem to care about the two generic attributes in drinking water quality, safety and taste and odour. In the case of the safety attribute, the coefficient is significant in all four classes. This result predicts that every respondent would pay to improve the safety attribute. About 73.6% of the respondents who are included in Classes 1, 2 and 4 seems to have the willingness to pay to improve the taste and odour attribute because the coefficients of the attribute in the classes are significant. The coefficient of the colour attribute is significant only in Class 4. Thus, about 23.5% of the respondents has the WTP to improve the colour attribute. With respect to the goodness of fit, the ANA 2 model shows 0.2864 for the pseudo-R^2.

6.6 Marginal Willingness to Pay

This subsection will explore how to calculate the marginal wiliness to pay for the three types of logit models; MNL, RPL, and LCM. To calculate the MWTPs of the two MNL models, Equation (3.53) is used, as discussed in Section 3.8. The MWTPs of the two RPL models are computed by applying the individual coefficients to Equation (3.53). In the case of the three LCM models, the calculation of the MWTPs is more complicated.

When the interaction terms between the cost and the hypothetical bias treatments are used like in Equation (6.13), the MWTPs can be calculated by adding the interaction terms to the denominator of Equation (3.53) as followed,

$$\text{MWTP} = -\frac{\beta_j}{\beta_p+\theta_{both}\cdot D_{both}+\theta_{cheap}\cdot D_{cheap}+\theta_{honest}\cdot D_{honest}} \quad (6.19).$$

In Equation (6.19), β_j is the coefficient of an attribute, and θ_{both}, θ_{cheap}, and θ_{honest} are the three coefficients of the interaction terms between the cost and dummies of hypothetical bias treatments, and D_{both}, D_{cheap}, and D_{honest} are the dummies of the hypothetical bias treatments as discussed in the subsection 6.2.3. Equation (6.19) provides the MWTPs for the four models using the interaction term between the cost variable and dummies of hypothetical bias treatments; MNL2, RPL2, FAA2, and ANA2. As shown in Table 6.5, this study divided four blocks of the respondents and used the hypothetical bias treatments. Block 1 used both of them. Block 2 used cheap talks and Block 3 did honest priming task. Block 4 used none. When measuring the MWTPs, the coefficients of the hypothetical bias treatments were applied to each block. For example, in Block 4, the denominator of Equation (6.19) will be β_p because the three coefficients of hypothetical bias treatments $\theta_{both} \cdot D_{both}$, $\theta_{cheap} \cdot D_{cheap}$, and $\theta_{honest} \cdot D_{honest}$ are all zero so only β_p remains in denominator in the equation.

RPL and LCM provide individual estimates of coefficients as a result of analysis. Therefore, the models can apply Equation (6.19) to each of the respondents. For example, the MWTPs of the respondents in Block 1 can be calculated as below,

$$\mathrm{MWTP}_{\mathrm{Block1}} = -\frac{\beta_j}{\beta_p + \theta_{both} \cdot D_{both}} \qquad (6.20).$$

In Equation (6.20), $\theta_{cheap} \cdot D_{cheap}$, and $\theta_{honest} \cdot D_{honest}$ disappear because D_{cheap}, and D_{honest} are zeros in Block 1. In particular, the MNL 1 model provides one coefficient for each attribute. Therefore, the MWTPs of the MNL 1 model show the same values in each block. In this way, each MWTP of the respondents can be calculated. Using the individual MWTPs, MWTP spaces can be calculated, exactly 406 MWTPs for each attribute. From the MWTP spaces, it is possible to calculate the mean and median MWTP values.

In particular, the LCM models can show the personal estimations of each class and the individual specific probabilities of class membership. The MWTPs of each class are calculated by using Equation (3.53). In this step, it is important to look into the significance of each coefficient and the sign of the coefficient of the cost variable. When the coefficient of the cost variable is insignificant, it means that the respondent doesn't care about the cost. The interpretation should be made with caution in terms of economics. There may be two cases when the coefficient of cost is insignificant. One is when the coefficients of the generic variables are also insignificant, and the other is when the coefficients of other generic variables are significant. When the coefficients of all generic attributes including the cost are insignificant, one can say that the respondent had no willingness to pay to improve the attributes. In the second case, one can say that the people would pay for improvement of the other attributes because they can find more utility when the attributes are improved and also they don't care about the cost. In other words, people might follow others' decision and accept some additional cost. However, the values of WTPs for this case are set to zero when calculating the mean and median WTPs. The MWTP of each class is weighted by the individual specific probabilities of class membership. In this way, the individual MWTPs as a final product are computed. Using those individual MWTPs, the mean and median values of each MWTP can be calculated.

6.6.1 Mean Values of MWTP

So far, eight models have been explored. Table 6.15 shows the mean WTPs of each attribute of the models.

Table 6. 15 *Estimation of the* ***mean*** *MWTPs*

Model	MNL 1	MNL 2	RPL 1	RPL 2	FAA 1	FAA 2	ANA 1	ANA 2
Safety (USD)	0.0520 (0.044)	0.0485 (0.041)	0.0523 (0.045)	0.0491 (0.042)	0.0627 (0.053)	0.0521 (0.044)	0.0666 (0.057)	0.0974 (0.083)
Taste and odour (USD)	0.0069 (0.006)	0.0079 (0.007)	0.0082 (0.007)	0.0146 (0.012)	0.0182 (0.016)	0.0144 (0.012)	0.0146 (0.012)	0.0217 (0.019)
Colour (USD)	0.0303 (0.026)	0.0300 (0.026)	0.0171 (0.015)	0.0048 (0.004)	0.0871 (0.074)	0.0223 (0.019)	0.0690 (0.059)	0.0284 (0.024)

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

The ANA 2 model shows the greatest mean MWTPs of all three attributes. The RPL 2 model shows the smallest mean MWTP of the safety and colour attributes, and the MNL 1 model shows the smallest mean MWTP of the taste and odour attribute. As mentioned earlier, the MNL 2 model can provide different MWTPs in each block because there are three coefficients for the interaction terms between the cost variable and the hypothetical bias treatments. Therefore, the MNL 2 model could give four different MWTPs for the four blocks. In Table 6.15, the mean MWTPs of the MNL 2 was calculated by dividing each coefficient of the three attributes; safety, taste and odour, and colour with the sum of the coefficient of the cost variable and the one of the interaction term between the cost variable and the dummy of representing the use of both hypothetical bias treatments; D_{both}. The reason the dummy of D_{both} is that the MWTP shows a value close to the mean MWTP value for the four MWTPs.

6.6.2 Median Values of MWTP

The distribution of the estimated individual WTPs of the six models can also provide the median MWTPs, as shown in Table 6.16.

Table 6. 16 *Estimation of the* ***median*** *MWTPs*

KRW 1000	RPL 1	RPL 2	FAA 1	FAA 2	ANA 1	ANA 2
Safety (USD)	0.0510 (0.043)	0.0434 (0.037)	0.0519 (0.044)	0.0394 (0.034)	0.0468 (0.040)	0.0396 (0.034)
Taste and odour (USD)	0.0090 (0.008)	0.0100 (0.009)	0.0143 (0.012)	0.0106 (0.009)	0.0063 (0.005)	0.0177 (0.015)
Colour (USD)	0.0017 (0.001)	0.0 (0.0)	0.0001 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0020 (0.002)

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

As shown in Table 6.16, the FAA 1 model shows the largest median MWTP of the safety attribute and the FAA 2 model shows the smallest one. With respect to the taste and odour attribute, the ANA 2 model produces the largest median MWTP, and the ANA 1 model reveals the smallest one. Concerning the colour attribute, the ANA 2 model shows the largest median MWTP, and the RPL 2, FAA 2, and ANA 1 models produce zero values. When comparing the mean and median values, the medians are smaller than the mean values.

6.6.3 Effect of Hypothetical Bias Treatments

In this research, four models use the ASCs of the three dummy variables and four models use the interaction terms between the dummies of hypothetical bias and the cost variable to explore the effect of the hypothetical bias treatments. Table 6.17 shows the estimation of the ASCs of dummies of the hypothetical bias treatments from the four models discussed earlier.

Table 6. 17 *Estimation of the ASCs of the hypothetical bias treatments*

Variable		MNL 1	RPL 1	FAA 1					ANA 1				
				Class 1	Class 2	Class 3	Class 4	Class 5	Class 1	Class 2	Class 3	Class 4	Class 5
Ozone	D_{both}	-0.8983 (0.0000)	-3.6880 (0.0235)	-10.626 (0.1269)	-7.4898 (0.0000)	-0.9470 (0.0862)	-2.1771 (0.0000)	-0.1192 (0.8737)	-3.6684 (0.0472)	-4.2468 (0.0000)	-8.6509 (0.9438)	-1.9746 (0.2125)	-1.6949 (0.0136)
	D_{cheap}	-1.1993 (0.0000)	-5.6024 (0.0115)	2.6389 (0.2827)	-6.7878 (0.0000)	-0.7129 (0.1896)	-1.8695 (0.0000)	4.4445 (0.4152)	4.3111 (0.9981)	-2.1275 (0.0303)	-8.3258 (0.9792)	-5.2732 (0.0014)	-1.0262 (0.1561)
	D_{honest}	-1.3843 (0.0000)	1.2622 (0.3493)	-1.1561 (0.6264)	-5.6710 (0.0000)	-1.9741 (0.0000)	-2.5258 (0.0000)	1.1198 (0.7615)	5.2144 (0.9988)	-4.4826 (0.0000)	0.0695 (0.9661)	-4.9345 (0.0023)	-2.6401 (0.0000)
GAC	D_{both}	-0.4396 (0.0036)	-0.5833 (0.3336)	-2.6318 (0.0218)	-5.8378 (0.0003)	-0.6680 (0.1279)	-1.1580 (0.0000)	0.8349 (0.2624)	-1.8130 (0.3076)	-3.5534 (0.0000)	-0.6633 (0.0817)	-1.7025 (0.2631)	-1.3913 (0.0233)
	D_{cheap}	-1.3748 (0.0000)	-0.8021 (0.1389)	-3.8261 (0.0017)	-7.2870 (0.0000)	-1.4785 (0.0007)	-2.2261 (0.0000)	4.4646 (0.4136)	4.7046 (0.9979)	-2.2884 (0.0000)	-1.4024 (0.0000)	-5.6954 (0.0005)	-1.8048 (0.0091)
	D_{honest}	-0.8966 (0.0000)	-1.0909 (0.0630)	-2.3386 (0.0232)	-5.6070 (0.0000)	-2.4787 (0.0000)	-1.6462 (0.0000)	2.3862 (0.5152)	6.8215 (0.9984)	-3.1666 (0.0000)	0.2009 (0.6191)	-4.5187 (0.0051)	-3.1014 (0.0000)

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

Table 6.17 has 12 columns for the coefficients of the four models because the FAA 1 and ANA 1 models are the latent class logit model so that they provided the estimations of the coefficients for each class. First, the coefficients of the three dummies in the MNL 1 are negative and significant at the 99% significance level. Second, in the case of the RPL 1 model, the coefficients of the dummies of hypothetical bias treatments are negative when they are significant at a 95 % significance level. Third, in the case of the FAA 1 and ANA 1 models, when the coefficients of each class are significant at the 95% significance level, they show negative signs.

Three cases could be considered in terms of significance of the coefficients of the dummies. The first case is when the coefficients are statistically insignificant. In this case, two interpretations could be possible. One is that the hypothetical bias treatments are supposed to be ineffective in moderating the bias. Another is that there might be no hypothetical bias. If the coefficients are statistically significant, the hypothetical bias like overstatement or understatement could be assumed to exist. The coefficients would be negative or positive.

Negative significant coefficients of the dummies of the hypothetical bias treatments for the two alternatives mean that the utilities of them are less than the one of the status quo option, all other things being equal. Therefore, negative significant coefficients could be considered to show that the respondents have the hypothetical bias of overstatement. Otherwise, positive significant coefficients mean that the utilities of the two advanced alternatives are larger than the one of the status quo option. Thus, positive significant coefficients could be regarded to show that the respondents have the hypothetical bias of understatement. As a result, the negative significant coefficients of the dummies in Table 6.17 imply that all treatments for mitigating hypothetical bias are successful in reducing hypothetical bias. If people answer the questionnaire with the hypothetical bias treatment, they are less likely to choose the two advanced alternatives than the respondents who answer the survey without the treatments.

Table 6.18 shows the estimation of the interaction terms between the dummies of the hypothetical bias treatments and the cost variable from the four models.

Table 6. 18 *Estimation of the interaction terms of three models*

Variable	MNL 2	RPL 2	FAA 2				ANA 2			
			Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 4
Cost	-0.4167 (0.0000)	-0.6511 (0.0000)	0.1031 (0.6279)	-0.3401 (0.0191)	-1.5445 (0.0000)	-0.6073 (0.0000)	-1.4094 (0.0000)	-0.2147 (0.0286)	-0.5189 (0.0036)	-0.4821 (0.0027)
$D_{both}\cdot x4$	-0.2074 (0.0000)	-0.2343 (0.0145)	-0.1525 (0.4871)	-1.3588 (0.0000)	0.3822 (0.0478)	0.3129 (0.0144)	0.0 (fixed)	-0.0157 (0.9041)	-0.4940 (0.0145)	0.1479 (0.3916)
$D_{cheap}\cdot x4$	-0.3133 (0.0000)	-0.2730 (0.0027)	-0.7850 (0.0001)	-0.1374 (0.2983)	-2.3754 (0.0000)	-1.4674 (0.0000)	-1.9072 (0.0000)	0.0 (fixed)	-1.1236 (0.0000)	-1.1481 (0.0000)
$D_{honest}\cdot x4$	-0.4233 (0.0000)	-0.6582 (0.0000)	-0.6763 (0.0009)	-1.5783 (0.0000)	-0.7179 (0.0113)	0.3129 (0.0000)	-0.4544 (0.0813)	-0.4846 (0.0000)	-2.2527 (0.0000)	-0.0075 (0.9676)

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

It could be discussed if the negative signs of the coefficients of the interaction terms between the cost variable and the dummies of hypothetical bias treatments mean that the hypothetical bias was mitigated. As discussed in the subsection 6.2.3, Equation (6.13) shows the utility forms when using the interaction terms between the cost variable and the dummies of hypothetical bias treatments, and the direction of the coefficients of the dummies of hypothetical bias treatments allows for testing whether the hypothetical bias leads to respondents' overstatement or understatement. It can be considered that if people have a hypothetical bias of overstatement and the treatment of hypothetical bias is effective, the coefficients of the interaction terms will be negative. When the coefficients of the interaction terms between the cost variable and the dummies of hypothetical bias treatments are negative, the utilities of the two advanced alternatives are supposed to be less than the one of the status quo option because the cost variable of the two advanced alternatives are larger than the one of it, as shown in Table 4.13, which represents the final choice sets of experimental design. In this way, the respondents will choose less the two advanced alternatives than the status quo option and subsequently, the MWTPs will be calculated as smaller values compared to the situation without the hypothetical bias treatments.

As shown in Table 6.18, the coefficients of the interaction terms of the hypothetical bias treatments in the MNL 2 and RPL 2 are significant at the 99% significance level and show negative signs. In Classes 1, 2 and 3 of the FAA 2 model, when the coefficients of the interaction terms are significant at the 95% significance level, they show negative signs. In the case of the ANA 2 model, when the coefficients are significant at the 95% significance level, they also show negative signs. This result suggests that the treatments for mitigating hypothetical bias are in effect. However, in Class 4, the coefficients of the interaction terms of $D_{both} \cdot x4$ and $D_{honest} \cdot x4$ are positive even though they are significant at the 95% significance level. This result is inconsistent with the previous results of the other classes of the FAA 2 and other models. When looking into the size of the coefficients, the coefficients of the two interaction terms are smaller than the one of cost. Even though the coefficients of the two interaction terms are positive, the total sign of summing the coefficients of the interaction terms and cost is still negative. Consequently, the MWTP of each attribute can be calculated because the denominator in Equation (6.19) is still negative. Therefore, the respondents in Class 4 of FAA 2 model could be interpreted to have the hypothetical bias of understatement unlike the other people in other classes.

The other point to be mentioned concerns how to calculate the effects of the hypothetical bias treatments. When the interaction terms between the dummies of the hypothetical bias treatments and cost variable are used, the coefficients of the interaction terms act as the added denominator for calculating the MWTP. If the coefficient of one attribute is divided by the coefficient of the cost without adding the coefficients of the interaction term, the MWTP is the base value without the effect of the hypothetical bias treatments. In this way, the effect per the hypothetical bias treatment can be estimated.

6.6.4 Confidence Interval of the Median MWTP

When using the median value of the latent class logit model, the confidence interval of the median value can be explored. This exploration provides the statistical range of estimates; the range can be used for sensitivity analysis. The standard error of the median MWTPs of an LCM model can be used for testing the confidence. A simulation method is used in calculating the standard error of one MWTP using the steps below,

1) Using 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) To simulate an LCM model and to calculated the individual class probabilities according to the generated coefficient vector.

3) Multiplying the simulated individual class probabilities with the simulated WTPs of all classes, one WTP of each respondent could be generated.

4) Making one WTP distribution of calculating the WTPs of all respondents, one median WTP from the distribution could be measured.

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

Through repeating the simulation 1,000 times, a median MWTP space is calculated[18]. The ANA 1 model is chosen for the simulation. Table 6.19 shows the result of simulation for calculating the median MWTP space of the ANA 1 model.

Table 6. 19 *Confidence interval of the median MWTPs 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

As shown in Table 6.20, there is no confidence interval for the colour attribute. The reason why colour is not included here is because each median estimate for the attribute is simulated at zero. As shown in Table 6.12, the coefficients of colour are estimated at 0.1635 for Class 1 and 0 for the other four classes (Classes 2 through 5). When simulating the median value of the colour attribute, each value from the simulation following the steps described above show zero. For this reason, the confidence interval of colour is not included in Table 6.20. The averages of the two median values are larger than the median values of the ANA 1 model. The 95% confidence interval of the MWTPs of the two attributes includes the MWTPs of the ANA 1 model but the two average MWTPs from the space are larger than the mean values.

The other approach to estimate the confidence interval is called "statistical bootstrap". From the individual WTPs of the ANA 1 model, the bootstrapped samples can be generated with replacement. In this research, the samples were simulated for a 200,000 sample size because

[18] The NLOGIT 5 program is used for the simulation, and a code is attached in the appendix.

the households served by the waterworks equal to 196,712, which will be explored in the next subsection. Through simulation of the re-sampling 1,000 times, the median values of the WTPs are measured. Table 6.20 shows the confidence interval of the median MWTPs of the ANA 1 model by using "bootstrapping".

Table 6. 20 *Confidence interval of the median MWTPs 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 range compared to the taste and odour attribute of the simulation method above. These two results can provide the ranges of the MWTPs for sensitivity analysis. For example, the range from the simulation can be chosen for the safety attribute and the range from the bootstrap can be used for the taste and odour, because they provide lower WTPs for the two attributes, respectively.

6.7 Estimation of Benefit

6.7.1 Willingness to Pay per Household

It is possible to calculate the WTP per household to improve drinking water quality by using the estimated MWTPs of each attribute of drinking water quality. In Section 3.8, Equation (3.53) expressed the MWTP per household of alternative *j*. By using the equation, the WTP per household of each attribute for *j* alternative can be expressed as below,

$$WTP_{j,safe} = \Delta x_{j,safe} \times MWTP_{safe}$$

$$WTP_{j,TandO} = \Delta x_{j,TandO} \times MWTP_{TandO}$$

$$WTP_{j,colour} = \Delta x_{j,colour} \times MWTP_{colour} \quad (6.21).$$

The WTP for improvement of a good can be computed by multiplying the improvement of each attribute and the willingness to pay for a one -unit improvement. Thus, it is possible to calculate the total WTP per household for the two advanced treatments using Equation (6.21).

To calculate the total willingness to pay per household to improve drinking water quality, the type of average for the MWTP must be chosen. However, Lockwood et al. (1993) mention 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 for the allocation of a public good. Therefore, in this research, the WTPs using the median MWTPs are compared with those using the mean MWTPs. Tables 6.21 and 6.22 show examples of the WTP calculations per household for the two advanced alternatives using the mean and median MWTP values of the ANA 1 model.

Table 6. 21 *Benefits using the mean MWTPs of the ANA 1 model*

KRW 1000		Safety	Taste and odour	Colour	Sum
Mean of MWTP (m)		0.06659	0.01463	0.06904	
GAC	change of attribute (Δx_i)	34 (40 to 6)	80 (10 to 90)	9 (90 to 99)	
	Benefit (m×Δx_i)	2.264 (USD 1.93)	1.171 (USD 1.00)	0.621 (USD 0.53)	4.056 (USD 3.46)
Ozone + GAC	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)	2.597 (USD 2.21)	1.315 (USD 1.12)	0.684 (USD 0.58)	4.596 (USD 3.92)

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

Table 6. 22 *Benefits using the median MWTPs of the ANA 1 model*

KRW 1000		Safety	Taste and odour	Colour	Sum
Median of MWTP (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 (USD 1.36)	0.504 (USD 0.43)	0	2.094 (USD 1.79)
Ozone + GAC	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 (USD 1.56)	0.567 (USD 0.48)	0	2.391 (USD 2.04)

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

Using the mean MWTPs, the WTP per household of the two advanced alternatives is larger than when using the median MWTP. Thus, using the median MWTPs is more cautious in measuring the WTP per household to improve the drinking water quality. The ANA 1 model is chosen for the basic estimate because the model shows the lowest median values for the MWTPs. The MWTPs of the all models can be used for sensitivity analysis. Table 6.23 shows the comparison of the benefits from the MWTP estimates of the eight different models.

Table 6. 23 *Benefits from the eight models*

KRW		MNL 1	MNL 2	RPL 1	RPL 2	FAA 1	FAA 2	ANA 1	ANA 2
GAC	Mean (USD)	2595 (2.21)	2551 (2.18)	3206 (2.73)	3270 (2.79)	4374 (3.73)	3127 (2.67)	4056 (3.46)	5370 (4.58)
	Median (USD)	-	-	2467 (2.10)	2274 (1.94)	2910 (2.48)	2186 (1.86)	2094 (1.79)	2781 (2.37)
Ozone + GAC	Mean (USD)	2951 (2.52)	2899 (2.47)	3633 (3.10)	3703 (3.16)	4946 (4.22)	3550 (3.03)	4596 (3.92)	6035 (5.15)
	Median (USD)	-	-	2813 (2.40)	2589 (2.21)	3312 (2.82)	2488 (2.12)	2391 (2.04)	3156 (2.69)

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

As shown in Table 6.23, all benefits of using the median MWTPs are less than those obtained for the mean MWTPs. The WTP of the ANA 1 model is less than the others. Therefore, the ANA 1 model can be used for measuring the benefits as a lower bound. Furthermore, the benefits of all models can be used for sensitivity analysis.

Other sources for the benefit estimation can be compared. Table 6.24 shows the estimations of this research and the values that other studies report as well as the monthly spending in bottled water per household in South Korea, as discussed in Section 1 and 2.

Table 6. 24 *Benefits estimated in this research, in other studies and spending for bottled water*

WTP	Median of ANA1 (2015)	Mean of ANA1 (2015)	Kwak (1994)	Um et al (2002)	Park et al (2007)	Kwak et al (2013)	Bottled water (2014)
KRW (USD)	2,391 (2.04)	4,596 (3.92)	7,819 (6.64)	6,947-10,127 (5.9-8.6)	1,439-3,661 (1.23–3.12)	2,638 (2.24)	2,524* (2.15)

Note. The prices represented the monthly additional WTP per household and reflected the inflation between the years and 2015. * means that the price reflected the inflation between 105.17 in 2014 and 100.19 in 2015.

As shown in Table 6.24, the estimations of this research are included in the range of other measures between KRW 2,287 and 10,127, and the median value of ANA 1 approaches the lowest value, KRW 2,287 in the range. In particular, the median WTP of ANA 1 model, KRW 2,391 is similar to the monthly spending in bottled water, KRW 2,405. In this sense, the estimation of the WTP can be compared with other previous values and is tested for validity.

6.7.2 Social Benefits

To estimate the total benefit of improving drinking water quality, it is necessary to know the population and the number of households served by the waterworks. In 2009, the number of people served by the waterworks was reported as 511,451 (Ministry of Environment, South Korea[b], 2010). However, after that year, there is no report about the number of people served. Therefore, it is necessary to estimate this number.

The trends in the number of citizens in Cheongju City and the annual amount of drinking water provided by the Cheongju Waterworks provide indications. Table 6.25 shows the data about population of the city and the production of drinking water from the waterworks.

Table 6. 25 *Changes of the city population and drinking water production of the waterworks*

year	2009	2010	2011	2012	2013	2014	2015
population	648,598	661,793	668,199	672,849	679,301	831,521	831,912
1,000 m^3/year	53,405	55,960	59,607	62,998	67,536	68,521	70,235

Note. The sources are from Cheongju City Government and Korea-Water.

The population of the city continuously increases from 648,598 in 2009 to 846,650 in 2016. Also, the amount of drinking water supplied by the waterworks has consistently risen. Thus, it is reasonable to presume that the number of people served by the waterworks has increased.

The trend in litre per capita day (LPCD) can support an increase in the number of people served by the waterworks. Table 6.26 shows the trends in LPCD in the city and South Korea.

Table 6. 26 *Trend of LPCD in Cheongju City and South Korea*

Year	2010	2011	2012	2013	2014
Cheongju	382	390	400	412	391
South Korea	333	335	332	335	335

Note. The sources are from Ministry of Environment, South Korea, and Cheongju City.

In the target area, the LPCD seems to be consistently stable around 395 L, which can support an increase in the number of people served. Observing the trend of LPCDs, the LPCD of the whole country appears stable over the years. However, the LPCD in 2012 shows a slight decrease because there was a severe draught in the year after 1910 in South Korea. In the case of Cheongju City, the LPCD shows a decrease in 2014 after a gradual ascent. This decrease seems to be caused by a 9.7 % increase in water -bills in February 2014 in the city. The price elasticity of demand can be used for measuring how much people react to the change in their waters-bill. The point elasticity[19] is calculated at 0.5258, which is less than one. In this case, the elasticity value means that if the price of a commodity increases by one percentage point, then the consumption will decrease by 0.53 %. This result illustrates that the drinking water consumption is inelastic.

Assuming the LPCD is stable, the increase in the supply from the waterworks would mean an increase in consumers. However, how many people are served by the waterworks is not exactly reported. Thus, the 2009 figure of 511,451 is used, which can be considered a lower bound. The average family size per household is reported as 2.6 (Cheongju City Government, 2015), so the number of households served is calculated as 196,712 (511,451/2.6).

The social benefits are calculated by multiplying the number of households served by the waterworks with the WTPs per household. Table 6.27 shows the monthly benefit for the two alternatives for improving drinking water quality from the six models.

[19] Point elasticity is calculated by the expression of $\frac{P}{Q} \cdot \frac{\Delta Q}{\Delta P}$. Here, p is price, Q is the quantity of consumption. ΔQ and ΔP stand for the changes in the two variables.

Table 6. 27 *Monthly social benefit of improving tap water quality per month*

KRW million (USD thousand)	RPL 1	RPL 2	FAA 1	FAA 2	ANA 1	ANA 2
GAC	485 (414)	447 (381)	572 (488)	430 (367)	412 (351)	547 (467)
Ozone + GAC	553 (472)	509 (434)	652 (556)	489 (417)	470 (401)	621 (530)

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

The monthly benefit from the GAC option for improving drinking water quality is estimated to be between KRW 412 and 572 million, and the benefit from the ozone plus GAC option is from KRW 470 to 652 million using the median MWTPs of the six models. Table 6.28 shows the total annual benefit for the two alternatives.

Table 6. 28 *Annual social benefit of improving tap water quality*

KRW million (USD thousand)	RPL 1	RPL 2	FAA 1	FAA 2	ANA 1	ANA 2
GAC	5,823 (4,966)	5,368 (4,578)	6,869 (5,858)	5,160 (4,401)	4,944 (4,217)	6,565 (5,599)
Ozone + GAC	6,744 (5,752)	6,111 (5,212)	7,818 (6,668)	5,873 (5,009)	5,643 (4,813)	7,451 (6,355)

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

The total annual benefit from the GAC method is estimated to be between KRW 4,943 and 7,665 million, and the benefit from the ozone plus GAC treatment is from KRW 5,644 to 8,680 million using the median MWTPs of the six models.

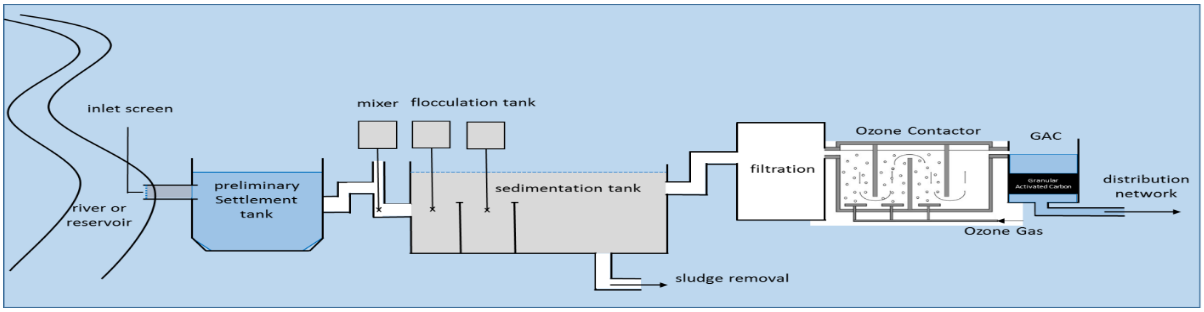
So far, eight models have been analysed for estimating the social benefits of improving drinking water quality. In the next section, cost estimation will be conducted. Later, cost-benefit analysis will follow. In the section on cost-benefit analysis, sensitivity analysis will also be implemented by assuming several sorts of scenarios. For example, the social benefits will decrease uniformly after the first year or even disappear after that year, which will be an extreme case. Also, several sorts of discount rates will be applied to the sensitivity analysis. All these values of the benefits from the median MWTPs will be used for the sensitivity analysis.

Chapter 7. Cost Estimation

7.1 Waterworks Process

It is necessary to estimate the costs of improving drinking water quality to investigate the economic feasibility of the investment in one waterworks. In this section, all types of costs of installing two advanced water treatment systems will be explored. For this purpose, it is useful to understand the process of purifying water in waterworks. The primary process is rapid sand filtration, called “a conventional type” because it has been widely used around the world, as mentioned in Section 1.5. The rapid filtration system has limitations such as an inability to remove protozoan. The conventional treatment system is also unable to remove geosmin and 2-MIB, known as substances that cause an unpleasant taste and odour in drinking tap water. Advanced filtration (water treatment) systems can be an alternative to overcome the limitations of the current water treatment systems and can resolve several matters that conventional system cannot. For example, the systems can deactivate pathogenic protozoan, sterilize virus and bacteria, oxidize and remove several synthetic organic chemicals, disable manganese and iron, and disintegrate and remove trihalomethanes. Rapid filtration systems have been a major method for supplying drinking water for more than 100 years, but alternative methods are gradually being installed to provide much safer and cleaner drinking water. Figure 7.1 shows the positions of the two advanced water treatment systems.

Figure 7. 1 *Positions of the two added advanced water treatment systems*



Note. The source is from Korea water. This figure is different to Figure 1.6.

An ozone facility can be installed before or after the filtration process, pre and post -ozonization[20]. Cho (2007) reported that post -ozonization is more efficient, using a smaller amount of ozone. Many waterworks in South Korea have applied the post -ozonization process. Ozone has greater oxidation potential to make iron, manganese and sulphur form insoluble metal oxides or elemental sulphur than other disinfection processes. It also eliminates organic particles and chemicals through coagulation or chemical oxidation (Langlais et al., 1991).

There are two main activated carbons; granular activated carbon and powdered activated carbon. Cho (2007) reports that the GAC process has greater economic effectiveness than the PAC process in water treatment. GAC has strong power to adsorb synthetic organic chemicals and natural organic compounds in raw water because it has numerous porocytes through which a large surface area can absorb contaminants.

Ozone treatment is commonly installed with the GAC process in South Korea. The main reason is that the GAC process can adsorb the harmful by-products that the ozone treatment produces by reacting with some organics like humic and fulvic acid in water. However, in the U.S., Europe and Japan, many waterworks installed the ozone and GAC processes alone or together to purify raw water with micro pollutants such as ammonic nitrogen, phenols, trihalomethans and algae because the two treatment processes require less in maintenance and operating costs than other types of advanced processes (Kim, 2011).

7.2 Assumptions for Cost Estimation

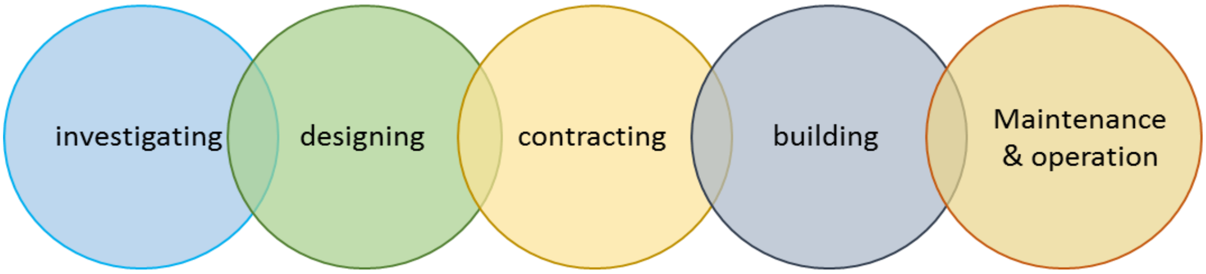
7.2.1 Phases of Public Projects

There are many restrictions in estimating costs. Therefore, it is necessary to make some assumptions for estimating the costs of the two advanced water treatment systems. Several

[20] Ozonization means that ozone is input into the raw water and bubbled up for the purpose of purifying water.

stages are involved in launching a new treatment system. Figure 7.2 shows the phases for a new public project.

Figure 7. 2 *Phases for a new public project*



In South Korea, all waterworks are owned and operated by the Korean government or local governments. Therefore, projects on the waterworks often follow a public process. As shown inn Figure 7.2, investigating is the first phase for testing the feasibility of new public investments. Several sorts of preliminary costs can be used for analysing the feasibility of a project. In the second phase, a reasonable cost must be estimated for launching the chosen project. The cost of designing the 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. If every bidding price is higher than the cost of designing, then the bid fails. Therefore, most bids by governments in South Korea usually succeed with a lower price than the designed cost proposed by the governments[21].

Design requires a significant expenditure. Therefore, it is necessary to estimate the cost of a new public project before wasting resources to draw the actual design documents. There are two stages for designing, basic and actual design for public projects in South Korea. Legal investigation of the feasibility for a public project is usually implemented in the stage of basic design. This will be described in subsection 7.2.5.

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[21] According to the Act on Contracts to which the State is a Party, South Korea, all government contracts should be done under the preliminary designed price. If not, the bid will not proceed.

In the contracting phase, bidders also incur many bidding costs as mentioned above. 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 to be valid. Therefore, a preliminary cost is used to investigate the feasibility in this research.

7.2.2 Construction Period

Some assumptions are necessary for estimating the cost of installing a new advanced water treatment system. There are two main stages, construction and operation. First, the construction for a new advanced treatment system takes time (more than one year) so it must be considered by referring to previous projects conducted by Korea-Water in South Korea. Table 7.1 summarises the three projects referenced.

Table 7. 1 *Summary of three projects installing Ozone plus GAC treatment systems*

Waterworks	Project term (month)	Capacity (m^3/day)	Project cost (KRW million)
Seongnam	02/2008 – 12/2011 (47)	630,000	52,723 (USD 44.97 million)
Deokso	07/2012 – 05/2015 (35)	450,000	25,800 (USD 22.0 million)
Goyang	06/2005 – 06/2009 (38)	210,000	17,951 (USD 15.31 million)

Note. Source is from Korea-Water. The price unit is KRW million.

As shown in Table 7.1, the three projects show different project terms between 35 and 47 months. The capacity of Cheongju Waterworks is 403,000 m^3/day so it is close to the one of Deokso waterworks (450,000 m^3/day). It might seem to be reasonable to assume the project term to be around three years (36 months) but it would be more cautious to assume the project term to be four years (48 months). Therefore, the project term is set at four years, based on the project of Seongnam waterworks. Table 7.2 shows the summary of the project.

Table 7. 2 *Summary of the project installed ozone plus GAC system in Seongnam waterworks*

Name	Advanced water treatment process project of Seongnam water treatment plant					
Capacity	630 thousand m^3 per day					
Amount	KRW 52,723 million					
Term	02/2008 – 12/2011 (4 years)					
Schedule	Year	2008	2009	2010	2011	Sum
	amount(KRW million) (USD million)	6,435 (5.49)	15,994 (13.64)	15,301 (13.05)	14,993 (12.79)	52,723 (44.97)
	proportion	12 %	30 %	29 %	28 %	100 %

Note. Source from Korea-Water. The exchange rate is based on 31/12/2015.

Based on Table 7.2, it is assumed that the construction/ costs are spent at the rate of 10 % in year 2 and 30 % from year 3 through 5 because the designing is assumed to be conducted in Year 1. Table 7.3 shows the schedule for design and construction cost.

Table 7. 3 *Schedule for design and construction cost*

year 1	year 2	year 3	year 4	year 5
Designing	10%	30%	30%	30%

In addition, 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 starts in the fifth year, after the construction.

If the project takes longer, it loses feasibility. 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, 2014). Regarding the length of design and construction, one might ask why the standard or the terms of previous projects should be referenced. Actually, all waterworks in South Korea are owned by the Korean government or local governments. Thus, the projects on waterworks should follow the standards or laws related to these entities. If public officials don't follow the standards or laws, they must be audited or investigated and as a result, might be punished by, for example, removal from a position, salary reduction, suspension or expulsion plus indemnification and additional charges. The reason for the punishment might, for example, be dereliction of duty[22]. If a project can be completed in a shorter term and with lower cost, and if a public official has set a longer term and higher cost for the project, the person would be investigated. However, one-year delay in construction is a more cautious approach for sensitivity analysis although those cases hardly ever occur. In this regard, eight previous projects which installed the Ozone plus GAC treatment in South Korea will be explored to confirm the length of the construction period, in subsection 7.3.2. All the projects are completed in less than five years (Ministry of Environment, South Korea, 2009).

Despite the strict restrictions with regard to a longer construction term, one scenario of determent is made for sensitivity analysis. With one -year delay, the construction period would be six years including design and the flow of construction costs should be reallocated. Table 7.4 shows an example of the schedule for design and construction.

Table 7. 4 *Schedule for design and construction for six years*

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Design	10 %	20 %	25 %	25 %	20 %

The design is also assumed to be done in the first year. It is assumed that the construction is delayed from the second year and completed in the sixth year. Thus, the project is assumed to spend one more year compared to the basic scenario. This scenario will be used for sensitivity analysis in the next section.

[22] According to the State Public Official Act, South Korea, when a public official violates or neglects obligations on duties (including those imposed on him or her by other statutes due to his or her status as a public official) a resolution on disciplinary action and additional charges are requested and taken.

7.2.3 Project Service Life

Each project has its business life, a major factor in 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. As discussed in subsection 2.2.3, the project service life of advanced water treatment systems is set at 20 years according to the Enforcement Regulation of Local Public Enterprises Act, 2014 of South Korea. This period can be used as an institutional business life of the water treatment systems.

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, as described in Section 7.1. The technical properties of the equipment and concrete structure imply the project service lives of the two options. In this regard, the Korea Appraisal Board (2013) reports the service lives of tangible fixed assets in terms of the technical property. Table 7.5 shows some part of reporting for the two main facilities.

Table 7. 5 *Service Lives of Tangible Fixed Assets*

Code	Facility	Years of Service life
1-10-1	Water treatment facility	
	Cohesion Equipment	15-20
	Sedimentation Equipment	15-20
	Floatation Equipment	15-20
	Filtering Equipment	15-20
	Water treatment Equipment	15-20
	Disinfection Equipment	15-20
	Chlorination Equipment	15-20
	Aeration Equipment	15-20
	Ozonization Equipment	**15-20**
	Adsorption Equipment	15-20
	Sludge Equipment	15-20
3-3-2	Filtration Structure	
	Reinforced Concrete Structure	**40-50**

Note. Korea Appraisal Board, 2013.

As shown in Table 7.5, 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. For example, Maegok[23] waterworks installing the GAC and ozone treatment systems in 2000 has been supplying drinking water by using the two advanced facilities. In this regard, setting the service life of the two advanced treatment systems at 20 years is justified. When the costs occur first and the returns will follow, a longer business life usually provides a higher NPV and B/C. The shorter periods will be tested with sensitivity analysis.

Regarding the business life of the project, one point should be noted. If more people use tap water because the quality of tap water improves, the amortisation of the treatment facilities may be faster. In this case, the business lives of the projects could also reduce and the social benefit would increase in line with the increase in the number of people enjoying the improved drinking tap water. However, some scenarios with shorter business lives can apply to the case, which will be explored in the next section.

7.2.4 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. That is, the expenditure of most businesses comes first, and the returns come later. A rise in the social discount rate usually increases expenditure, and decreases return. The risk comes from an increase in the social discount rate. Therefore, the economic feasibility of a public investment is likely to be more valid as the discount rate decreases.

As discussed in subsection 2.2.4, 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

[23] The waterworks are described in Table 7.15.

the Korea Development Institute (2013). The discount rate applied to this research is that suggested in 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. The Korean government is studying new guidelines for preliminary feasibility studies for the public sector. However, this study is not completed and the Korean government is considering reducing the discount rate which usually makes the feasibility more valid.

In this respect, it is useful to explore the social 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 (Spackman, 2008). Table 7.6 shows the countries using the SRTP to estimate the social discount rate.

Table 7. 6 *Countries using SRTP and the rate for each country*

Country	Norway	Germany	Spain	U.K	Italy	France	U.S
rate	3.5%	3%	4%	3.5%	5%	4%	0.5-3%

Note. Spackman, M., 2008.

The most typical way to estimate the SRTR is to use Ramsey's approach (Spackman, 2008). Spackman (2008) highlights that SRTP is not controversial in terms of welfare economics by citing Arrow (1995), who refers to "Ramsey's well-known expression". Also, Pearce and Ulph (1995) support his opinion; Ramsey's way is the most appropriate for determining the social discount rate when considering practicality. Feldstein (1964) formulates the of SRTP of Ramsey's expression as below,

$$r = \rho + \mu \cdot g \quad (7.1).$$

In Equation (7.1), r is a social discount rate, ρ is a utility discount rate reflecting the pure time preference, μ stands for the elasticity of the marginal utility of consumption, and g is the annual real consumption growth per capita.

Using Equation (7.1), Choi and Park (2015) estimated the social discount rate in South Korea. They estimate the utility discount rate reflecting the pure time preference at 0.86%-1.1% per year by using the real return rate of savings after tax in South Korea. The elasticity of the marginal utility of consumption is estimated to be between 0.73 and 1.12. They also presumed an annual real consumption growth rate per capita from 2.2% to 3% by considering the gross domestic product (GDP) growth rate per capita in South Korea. As a result, they 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; 5.5%. 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 South Korea and the drop in the interest rate caused by a decrease of saving rate. For reference, Table 7.7 shows the recent economic growth rate of South Korea.

Table 7. 7 *Economic Growth Rates of South Korea*

Year	2011	2012	2013	2014	2015	2016
Growth rate (%)	3.7	2.3	2.9	3.3	2.8	2.8

Note. The source is from the database of Bank of Korea.

The authors conclude that the present social discount rate for public projects in South Korea is higher than the estimated range of the SRTP in 2013. Therefore, the range between 4.5 % and 5.5 % can be used for sensitivity analysis. However, a broader range can also be used for a more careful approach to sensitivity analysis. Therefore, several points for the social discount rate between 1 % and 10 % will be used for the sensitivity analysis.

7.2.5 Design Cost

The third category of assumptions to be discussed is the design cost. The Korean government suggests standards for cost of business engineering. Table 7.8 shows the ratios of design costs as a proportion of the sum of the construction cost of a public project.

Table 7. 8 *Standards of cost for business engineering in construction*

KRW billion	basic design	working design	construction supervision	sum
less than 10	1.51 %	3.01 %	1.41 %	5.93 %
10 ≤ < 20	1.46 %	2.91 %	1.37 %	5.74 %
20 ≤ < 30	1.45 %	2.90 %	1.35 %	5.70 %
30 ≤ < 50	1.41 %	2.84 %	1.33 %	5.58 %
50 ≤ < 100	1.40 %	2.79 %	1.30 %	5.49 %
100 ≤ < 200	1.38 %	2.76 %	1.28 %	5.42 %
200 ≤ < 300	1.37 %	2.72 %	1.25 %	5.34 %

Note. Ministry of Trade, Industry and Energy, South Korea, 2015.

The design costs of the two treatment systems are estimated according to the standard ratios. For example, if a public project is KRW 50 billion, then the design cost is 4.39% (basic design 1.40% plus working design 2.79%). That is KRW 2,145 million (GBP 1.2 million, approximately). In the case of construction supervision costs are allocated according to the ratio of construction cost as shown in Table 7.3 and 7.4.

One mentionable point is related to investigating. When conducting the basic design in South Korea, the feasibility of public projects is usually investigated. Thus, the investigating costs can be included in the cost of the basic design. For example, when the project cost is KRW 50 billion, the cost of basic design would be KRW 700 million (USD 594,000), which accommodates the investigating cost.

Another notable point concerns contracting cost. The Korean government has introduced electronic procurement for public contracts. By using electronic procurement, the Korean government can innovatively save contracting costs for public projects (OECD, 2016).

Waterworks in South Korea are owned by the Korean government or local governments so new projects for the waterworks must use the electronic procurement according to a law[24]. 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.

7.3 Estimation of Costs

It is complicated to estimate the construction cost without the design. Even the costs from the design are not fixed due to the bidding process. Furthermore, in practice, the cost usually changes during the construction period. Nevertheless, it is essential to estimate the cost even without a design when examining economic feasibility, because it would be absurd to spend a large amount of money for a design without its feasibility being assessed first. There are many appropriate standards for cost estimation. Government guidelines and precedents for similar projects have been used for cost estimation. Therefore, the standards of the Seoul metropolitan government and the unit costs of some previous projects in South Korea are used for estimating the construction costs, and a study and the unit costs of precedential projects of the two advanced treatment systems are used for estimating the operation costs.

7.3.1 Cheongju Waterworks

The target waterworks on which this research focused is the Cheongju Waterworks, which was discussed in subsection 1.6, Chapter 1. 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 in waterworks should be assumed for measuring the operating costs because the operating cost will be proportional to the rate. The utilisation rate is defined as below,

[24] The law is the Enforcement Decree of the Act on Contract to which the State is a Party, South Korea.

$$utilization\ rate\ (\%) = \frac{total\ supply\ amount\ per\ year\ (m^3)}{total\ capacity\ per\ year\ (m^3)} \times 100 \qquad (7.2).$$

Table 7.9 shows the utilization rate of Cheongju Waterworks from 2010 through 2015.

Table 7. 9 *Utilization rate of Cheongju Waterworks*

Year	2010	2011	2012	2013	2014	2015
Annual supply (thousand $m^3/year$)	55,960	59,670	62,667	67,535	68,520	70,234
Utilization rate (%)	38.0	40.5	42.8	45.9	46.6	47.7

Note. The source is from Korea-Water.

The utilization rate is calculated by Equation (7.2). Until now, the utilisation rate has increased very gradually, which means that the waterworks are getting a larger supply of drinking tap water to citizens. However, it is also necessary to estimate the future supply of the waterworks. For that reason, the amount and utilisation rate of the last year, 2015, is used for measuring operating costs.

7.3.2 Construction Costs

In 2008, the Office of Waterworks of Seoul Metropolitan Government examined the unit cost of constructing two advanced treatment systems in South Korea and published the data for reference and precedent. Table 7.10 shows the unit cost.

Table 7. 10 *Unit cost of constructing two advanced treatment systems*

Capacity	thousand m^3/d	100	200	400	700	1000
Granular Activated Carbon	KRW thousand (USD)	107.8 (91.94)	100 (85.29)	86 (73.35)	81.7 (69.68)	74 (63.11)
Ozone	KRW thousand (USD)	30 (25.59)	28 (23.88)	25 (21.32)	23 (19.62)	20 (17.06)

Note. Seoul Metropolitan Government, 2008. The exchange rate is based on 31/12/2015.

Therefore, the minimum construction cost is estimated at KRW 34,658 million for GAC only (86 x 403). However, the cost is at the 2008 price, so it is necessary to allow for inflation after that year. Table 7.11 shows the producer price index of the water industry in South Korea from 2000 through 2014.

Table 7. 11 *Producer price index of water industry from 2000 to 2014*

Year	2000	2002	2006	2007	2008	2009	2010	2011	2012	2013	2014
Index	65.35	74.75	90.41	93.8	96.53	96.33	100	106.71	107.45	105.73	105.17

Note. Source is from the database of Bank of Korea.

A deflation period is apparent after 2012. To calculate the cost on the basis of the 2015 price, it is necessary to consider inflation from 2008 through 2014. In this case, the price index is calculated as 108.95 (105.17/96.53). Table 7.12 shows the newly calculated unit construction costs according to the standard of Seoul Metropolitan Government.

Table 7. 12 *Unit construction cost reflecting 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. Table 7.13 shows the estimation of construction costs.

Table 7. 13 *Estimation of construction costs*

system	unit cost of construction (KRW thousand/m^3)	total capacity (m^3)	construction cost (KRW thousand)
GAC	93.7	403,000	37,761,100 (USD 32,205 thousand)
Ozone	27.2	403,000	10,961,600 (USD 9,349 thousand)

Next, the design costs and construction supervision costs are calculated according to Table 7.8. The sum of the costs of the two methods is KRW 48,722,700 thousand, so it falls into the category of less than KRW 50 billion. 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%. The construction costs of the ozone plus GAC are close to KRW 50 billion so costs could exceed the threshold. However, when the ratios of design and supervision costs decrease, the amount of designing and supervision costs will increase more slowly. Therefore, the ratios of designing and supervision; 2.84% and 1.33% can provide maximum ratios for the two costs. Table 7.14 shows the total costs including the estimation of design costs and construction supervision costs.

Table 7. 14 *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 justify the estimates of the construction costs, it is useful to look into the costs of other previous projects installed the same treatment systems in South Korea. Table 7.15 shows the unit costs of eight previous projects for installing the two advanced treatment systems. The unit cost for installing the two alternatives in Cheongju Waterworks is included in the last row of the table. The unit costs in the last column show the unit costs reflecting the inflation between two terms, each completion year and 2015 according to the inflation indexes in Table 7.11. The unit construction cost of installing the two advanced treatments in Cheongju Waterworks is estimated at KRW 127,645 based on the 2015 price. The unit cost of the eight previous projects ranges from KRW 60,960 to 153,425 for the ozone plus GAC systems.

Table 7. 15 *Unit cost of other previous projects constructing ozone plus GAC systems*

City	Waterworks	Facility (㎥ per day)	Total cost (KRW million)	Unit cost (KRW/㎥)	Complete year	Unit cost based on 2015 price
Daegu	Maegok	800,000	63,800	79,750	2000	128,344 (USD 109,462)
Ulsan	Seonam	60,000	4,028	67,133	2002	94,453 (USD 80,557)
Pusan	Maeri	1,050,000	114,500	109,048	2002	153,425 (USD 130,853)
Paju	Munsan	144,000	17,380	120,694	2006	140,398 (USD 119,742)
Daegu	Duryu	400,000	21,748	54,370	2007	60,960 (USD 51,991)
Goyang	Goyang*	210,000	17,951	85,481	2009	93,325 (USD 79,595)
Seongnam	Seongnam*	630,000	52,723	83,687	2011	82,479 (USD 70,345)
Namyangju	Deokso*	450,000	25,800	57,333	2015	57,333 (USD 48,898)
Cheongju	Cheongju*	403,000	51,441	127,645	2015	127,645 (USD 108,866)

Note. The source is from the Minister of Environment, South Korea, 2009. The unit costs based on 2015 price were calculated by using the producer price index in Table 7.9. * represents the waterworks of Korea-Water.

Therefore, the estimates of the 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 Section 8. In particular, the highest value of the unit cost, KRW 153,425, acts as an upper bound for estimating the construction cost.

The flow of construction costs is assumed according to the proportion for construction from Table 7.3. Table 7.16 shows the derived flow by using the basic estimates of designing and construction costs.

Table 7. 16 *Flow of construction costs*

KRW thousand	year 1	year 2	year 3	year 4	year 5
GAC (USD)	1,604,847 (1,367,739)	3,776,110 (3,220,563)	11,478,997 (9,790,189)	11,478,997 (9,790,189)	11,478,997 (9,790,189)
Ozone (USD)	465,868 (397,329)	1,096,160 (934,891)	3,332,217 (2,841,976)	3,332,217 (2,841,976)	3,332,217 (2,841,976)

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

As discussed in Section 7.2.2, with a one year delay, the construct period would be six years and the flow of designing and construction costs should also be allocated. Table 7.17 shows an example of the schedule for design and construction costs according to Table 7.4.

Table 7. 17 *Schedule for design and construction for six years*

KRW thousand	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
GAC (USD)	1,604,847 (1,368,739)	3,776,100 (3,220,554)	9,440,275 (8,051,407)	9,440,275 (8,051,407)	9,440,275 (8,051,407)	5,664,165 (4,830,844)
Ozone (USD)	465,868 (397,329)	1,096,160 (934,891)	2,740,400 (2,337,228)	2,740,400 (2,337,228)	2,740,400 (2,337,228)	1,644,240 (1,402,337)

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

The project is assumed to spend one more year than in the basic scenario. This scenario will be used for sensitivity analysis in the next section.

7.3.3 Operating Costs

Similar to the case of construction costs, operating costs are estimated by using the unit cost of operating the two advanced treatment systems. Lee et al. (2008) report the unit cost per m^3 of operating the two advanced treatment systems according to five waterworks capacities in 2008. In addition, the actual unit costs of operating ozonization and GAC facilities of two waterworks of Korea-Water are explored. Table 7.18 shows the unit costs of operating the two advanced treatment systems in seven waterworks in South Korea.

Table 7. 18 *Unit costs of operating two advanced treatment systems*

Supply of water (thousand m^3 per day)	30	100	210*	243*	300	600	800
GAC (KRW thousand/ m^3) (USD)	5.9 (5.03)	5.9 (5.03)	2.6 (2.22)	5.0 (4.26)	5.9 (5.03)	5.9 (5.03)	5.9 (5.03)
Ozone (KRW thousand/ m^3) (USD)	2.1 (1.79)	1.9 (1.62)	1.4 (1.19)	1.7 (1.45)	1.7 (1.45)	1.6 (1.36)	1.5 (1.28)

Note. Lee, K-H et al., 2008. * means the sources from Korea-Water. The exchange rate is based on 31/12/2015.

As shown in Table 7.18, the operation cost for GAC is nearly constant except for two actual cases of Korea-Water, but the cost of ozone treatment shows the merits of economies of scale. In other words, the cost of ozone treatment decreases as the capacity of waterworks increases.

In the case of the GAC, the recycling cost and the supplement cost of lost carbon are the two primary parts, and the main costs of ozone treatment come from the cost of purchasing pure oxygen and electricity. The operating costs for the two advanced treatment systems are evaluated based on the data of the eight waterworks: Maegok, Seonam, Maeri, Munsan, Duryu, Goyang, Seongnam and Deokso. Total operating costs decrease as the capacity of the waterworks increases. Although the capacity of Cheongju Waterworks is 403,000 m^3 per day, KRW 1,700, the unit cost of the capacity 300,000 m^3 per day is used for a more cautious approach even though the actual unit costs of the two waterworks of Korea-Water show lower costs. In addition, the operating days should be considered. Usually, the ozone treatment is implemented during the rampant seasons of blue-green algae such as spring and summer in South Korea. As shown in Figure 4.2, the maximum days of blue-green algae breakout per year in Lake Daecheong has been 115 days since 2000. Therefore, it is acceptable to set the operating days to 115 for the ozone treatment system. This assumption results in a decrease in operating cost for ozone treatment equipment and might result in expansion of the project service life of the facility.

Another issue related to the unit operating cost is inflation. As with the construction costs, the operating costs should also reflect any change in price. Therefore, in this research, the unit costs are multiplied by the calculated index, 108.95 reflecting inflation from 2008 through 2014. Table 7.19 shows the unit operating costs and total costs of supplying the expected amount from the two treatment methods and reflecting inflation after the construction period.

Table 7. 19 *Estimation of operating costs*

System	GAC	Ozone
unit operating cost (KRW/m^3) (USD)	6.428 (5.48)	1.852 (1.58)
total operation cost (KRW thousand) (USD)	451,464 (385,044)	40,982 (34,953)

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

It is worth considering the case of an increase in demand for drinking tap water in the target areas. If the supply of water increases the operating cost will follow the increase, which could be a shortcoming of the benefit-cost analysis. However, the benefit side may have one defensible point. The increase in demand could mean an increase in the population served. In that case, the increase in operating costs could be covered by the benefits for newly included people. Supporting this point of view, LPCD is worth mentioning. LPCD is defined as the average water supply amount per individual per day, as discussed in Subsection 6.7.2. An increase in the supply of drinking water means a rise in the population served or in LPCD because the supply of drinking water is usually equal to the demand. This is understandable when imagining the pipelines for supplying tap water from the waterworks to households. Table 6.26 in Subsection 6.7.2 showed the trend in LPCD in the target area during the past five years.

The LPCD has been stable since 2010. Also, the population of the city has grown steadily from 648,597 in 2009 to 831,912 in 2015, as discussed in 6.7. Therefore, it is reasonable to assume that the demand for drinking tap water in 2015 can serve the lower bound. If the demand for water increases because of the improved quality, amortisation of the facilities may be worth considering. In that case, scenarios with shorter business lives of the projects may cover the case, as discussed in subsection 7.2.3. If the population in the city increases significantly and the waterworks cannot accommodate the new people, then new waterworks must be built. This case is actually beyond the scope of this research. Consequently, it is feasible to connect the increase in supply to the population served.

7.4 Cost Flows

It is possible to estimate the cost flow for an example of the construction period because the project service length is set at 20 years for a basic scenario. Table 7.21 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 7. 20 *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.

So far, estimations of the costs for the two advanced water treatment systems have been explored. Also, several assumptions are discussed with respect to factors such as the business life, social discount rate, social benefit, risk and uncertainty, confidence interval of MWTPs, and social cost estimation for the cost-benefit analysis. The ranges of the factors will be used for scenarios for the sensitivity analysis, which will be explored in Chapter 8. Moreover, there will be a brief analysis where the estimates of the costs of installing new advanced treatment systems will be compared to the costs of protecting the catchment area.

Chapter 8. Cost-Benefit Analysis

To test the feasibility of investment in improving drinking tap water in the target areas in South Korea, cost-benefit analysis will be used. CBA is defined as a procedure for aggregating the monetary values of the gains and losses for individuals and expressing them as a net social gain or loss (Pearce, 1983). Many public sector companies have used the CBA approach to test the feasibility of their investments (Korea Development Institute, 2013). In this research, CBA is used for assessing the feasibility of improving drinking water quality.

8.1 Assumptions

Before starting the CBA, it is necessary to discuss some assumptions. The four main ones are business life, social discount rate, benefit range, and advantaged people.

8.1.1 Business Life

Each project has a business life, a major factor in its feasibility. Most business projects require huge initial expenditure, and the returns follow later. The business life of the two advanced systems is set at 20 years according to the project service lives. However, the ozone system mainly consists of ozonisation equipment for which service life is between 15 and 20 years (Korea Appraisal Board, 2013). Thus, 15 years can serve as a lower bound of the business life, but 10 years is a more cautious approach. Consequently, the business life is assumed to be in the range between 10 and 20 years in this research. Moreover, the construction period was assumed to be five years and the newly treated drinking water is supplied in the fifth year. Thus, the cash flow is set in the range from year 1 through year 24.

8.1.2 Social Discount Rate

As discussed in subsection 7.2.4, 5.5% has been the institutional social discount rate in South Korea. More recently, Choi and Park (2015) study a social discount rate by using the social rate of time preference. They argue that 4.5% is the social discount rate of reflecting the recent economic state in South Korea. Therefore, 4.5% can serve as a benchmark value for the social discount rate for CBA. If the social discount rate increases the values of CBA usually worsen. In this sense, the institutional social discount rate, 5.5% would be an upper bound for the range of the social discount rate. However, a broader range provides more cautious measurements for the cost-benefit analysis. Therefore, the range of the social discount rate is set between 1% and 10% in this research.

8.1.3 Range of Social Benefits

As discussed in Section 6.6, the MWTPs are estimated by using the eight logit models. The ANA 1 model is chosen for analysis because it shows the lowest estimates for the median MWTPs. Furthermore, the confidence intervals of the median MWTPs are explored in subsection 6.6.4. To measure the intervals, two methods are used; one is the simulation approach and the other is the statistical bootstrapping. For the sensitivity analysis, the two lowest values for the two attributes can be used. The MWTP of the colour attribute is set to zero. Consequently, two scenarios are analysed in conducting the sensitivity analysis.

Another point to be discussed is how many people will benefit from the improved quality of drinking tap water. With improved quality of drinking tap water, some people would switch from their current mitigating behaviours to one of the two alternatives. In this regard, the proportion of people who change their behaviours should be considered. In the sample of this research, 573 people take part in the survey. However, after deleting ‘ineffective’ and ‘label heuristic’ cases and outliers, the sample consisting of 406 respondents remains.

All the eight models of this study use the alternative specific constant (ASC) for the two advanced alternatives to normalize one of the status quo. The value of ASC could be interpreted as the average effect of not included factors on the utility of the two advanced alternatives compared to the status quo option as discussed in Section 6.1 and 6.2. Equation (6.7) shows an example of the utility function form having the ASC, α_j, generic variables, X_{ijk}, socioeconomic variable, Z_l, and the dummies of the hypothetical bias treatments, D_m. Equation (6.7) can be changed for representing three alternatives as follows,

$$U_{i,Oz} = \alpha_{oz} + \beta_k \cdot X_{i,oz,k} + \gamma_{l,oz} \cdot Z_{il} + \theta_{m,oz} \cdot D_{im} + \varepsilon_{i,oz}$$
$$U_{i,GAC} = \alpha_{GAC} + \beta_k \cdot X_{i,GAC,k} + \gamma_{l,GAC} \cdot Z_{il} + \theta_{m,GAC} \cdot D_{im} + \varepsilon_{i,GAC}$$
$$U_{i,SQ} = \beta_{ik} \cdot X_{i,SQ,k} + \varepsilon_{ijt} \quad (8.1).$$

Here, the coefficients of the ASCs, α_{oz} and α_{GAC} could be positive or negative. If they are positive, it suggests that the respondent *i* prefer the two advanced alternatives compared to the status quo when all the socioeconomic variables of the respondent are zero. If both of them are negative, it implies that the respondent *i* won't pay any more to improve the drinking tap water quality when all the socioeconomic variables are zero. However, there is no one who has all zero socioeconomic variables in the sample. Therefore, it is necessary to calculate the sum of the coefficients of the ASC and socioeconomic variables to find out how many respondents deny installing the advanced alternatives. Table 8.1 shows the proportion of the respondents who show negative sums of ASC for the two advanced options.

Table 8. 1 *Proportion of respondents with negative ASC sums of the two advanced options*

SAMPLE	MNL1	MNL2	RPL1	RPL2	FAA1	FAA2	ANA1	ANA2
406	9 (2.2%)	0 (0%)	42 (10.3%)	0 (0%)	46 (11.3%)	55 (13.5%)	13 (3.2%)	63 (15.5%)

As shown in Table 8.1, the ANA 2 model shows the largest estimation of the respondents, 63 (15.5%) who have the negative sums for both of the two advanced alternatives. As discussed above, the respondents who have the negative sum values could be assumed to have zero WTPs for the advanced alternatives because they would like to prefer the status quo option.

In this respect, 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. The proportion 15.7% is close to the proportion 15.5%, which this research measured for the respondents who might have zero willingness to pays. In addition, the median marginal willingness to pay is used in measuring the social benefits in order to mitigate the effect of this group who is unwilling to pay. Therefore, using the proportion 15.5% for the respondents with zero willingness to pays could be reasonable for a sensitivity analysis.

8.1.4 Range of Social Costs

As explored in Section 7.3, the costs for installing the two advanced alternatives are estimated. The basic estimates for constructing the two advanced treatments follow the standard that Seoul Metropolitan Government issued in 2008. Although the estimates reflected inflation, a more critical approach might be helpful in investigating project feasibility. The eight projects that involve installing the same type of advanced treatments in South Korea since 2000 are explored. As shown in Table 7.12, the construction unit costs of Maegok, Maeri and Munsan are more than the estimate of the target waterworks; the unit cost of Maeri shows the largest value, 1.2 times the estimated unit cost of construction (KRW 153,425/127,645 per m^3). This value can provide the range for the construction unit cost.

Another scenario is related to the construction period. The basic scenario sets five years for design and construction. Despite legal restrictions, the scenario with a one-year delay in completing construction is employed for sensitivity analysis, as discussed in Section 7.2. In the case, the schedule for design and construction follows the example in Table 7.4.

8.1.5 Summary of Assumption

Table 8.2 shows a summary of assumptions for five factors in the cost-benefit analysis.

Table 8. 2 *Assumption for five factors*

Factor		Range
Business life (years)		10 – **20**
Social discount rate (%/year)		**1** – 10
Benefit	MWTP of safety (KRW 1000)	0.0365, 0.0465 – **0.0468**
	MWTP of taste and odour (KRW 1000)	0.0063, 0.0060 – **0.0066**
	Advantaged household	166,222 - **196,712**
Construction cost (KRW per m^3/day)		**127,645** – 153,425

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

Several scenarios could be created by using the ranges for sensitivity analysis. The ranges are set for one direction. For example, the business life is set between 10 and 20 years. Actually, when the business life is extended, the three values for CBA would improve. Thus, the range of the business life is set under 20 years, and 10 years is used for a lower bound of the business life, as discussed in subsection 8.1.1. In this sense, the ranges of the five factors are set for a negative direction in terms of the CBA values.

8.2 Present Values of the Cash Flows

CBA uses three types of decision rules of discount cash flow: net present value, internal rate of return, and benefit to cost ratio. To implement CBA, it is necessary to establish the cash flows for the costs and benefits of improving the drinking water quality. In the earlier stage of the study, the cash flows are examined. This subsection will first address the cash flow for the costs and the benefits and calculate the present values by applying the basic social discount rate. Next, the three types of decision rules are calculated to test the feasibility.

8.2.1 Benefit Flow

In Section 6.7, the monthly social willingness to pay is examined. Table 8.3 shows the total monthly benefit for the two methods for improving drinking water quality within the target area comparing the three kinds of MWTPs.

Table 8. 3 *Social Benefits of improving drinking tap water quality*

KRW million (USD thousand)	GAC	Ozone plus GAC
Monthly Social Benefit	412 (351)	470 (401)
Annual Social Benefit	4,943 (4,216)	5,644 (4,814)

Note. USD 1 = KRW 1172.5, based on the exchange rate of 31/12/2015. 4,943=412 X 12.

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

Another point to discuss is when and how much of the social benefit should be applied to the cash flows. There would be no dispute about the social benefits from the first year when the improved drinking water is supplied to the public. In this research, the first supply year is the fifth year after starting construction of the advanced water treatment systems; that is, the first supply year is assumed to be 2019. However, after five years, the social benefits might be changed by any change in the real purchasing power of money. The survey is conducted in 2015 so the benefit is estimated on the basis of the price in 2015. For example, the median monthly benefit of the ozone plus GAC system per household is estimated at KRW 2,391, as discussed in Subsection 6.7.1.

The benefit value in 2019 would increase according to the social discount rate. Table 8.4 shows an example of the benefit value having the same present values from 2015 to 2019, assuming the social discount rate is 4.5 %.

Table 8. 4 *Benefit values from 2015 to 2019 having the same present values*

KRW	2015	2016	2017	2018	2019
Benefit value (USD)	2,391 (2.04)	2,499 (2.13)	2,729 (2.33)	3,114 (2.66)	3,713 (3.17)

Note. The social discount rate was set 4.5 % in calculating the present values. USD 1 = KRW 1172.5.

The benefit value in 2019, KRW 3,713, is equal to the benefit value in 2015, KRW 2,391 in terms of the present value. Nevertheless, the value of the social benefits in 2015 is applied, reflecting a more conservative approach.

8.2.2 Cost Flows

In Section 7.4, the cash flow of the costs is discussed based on 2015 prices. As far as possible, the costs included all types of expenses. The costs are estimated to include two types of design costs, construction supervision, construction and maintenance and operating. The costs are calculated on the basis of standards and studies in South Korea, as discussed in Section 7.3. The cost flows for the two alternatives are shown in Table 7.17. Before assessing the present values of the cost flows, it is necessary to adjust them according to the two alternatives suggested in the questionnaire. Table 8.5 shows the cost flows modified for the two alternatives.

Table 8. 5 *Cost flows modified for the two alternatives*

KRW million	year 1	year 2	year 3	year 4	year 5	year 6	⋯	year 24
GAC (USD thousand)	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 + GAC (USD thousand)	2,071 (1,766)	4,872 (4,155)	14,811 (12,632)	14,811 (12,632)	15,262 (13,017)	492 (420)	492 (420)	492 (420)

Note. The last line is different than Table 7.21. USD 1 = KRW 1172.5.

By using the cost flows in Table 8.5, it is possible to calculate the present values.

8.2.3 Discount Cash Flow Rules

To calculate the present values, the social discount rate is critical because the present values will change according to any change in the social discount rate. In this research, 4.5% is used as the basic social discount rate, as discussed in Section 8.1.2. Table 8.6 shows the cash flows of the GAC alternative and the present values.

Table 8. 6 *Cash Flows of the GAC alternative*

Year	Constant Value		Present Value[25]		NPV
	Cost	Benefit	Cost	Benefit	(r=4.5%)
2015	1,605		1,605		-1,605
2016	3,776		3,579		-3,579
2017	11,479		10,313		-10,313
2018	11,479		9,776		-9,776
2019	11,930	4,943	10,004	4,145	-5,859
2020	451	4,943	362	3,966	3,605
2021	451	4,943	346	3,796	3,449
2022	451	4,943	331	3,632	3,301
2023	451	4,943	317	3,476	3,159
2024	451	4,943	303	3,326	3,023
2025	451	4,943	290	3,183	2,893
2026	451	4,943	278	3,046	2,768
2027	451	4,943	266	2,915	2,649
2028	451	4,943	254	2,789	2,535
2029	451	4,943	244	2,669	2,426
2030	451	4,943	233	2,554	2,321
2031	451	4,943	223	2,444	2,221
2032	451	4,943	213	2,339	2,125
2033	451	4,943	204	2,238	2,034
2034	451	4,943	195	2,142	1,946
2035	451	4,943	187	2,050	1,863
2036	451	4,943	179	1,961	1,782
2037	451	4,943	171	1,877	1,706
2038	451	4,943	164	1,796	1,632
sum	48,838 (USD 42 million)	98,860 (USD 84 million)	40,556 (USD 35 million)	56,344 (USD 48 million)	15,788 (USD 13 million)

Note. The price unit is KRW million. USD 1 = KRW 1172.5, based on the exchange rate of 31/12/2015.

[25] The present values were calculated by using the expression of "Net Present Value (NPV)"; NPV=$\frac{E(X_t)}{(1+r)^t}$. $E(X_t)$ is the cash flow in year t, r is the social discount rate. This way for calculating the NPVs was discussed in subsection 2.2.2.

In the last row of Table 8.5, the NPV of the GAC alternative is estimated as KRW 15,788 million (USD 13 million). The B/C ratio is estimated at 1.389 (KRW million 56,344/40,556). Table 8.7 shows the cash flows of the ozone plus GAC alternative.

Table 8. 7 *Cash Flows of the Ozone plus GAC alternative*

Year	Constant Value		Present Value		NPV
	Cost	Benefit	Cost	Benefit	(d=4.5%)
2015	2,071		2,071		-2,071
2016	4,872		4,662		-4,662
2017	14,811		13,563		-13,563
2018	14,811		12,979		-12,979
2019	15,262	5,644	12,798	4,733	-8,065
2020	492	5,644	395	4,529	4,134
2021	492	5,644	378	4,334	3,956
2022	492	5,644	362	4,147	3,786
2023	492	5,644	346	3,969	3,623
2024	492	5,644	331	3,798	3,467
2025	492	5,644	317	3,634	3,318
2026	492	5,644	303	3,478	3,175
2027	492	5,644	290	3,328	3,038
2028	492	5,644	278	3,185	2,907
2029	492	5,644	266	3,048	2,782
2030	492	5,644	254	2,916	2,662
2031	492	5,644	243	2,791	2,548
2032	492	5,644	233	2,671	2,438
2033	492	5,644	223	2,556	2,333
2034	492	5,644	213	2,446	2,232
2035	492	5,644	204	2,340	2,136
2036	492	5,644	195	2,239	2,044
2037	492	5,644	187	2,143	1,956
2038	492	5,644	179	2,051	1,872
sum	61,175 (USD 52 million)	112,881 (USD 96 million)	51,269 (USD 44 million)	64,336 (USD 55 million)	13,067 (USD 11 million)

Note. The price unit is KRW million. USD 1 = KRW 1172.5, based on the exchange rate of 31/12/2015.

In the last row of Table 8.6, the NPV of the ozone plus GAC alternative appears as KRW 13,067 million (USD 11 million), which is smaller than the NPV of the GAC alternative. This result means that the cost of the ozone treatment system overtakes the benefit. The three discount cash flow methods allow a more exact analysis of which alternative is more effective. Table 8.8 shows the results of CBA of the two alternatives when using the whole data set to calculate the social benefits.

Table 8. 8 *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 result is not a "sufficient" condition of the investment but rather a "necessary" condition. If a discount rate of 8.97% applies to the GAC alternative, then its NPV would be zero and the B/C ratio would be one. Moreover, which alternative is more efficient is of an interest. The B/C ratio is recommended as the best decision -making tool (Pearce, 1983). The B/C ratio of the GAC, 1.389, is greater than that of the ozone plus GAC, 1.225. If there iss a budget constraint for the investment, the GAC should be chosen. As a result, even though the two alternatives are feasible the GAC alternative is more efficient in terms of the B/C ratio.

8.3 Sensitivity Analysis

So far, the costs and benefit for installing the new advanced water treatment systems have been estimated. However, in practice the costs and benefits are not perfectly predictable with certainty. In the following subsection, various sensitivity analyses will be discussed.

8.3.1 Risk and Uncertainty

There is risk and uncertainty in estimating future figures. In this research, many kinds of figures, costs, benefits, business life and social discount rate, have been used for the cost-benefit analysis. Risk is defined as a situation in which some values are known with their probabilities. When the probabilities are unknown, the situation is defined as uncertainty. A risk premium approach will be used for dealing with the risk and uncertainty, by adding a risk premium to the social discount rate. Four categories of scenarios will be used. The first is related to the risk premium approach, which adds a premium to the chosen social discount rate of 4.5%. The second concerns the business life, which drops from 20 years to 10. The third relates to the cost; the construction costs increase by 20%, which is the percentage from comparing the largest unit construction cost among the previous eight projects with the unit cost of the standard, as discussed in Section 7.3.2. The last category contains several scenarios that manipulate the benefits.

8.3.2 Risk Premium Approach

Table 8.9 shows the result of the cost-benefit analysis with 14 social discount rates between 1.0% and 10.0%.

Table 8. 9 *Cost-Benefit Analysis of the two alternatives with several discount rates*

Social discount rate	GAC		Ozone plus GAC	
	NPV (KRW million)	B/C	NPV (million)	B/C
1.0 %	39,907 (USD 34.0 million)	1.855	40,254 (USD 34.3 million)	1.687
1.5 %	35,492 (USD 30.3 million)	1.777	35,262 (USD 30.1 million)	1.614
2.0 %	31,452 (USD 26.8 million)	1.703	30,699 (USD 26.2 million)	1.546
2.5 %	27,753 (USD 23.7 million)	1.634	26,526 (USD 22.6 million)	1.481
3.0 %	24,363 (USD 20.8 million)	1.567	22,706 (USD 19.4 million)	1.419
3.5 %	21,256 (USD 18.1 million)	1.505	19,209 (USD 16.4 million)	1.361
4.0 %	18,405 (USD 15.7 million)	1.445	16,004 (USD 13.6 million)	1.307
4.5 %	15,788 (USD 13.5 million)	1.389	13,067 (USD 11.1 million)	1.225
5.0 %	13,385 (USD 11.4 million)	1.336	10,373 (USD 8.8 million)	1.206
5.5 %	11,176 (USD 9.5 million)	1.286	7,901 (USD 6.7 million)	1.159
6.0 %	9,145 (USD 7.8 million)	1.238	5,632 (USD 4.8 million)	1.116
6.5 %	7,277 (USD 6.2 million)	1.192	3,549 (USD 3.0 million)	1.074
7.0 %	5,558 (USD 4.7 million)	1.149	1,635 (USD 1.4 million)	1.035
10.0 %	-2,257 (USD -1.9 million)	0.933	-7,002 (USD -6.0 million)	0.838

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

When the discount rate changes from 1.0% to 7.0%, the feasibilities are sustained. However, when the discount rate reaches at 10.0%, the NPV values go down below zero and the B/C ratios are also below one. This result means that the two alternatives are not feasible in the case. When the discount rate decreases, usually the present value of the benefits increases. As discussed in subsection 8.1.1, the expenditure of most businesses comes first and returns come later. A decline in the social discount rate usually makes the returns increase and the expenditure decrease. The risk comes from an increase in the discount rate.

8.3.3 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, as discussed in Section 8.1.1. Therefore, a 15 year business life can serve as a lower bound of the business life of the alternative. However, a 10 -year business life may be a more careful approach for the sensitivity analysis. Table 8.10 shows the result of sensitivity analysis when the business lives of the two alternatives vary from 10 to 20 years.

Table 8. 10 *Sensitivity Analysis in the case that the business lives between 10 and 20 years*

Year	GAC			Ozone plus GAC		
	NPV (KRW million)	B/C	IRR	NPV (KRW million)	B/C	IRR
10	-4,268 (USD -3.6 million)	0.889	2.12 %	-9,937 (USD -8.5 million)	0.798	0.06 %
11	-1,843 (USD -1.6 million)	0.952	3.57 %	-7,155 (USD -6.1 million)	0.855	1.60 %
12	479 (USD 0.4 million)	1.012	4.72 %	-4,493 (USD -3.8 million)	0.909	2.83 %
13	2,700 (USD 2.3 million)	1.069	5.65 %	-1,945 (USD -1.7 million)	0.961	3.83 %
14	4,825 (USD 4.1 million)	1.122	6.42 %	493 (USD 0.4 million)	1.010	4.66 %
15	6,859 (USD 5.9 million)	1.173	7.05 %	2,826 (USD 2.4 million)	1.056	5.34 %
16	8,806 (USD 7.5 million)	1.221	7.57 %	5,058 (USD 4.3 million)	1.100	5.92 %
17	10,668 (USD 9.1 million)	1.266	8.01 %	7,194 (USD 6.1 million)	1.142	6.40 %
18	12,451 (USD 10.6 million)	1.310	8.39 %	9,239 (USD 7.9 million)	1.181	6.81 %
19	14,156 (USD 12.1 million)	1.350	8.70 %	11,195 (USD 9.5 million)	1.219	7.16 %
20	15,788 (USD 13.5 million)	1.389	8.97 %	13,067 (USD 11.1 million)	1.255	7.46 %

Note. The social discount rate was assumed to be 4.5%. USD 1 = KRW 1172.5.

As shown in Table 8.10, the GAC option sustains the feasibility when the business life exceeded 11 year, but the one of the ozone plus GAC option holds the validity when the business life exceeds 13 years. These results show the break-even points of the business lives of the two alternatives. Therefore, the break-even point of years for the GAC option is 12 and the break-even point of years for the ozone plus GAC is 14.

8.3.4 Decrease in Benefits

In this subsection, several analyses are examined for the case where the benefits changes. The first case assumes the benefits decrease to zero over 20 years, using a method similar to straight-line depreciation in accounting. Thus, 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, as shown in Table 8.11.

Table 8. 11 *Reduction of the benefit during 20 years*

Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Benefit (USD million)	5,644 (4.8)	5,347 (4.6)	5,050 (4.3)	4,753 (4.1)	4,456 (3.8)	4,159 (3.5)	3,862 (3.3)	3,565 (3.0)	3,268 (2.8)	2,971 (2.5)

Year	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Benefit (USD million)	2,674 (2.3)	2,376 (2.0)	2,079 (1.8)	1,782 (1.5)	1,485 (1.3)	1,188 (1.0)	891 (0.8)	594 (0.5)	297 (0.3)	0

Note. The price unit is KRW million. USD 1 = KRW 1172.5.

Table 8.12 shows the result of the sensitivity analysis in the case.

Table 8. 12 *Sensitivity Analysis in the case where the benefits are decreasing to zero*

KRW million	Present Cost	Present Benefit	NPV	B/C ratio	IRR
GAC (USD million)	40,556 (34.5)	32,457 (27.7)	-8,099 (-6.9)	0.800	0.23 %
Ozone + GAC (USD million)	51,269 (43.7)	37,061 (31.6)	-14,208 (-12.1)	0.723	-1.44 %

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

In this case, all the values are at the outside of the validity range of the two alternatives. Thus, if the social benefits from improvement of drinking tap water quality decreases, installing the new advanced treatment systems would not be feasible.

The second case assumes no benefit after the 12th year of operation. Table 8.13 shows the result of the sensitivity analysis in the case.

Table 8. 13 *Sensitivity Analysis when the benefits are removed after the 12th year*

KRW million	Present Cost	Present Benefit	NPV	B/C ratio	IRR
GAC (USD million)	39,019 (33.3)	39,497 (33.7)	479 (0.4)	1.012	4.72 %
Ozone + GAC (USD million)	49,592 (42.3)	45,099 (38.5)	-4,493 (-3.8)	0.909	2.83 %

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

The two alternatives show different results. The GAC alternative sustains the validity but the ozone plus GAC alternative does not. This result suggests that if the social benefits disappear before the 12th year, then the feasibility of the investments can be rejected.

Thirdly, the CBA is examined with a lower estimate of the benefits, that is, using the lower bound in the 95% confidence interval of simulating the median values of the MWTPs of the ANA 1 model. As shown in Table 8.1, the lower bound of the MWTP of the safety was estimated at KRW 0.0381 and that of the MWTP of the taste and odour is at KRW 0.0063. Table 8.14 shows the changes in the social benefits in the case.

Table 8. 14 *Change of Social Benefits of the lower bounds of the simulation*

KRW million	Monthly Social Benefit	Annual Social benefit
GAC	412 → 341	4,943 → 4,089
Ozone + GAC	470 → 388	5,644 → 4,663

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%). Table 8.15 shows the results of the CBA with the estimates of the lower bounds of the simulation.

Table 8. 15 *CBA when the estimates of the lower bounds of the simulation*

KRW million	Present Cost	Present Benefit	NPV	B/C ratio	IRR
GAC (USD million)	40,556 (34.6)	46,609 (39.8)	6,053 (5.2)	1.149	6.32%
Ozone + GAC (USD million)	51,269 (43.7)	53,155 (45.3)	1,886 (1.6)	1.037	4.95%

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

The values of the three discount cash flow methods show the feasibility of the two alternatives. When using the lower bound in the 95% confidence interval of the bootstrapping method, the lower bound of the MWTP of the safety is estimated at KRW 0.0465 and that of the taste and odour is at KRW 0.0060. Table 8.16 shows the changes in the social benefits.

Table 8. 16 *Change of Social Benefits of the lower bounds of the bootstrapping*

KRW million	Monthly Social Benefit	Annual Social benefit
GAC	412 → 344	4,943 → 4,132
Ozone + GAC	470 → 393	5,644 → 4,717

In this case, the annual social benefit of the GAC decreased by KRW 811 million (16.4%) and the one of the ozone plus GAC decreases by KRW 927 (19.3%). Table 8.17 shows the results of the CBA with the estimates of the lower bounds of the bootstrapping.

Table 8. 17 *CBA when the estimates of the lower bound MWTPs were used*

KRW million	Present Cost	Present Benefit	NPV	B/C ratio	IRR
GAC (USD million)	40,556 (34.6)	55,456 (47.3)	14,900 (12.7)	1.367	8.74%
Ozone + GAC (USD million)	51,269 (43.7)	63,315 (54.0)	12,042 (10.3)	1.235	7.24%

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

The result shows larger the discount cash flows values than ones for the simulation. Thus, the sensitivity analysis of the simulation method provides the lower values for the decision rules.

Last, the CBAs are examined when some residents do not want to pay any more to improve the quality of drinking tap water. Actually, one can assume that some people don't have a positive WTP for the two alternatives. These people should be excluded when calculating the social benefits. As discussed in subsection 8.1.3, this research measured the respondents who are assumed to have zero WTPs for the two advanced alternatives for the eight models. Among them, two models (MNL 2 and RPL 2) showed that nobody has the negative sums of the coefficients of ASC and socioeconomic factors. Also, the MNL models do not provide the individual coefficients. Therefore, the five models can be used for calculating the respondents who are assumed to have zero WTPs for the two advanced alternatives. Table 8.18 shows the result of the sensitivity analyses for the respondents with zero WTPs for the five models.

Table 8. 18 *Sensitivity analyses for the respondents with zero WTPs for the five models*

Model		RPL1	FAA1	FAA2	ANA1	ANA2
Respondents with zero WTPs		42	46	55	13	63
Proportion of the respondents with zero WTPs		10.3%	11.3%	13.5%	3.2%	15.5%
Proportion of the beneficiary (Beneficiary in population)		89.7% (176,451)	88.7% (174,484)	86.5% (170,156)	96.8% (196,083)	84.5% (166,222)
GAC	B/C	1.565	1.773	1.303	1.356	1.126
	NPV (USD million)	22,922 (19.6)	31,355 (26.7)	12,301 (10.5)	14,428 (12.3)	5,100 (4.4)
	IRR	10.77%	12.78%	8.05%	8.62%	6.04%
Ozone + GAC	B/C	1.410	1.596	1.171	1.224	1.014
	NPV (USD million)	21,043 (17.9)	30,571 (26.1)	8,757 (7.5)	11,477 (9.8)	730 (0.6)
	IRR	9.11%	10.96%	6.53%	7.12%	4.68%

Note. The unit of NPV is KRW million. USD 1 = KRW 1172.5, the exchange rate based on 31/12/2015.

As shown in Table 8.18, the ANA 2 model shows the lowest the three feasibility values (B/C, NPV, and IRR) because the number of beneficiary are assumed to be the largest and the MWTPs are measured to be lowest among the models. In that case, the number of households for measuring the social benefit dropped from 196,712 to 166,222. The social benefits were calculated by multiplying the number of households in the city and the household benefits, which were from MWTPs of each attribute. The household benefits would be changed because some respondents were assumed to have zero WTPs in the models. Thus, 63 respondents (15.5%) were excluded and the median MWTPs for each attribute re-calculated for 343 respondents for the ANA 2 model. Table 8.19 shows the results of the CBA when the households that would not want to pay for the improvement are excluded.

Table 8. 19 *CBA when the households with zero WTP are excluded*

KRW million	Present Cost	Present Benefit	NPV	B/C ratio	IRR
GAC (USD million)	40,555 (34.6)	45,655 (38.9)	5,100 (4.4)	1.126	6.04 %
Ozone + GAC (USD million)	51,269 (43.7)	51,999 (44.3)	730 (0.6)	1.014	4.68 %

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

Even when those households are excluded, the three discount cash flow values show that the projects remain valid. The B/C ratio of the GAC, 1.126 is greater than that of the ozone plus GAC, 1.014. If there is a budget constraint for the investment, the GAC should be chosen. As a result, even though the two alternatives are feasible the GAC alternative is more efficient in terms of the B/C ratio.

8.3.5 Increase in Costs

The second case for the sensitivity analysis is an increase in the construction unit costs. Despite the trend of a decreasing producer price index in South Korea since 2012, the assumption used is that there is a 20% increase in costs using the most expensive construction unit cost of previous cases in South Korea, as discussed in Section 8.1.4. Table 8.20 shows the result of the sensitivity analysis in the case.

Table 8. 20 *Sensitivity Analysis in the case of a 20% increase in costs*

KRW million	Present Cost	Present Benefit	NPV	B/C ratio	IRR
GAC (USD million)	47,714 (40.7)	56,344 (48.1)	8,630 (7.4)	1.181	6.64 %
Ozone + GAC (USD million)	60,483 (51.6)	64,336 (54.9)	3,852 (3.3)	1.064	5.26 %

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

Although the costs of the two alternatives increase by 20% the three discount cash flow values show that the projects remain valid. The investment in the new advanced water treatment system is assessed as feasible until the construction unit costs increase by 1.441 times (44.1%). Actually, even 20% increase in the construction costs is empirically unlikely for the following reasons. First is the bidding process for governmental contracts. Generally, the actual contract price is reduced from the preliminary price given by the government because of the competitive bidding process. In most governmental contracts, the company that bids the lowest price can win the contract. Therefore, the contract price will be the lowest bidding price so it can usually act as an upper bound for the price. The second relates to the social reputation of companies. Usually, when private companies conduct a government project in South Korea, they are cautious in changing the contract price between themselves and the government. Also, strict restrictions on apply with respect to increasing the contract price and increasing the contract amount by a law[26] of South Korea.

8.3.6 Determent of Construction

As discussed in Section 7.2.2 and 8.1.5, a one year delay in construction completion can be used as a scenario for sensitivity analysis. In this case, the total business life would be 25 years, because the project service life is 20 years and the construction period including the design is six years; the improved drinking tap water is assumed to be supplied in the sixth year. Table 8.21 shows the result of the sensitivity analysis in the case.

[26] The law is the Act on Contracts to which the State is a Party, South Korea. According to the Law, if a contractor cannot finish the task of the contract until the expiration date, a compensation penalty of determent must be imposed and paid, which amount is 0.1% of the contract price per day. Therefore, if a company deters a project for one year the determent penalty is 36.5% of the contract price. There are two more disadvantages for the company that deters a public contract. The first is that the company cannot bid on public contracts for three years after deterring the contract and second thing is that the company must pay more costs than specified in the contract before it finishes the project. Also, an increase in the contract amount is accepted only when the governments ask to change the contents of the contract.

Table 8. 21 *Sensitivity Analysis in the case of one year determent of construction*

KRW million	Present Cost	Present Benefit	NPV	B/C ratio	IRR
GAC (USD million)	39,672 (33.8)	53,918 (46.0)	14,324 (12.2)	1.362	8.31 %
Ozone + GAC (USD million)	49,899 (42.6)	61,565 (52.5)	11,666 (10.0)	1.234	7.04 %

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

Although the completion of the construction is delayed by one year, the three discount cash flow values show that the projects remain valid. The NPV of the GAC, KRW 14,324 million is greater than for the ozone plus GAC, KRW 11,666 million. The B/C ratio of the GAC, 1.362 is greater than for the ozone plus GAC, 1.234. If there is a budget constraint for the investment, the GAC should be chosen.

8.3.7 Distributive Weights

So far, a variety of CBAs has been used to test the feasibility of the two investments in improving drinking tap water quality. The benefits are measured by using the median WTPs of the 406 respondents in the target area. In using the same value for measuring the social benefits, the income distribution must be taken into account. When calculating the social benefits, using the same value requires equality of wealth. However, in the real world, there is much inequality of wealth. This may matter in measuring the social benefits. For this reason, distributional weights are sometimes used.

However, in this research, distributional weights are not used for two main reasons. The first is that the estimated median WTPs are small amounts for the sample. The median monthly income per household is estimated at KRW 4.364 million (USD 3,706). The proportion of the WTP for ozone plus GAC (KRW 2,391 = USD 2.03) to the average monthly income per household is 0.05 %. Therefore, each share can be considered a negligible amount in terms of distributional weights.

8.3.8 Summary of Sensitivity Analysis

To sum up the results of sensitivity analysis using the various scenarios, Table 8.22 shows the outline of the implemented sensitivity analyses.

Table 8. 22 *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 MWTPs	1.149	1.037	6,053 (USD 5.2)	1,886 (USD 1.6)	6.32	4.95
Exclusion of household without Benefit	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.

As shown in Table 8.22, the feasibility of the two alternatives for improving drinking water quality depends on the conditions. In the worst assumption, in which the social benefits decrease to zero in 20 years, the B/C ratio of the GAC is estimated at 0.800, and the NPV is estimated at negative KRW 8,099 million. The B/C ratio of the Ozone plus GAC is estimated at 0.723, and the NPV is estimated at negative KRW 14,208 million. Based on the results of several scenarios for the sensitivity analysis, the GAC option shows higher values for the NPV and B/C ratio. Therefore, the GAC option appears to be more robust than the ozone plus GAC.

8.4 Protecting the Catchment

Several scenarios of the CBA have been examined. However, if the raw water quality in the catchment of Lake Daecheong improves, the feasibility of the new advanced water treatment systems would be affected. In this subsection, the two approaches, improving the raw water quality and installing the new treatment systems are explored.

8.4.1 Improvement of the Raw Water Quality

Water pollution is a negative externality, as discussed in Section 1.4. If residents upstream release pollutants to a watershed, the residents downstream will suffer because of water pollution. Regarding the Geum River Basin, the difference between causers and sufferers seems to be simple because water flows from upstream site to downstream areas. There are three main ways to solve this problem of a negative externality; private negotiation, judicial dispute resolution, and administrative regulation.

Private negotiation is an example of a solution for a negative externality. Coase (1960) argues that if private negotiations are possible, socially efficient resource allocation can be achieved. The decision by a country's courts can only affect the benefit distribution between the upstream and downstream residents. Coase also claims that private negotiations can occur only when the number of people involved is small and the cost of negotiation is low. Consequently, both the downstream and upstream residents can gain more utility through private negotiations.

However, if the residents downstream question why they should pay, they might appeal to the courts regarding the water pollution. This is the judicial dispute resolution. If the pollutant emissions are illegal in the upstream areas, the residents downstream can sue the people upstream. However, if the pollutant emissions in the upstream areas are legally permissible, the court cannot prohibit the upstream residents from releasing pollutants.

Many people are involved in the basin and the cost of negotiations is likely to be substantial. Moreover, when the costs incurred by court ruling are expected to be large and it is unclear whether the pollutant emission upstream is illegal, administrative regulations might be considered. The most prominent method involves imposing taxes or penalties. As discussed in Chapter 1, if the government imposes a tax per unit of emissions upstream, the residents upstream will emit pollutants to match the marginal value of the cost per unit. On the other hand, the government can give a permission in which the residents upstream are allowed to emit the pollutants up to a social optimal point. If they emit more than the specified amount, they pay heavy fines or suffer other punishment. In this case, the residents upstream must internalise the costs of the pollution.

8.4.2 Improvement of Drinking Water Quality

The problem is that the residents in the upstream areas of the basin are emitting pollutants without legal sanctions. In this case, the people in Cheongju City must consider ways to drink cleaner water. If private negotiation with the residents upstream is possible and the costs for improving the water quality in the catchment area are less than the cost of installing new advanced treatment systems, the people in Cheongju City may prefer to pay the costs. However, the most important problem is how much and how quickly the improvement of drinking water quality improvement can be achieved.

Through this research, the citizens of Cheongju City show a monthly WTP of KRW 2,391 per household to obtain cleaner drinking tap water. The cost to supply cleaner water is approximately KRW 839 per month per household for the GAC option and KRW 1,057 for the ozone plus GAC. Such improved drinking water can be supplied in five years.

Probably, it may be more costly and time-consuming to improve the raw water quality upstream. For example, as discussed in Section 1.4.3, the monthly costs for treating livestock sewage in the upstream site are estimated at KRW 2,618 per household assuming every household in the basin pays for the costs. This is higher than the costs for installing the two advanced water treatment systems. Thus, controlling the causes of water pollution would be more effective than dealing with the effects. In fact, installing new livestock sewage treatment systems is about treating the effect. Therefore, many attempts should be made to prevent the causes of water pollution.

This discussion does not consider everything because someone has to pay the costs for preventing water pollution in the upstream site of the basin. Other sources of pollution also exist, including domestic, industrial, and agricultural. Even though some administrative regulations are imposed in the upstream areas, it will take a long time for the water quality in the catchment to improve. In this sense, the advanced water treatment systems should be recognized as a complementary method for supplying safer and cleaner drinking water to the people in the basin. Internalizing the costs of water pollution should be a primary path. In this sense, people who pollute could and (or) should be forced to pay the costs associated with the pollution.

It is difficult to think of the situation in which the raw water quality improves to the level that water treatment systems are not more necessary to provide drinking tap water. If less pollution occurs in the future, more advanced water treatment systems will not be necessary. To make the raw water clearer in the catchment area, people living in the basin must pay more to treat all sources of pollution (e.g. domestic, industry and farming). All approaches should and (or) could be implemented for preventing pollution in the long term. In addition, other benefits will come from clearer water in the catchment area, such as non-use values in terms of environmental economics. Some people in the basin would likely pay more just for improvement of the water in rivers, and lakes even though they do not go there. Therefore, to improve the raw water quality, additional studies should be conducted considering more extensive approaches for measuring the costs and benefits of clean water environment in the catchment area.

So far, the study suggests that the new advanced water treatment systems can act as a short-term complementary solution for supplying safer and cleaner drinking tap water. The results of this research indicate that the costs for water environment are related to other public spending. If people do not take care of the water environment, the pollution might increase until they are no longer able to treat the water for drinking. In that case, people would pay large costs for drinking tap water. Advanced water treatment systems offer a short-term solution and preventing water pollution is the long-term solution for safer and cleaner drinking water. In the short term, the new advanced water treatment systems can be installed for safer and cleaner water. However, people must acknowledge their contribution to pollution. When people learn to prevent water pollution and improve the raw water quality, they can save in future costs. In future, it is necessary to consider more comprehensive approaches including the costs and benefits of preventing water pollution in the upstream site of the basin, before implementing a public project to install advanced treatment systems.

Chapter 9. Conclusion

9.1 Overview

9.1.1 Motivation and Purpose of the Research

This research is triggered by the fact that many Koreans are dissatisfied with the quality of drinking tap water. The problem with drinking tap water quality is caused by pollution of the water environment. Most rivers as the main water resources, have been polluted since the fast industrialization in South Korea since 1970s. As a result, most waterworks at present have not been able to address problems like unpleasant taste and odour of drinking tap water.

With respect to the decrease in satisfaction with drinking water quality, consumers' trust in the water sector in South Korea has also decreased (72.1% of South Koreans distrust the organisations related to drinking tap water in 2016). Many people would not like to drink tap water as it is. Consequently, it is predictable that Korean people could underestimate the installing advanced water treatment systems and even protecting the catchment because of the distrust.

This research focuses on one city, Cheongju in South Korea. To supply safer and cleaner drinking tap water to citizens, improvement of raw water quality in the catchment should be a primary approach. Thus, the causes and levels of water pollution in Lake Daecheong as the water supply source of the city should first be addressed. However, this will take more time than if installing advanced water treatment facilities.

For a short-term solution, this thesis aims to test the feasibility of investment in installing two advanced water treatment systems, GAC and ozone plus GAC options. It is important to test the feasibility of a public project to achieve efficient allocation of scarce public budgets. This research does not analyse the costs and benefits of prevention of water pollution in the catchment for improving water quality. However, prevention of pollution and improvement of water quality need to be considered to devise a more comprehensive approach which would use several complementary methods.

9.1.2 Contents of the Research

This research used CBA to test the feasibility of two types of advanced water treatment systems in its final analysis. The thesis consists of three parts. The first part explores preparation for the research (Chapters 1 through 3). In the first part, literature related to the subject is reviewed and the methodologies are explored. The second part discusses the questionnaire, the refinement of the data and the measurement of WTP and social benefits (Chapters 4 through 6). The third part includes the cost estimations, cost-benefit analysis and conclusion (Chapters 7 through 9). More importantly, the last part examines the result of the CBA and sensitivity analysis of several scenarios. A variety of sensitivity analyses is carried out to address uncertainty and risk. This chapter concludes the paper.

9.2 Feasibility of the investment

9.2.1 Evaluation of the Social Benefits

Four types of questionnaires are given to respondents using different methods for mitigating potential hypothetical bias with the combination of budget constraint reminder, cheap talk and honest priming task. Three types of models - multi-nominal logit, random parameter logit, and latent class logit model - and eight logit models are used to estimate the marginal willingness to pay. Among them, the two RPLs and four LCMs provided MWTP spaces, which allows for measuring mean and median MWTPs. In a more cautious approach, the mean and median values of MWTPs are compared and the median MWTPs show lower values than the mean values and are therefore used in the subsequent cost-benefit analysis.

The estimates of WTPs per household using the MWTPs are between KRW 2,094 (USD 1.78[27]) and KRW 5,370 (USD 4.56) for the GAC alternative and between KRW 2,391 (USD 2.03) and KRW 6,035 (USD 5.13) for the ozone plus GAC option per month and household. Previous studies evaluating the WTPs regarding drinking water are explored, including three studies measuring the WTP in South Korea. Although they conducted with different methods, indifferent areas and years, the three studies show a range for the WTPs between KRW 2,322 and 7,236 (USD 2.2 - 6.1). These figures can be used as benchmark points for assessing the reliability and validity of the estimates of WTPs in this research. Moreover, the lower bounds are close to the spending for bottled water USD 2.28[28]. Considering that Koreans pay a significant amount for in-line water filters as well, this suggests that the WTP measures obtained in the present study are within a valid range.

9.2.2 Cost-Benefit Analysis

For the cost-benefit analysis, the median values of WTPs are used for a more cautious approach to evaluate the social benefits. The net present values of the two alternatives are larger than zero in the basic scenario (20 year business life, 4.5% social discount rate and 5 year construction period): KRW 15,788 million for GAC and KRW 13,067 million for ozone plus GAC. The benefit to cost ratio of the GAC (1.389) is larger than that of the ozone plus GAC (1.225). The values of NPVs and IRRs also show the same results as the B/C.

To cover risk and uncertainty, several scenarios of sensitivity analyses are examined, including the discount rate increases, costs increase, construction is delayed and benefits decrease. The worst case scenario of the sensitivity analyses is when the social benefits gradually decrease to zero during the business life. In this case, the NPVs of the two alternatives are lower than zero, negative KRW 8,099 million for GAC and negative KRW

[27] USD 1 = KRW 1172.5, based on the exchange rate at the end of 2015.

[28] The value is shown in Table 1.3.

14,208 million for ozone plus GAC. The B/C ratio of GAC is 0.800 and the one of ozone plus GAC is 0.723. As a result, the values do not sustain the validity of the two alternatives. Also, the three values (B/C, NPV, IRR) do not sustain the validity of the two options, when the business life is reduced from 20 years to 10. The sensitivity analysis suggests that the feasibility of the alternatives depend on the conditions of the project. Moreover, the result suggests that the GAC is a more robust option than ozone plus GAC because the decision rules of three discount cash flow methods show higher values for GAC.

9.3 Policy Implications

This research explores the feasibility of the two advanced water treatment alternatives in light of their social costs and benefits. The sensitivity analyses present the feasibility of the projects using the three discount cash flow values. The investments are shown to be beneficial to the people in Cheongju City under the basic assumptions discussed above.

Most people show lower interest in the colour attribute of drinking tap water. Using the WTP spaces, it is possible to determine which attribute is comparatively more important. Analysis of the WTP distributions indicates that safety, taste and odour are regarded as the critical attributes valued by the respondents. However, some attributes of a public good and service can be ruled out from the public decision–making processes.

The respondents seem to want to improve the drinking water quality depending on the cost. Analysing the choice proportions for each alternative is helpful in understanding the respondents' thoughts about improving drinking water quality. For example, 23.9% of the respondents wanted to maintain the status quo, 47.4%preferred the GAC option and only 28.7% preferred the ozone plus GAC option.

The GAC option is more robust in supplying safer and cleaner drinking tap water as a whole. The discount cash flow values provide more information about which alternative should be chosen. The B/C ratio can play a prominent role in the process of decision -making because it is considered the better decision rule among the three methods. The GAC option show higher values of the three decision rules (B/C, NPV, and IRR) than the ozone plus GAC in all scenarios.

9.4 Limitations of the Research

Despite the extent of this research has some limitations. This research did not investigate comprehensive methods of solving the issue of drinking water quality. Improving raw water quality in the catchment, and preventing water pollution in the basin should be investigated extensively by measuring the social benefits and costs before investing in new water treatment facilities.

9.4.1 Survey Instrument and Data Collection

First, some attributes have not been included in this research and could be added in the future. Drinking water quality in the present study is restricted to four attributes; safety, taste and odour, colour and cost (additional monthly water bill per household). For example, future studies might include “chlorine taste” as an additional attribute.

Second, depicting the safety attribute in the choice cards might allow the respondents to overestimate the probability of cancer risk. As discussed in subsection 4.4.6, to help the respondents understand, scatters of pixels are used in describing the levels of the safety attribute with the probabilities of how many people are diagnosed with cancer from drinking water when they have drunk water with certain levels of trihalomethans during their lives. However, the pixel size employed in the questionnaire is 100 times larger than the actual size. Thus, the enlarged pixels might influence the respondents to overestimate the safety problem.

Third, the way taste and odour, and colour, are described to the consumers may have triggered the problem of citizen-consumer gap. The levels of the two attributes are explained by using the levels of the proportions of how many people are satisfied with them. The respondents might be confused in answering the questionnaire because they might have acted as citizen rather than consumers. Therefore, the benefits may be overestimated by the choices of the respondents who chose the advanced options in terms of “altruistic citizenship”, even though they didn’t want to pay more as customers.

Fourth, 573 respondents participate in the survey for this research, but ineffective data and potential label heuristics emerge. Thus, 167 respondents’ data are excluded and just 406 samples are used for analysis of the coefficients. The sample size may be a limitation. A larger sample size would allow for better estimations if a higher survey budget were available.

Fifth, the estimation of coefficients from the pre-test data was used only for ex-post testing of the validity of the experimental design and not for generating it. Although the test result shows that the final experiment design does not worsen the D-efficiencies, the coefficients of the pre-test data can and should be used in future.

Sixth, the study has some limitations related to the representativeness of the sample. Five socio-economic factors are used for testing the sample representativeness: monthly water bill, gender, age, income and education. In the case of education, a large discrepancy between the sample and the population exists. Many highly educated people take part in the survey, and highly educated people are likely to have larger WTPs (Catalano et al, 2016). Therefore, the WTPs may be overestimated. Future studies may want to prevent the problem of ‘over-education’ present especially in online surveys.

Finally, interaction effects are ruled out in this research. However, it is assumed that no interaction effects exist between the attributes, first, because there seems to be no obvious relationships among the attributes, and second, more than 80% of respondent behaviour can be explained as main effects (Louviere, 1988). Future studies might however, consider interaction effects between the attributes if they seem appropriate.

9.4.2 Measuring the Benefits

Regarding hypothetical bias, this research does not measure the differences in WTPs which might be caused by the treatments for mitigating hypothetical bias. As discussed in subsection 6.6.3, the dummies of the hypothetical bias treatments were significant. This result implies that the hypothetical bias treatments might have reduce hypothetical bias. However, the study does not measure how much the treatment of hypothetical bias affected the MWTPs. Future research might attempt to quantify the difference in MWTPs resulting from hypothetical bias.

Regarding the methodology for analysing the discrete choices, this study uses the multinomial logit, random parameter logit, and latent class logit models. However, many other discrete choice models can be used, including random parameter probit, latent class random parameter logit and nested logit. Some of those models may provide additional insights into the respondents' choice probabilities and preferences.

This research uses the latent class logit models to accommodate the attribute non-attendance problem. The LCMs are well -suited for the ANA problem and can identify classes of people who ignore a specific attribute. The LCMs do not need to identify ex-ante which attribute is not important to specific class of people. The estimates of the LCMs reveal which coefficient of attribute is equal to zero. However, other types of logit models such as MNL or RPL can also be used for ANA at least as a robustness check.

9.4.3 Cost Estimation

The cost estimation can be updated with more recent data. It is based on the standards of Seoul Metropolitan Government, the study by Lee et al. in 2008, and the eight previous projects for installing the two alternatives, ozone and GAC in South Korea. Even though cost escalation is applied, the construction and operating costs of the two advanced water treatment systems may change with technical development of the systems and introduction of new alternative technologies with efficiency for water treatment. Therefore, more recent and precise cost estimation will provide the chance to judge the feasibility of the investment more correctly.

An investment in a chosen public project has opportunity cost. The costs could be invested in many other projects, instead. In this sense, the social opportunity cost must be considered. As discussed in Subsection 7.2.4, Watson (1992) states that the social discount rate can be regarded as the social opportunity cost. In this regard, the marginal social opportunity cost of capital is suggested as a method of measuring the social discount rate. However, this research explored another method (social rate of time preference) because many governments in developed countries apply in calculating the social discount rate. Future studies might use both methods and also other estimates for opportunity costs.

Moreover, note that the cost-benefit analysis is not sufficient to ensure the feasibility of an investment to improve drinking water quality. The result of cost-benefit analysis does not say everything about the feasibility of public investment, but rather suggests things to be noted in the decision-making process. Multi-criteria analysis offers an alternative approach that considers the preference of all stakeholders.

9.4.4 Future Research Challenges

This research does not deal with the distributive weights. The WTP spaces per household can be weighted according to the wealth distribution of the residents. A more progressive water bill system might be an alternative for resolving the distributive weighting issue. Therefore, more studies should look into changes in the WTP spaces.

There are also other types of consumers drinking tap water in the target area such as stores and restaurants. This research focuses on the drinking water consumed by households. However, if commercial units were included, the estimation of the social benefits might change. Therefore, including commercial and industrial units can provide more insightful estimation to understand the consumption behaviour of more residents.

Another point to note is that this research surveys people regardless of their position in their household. However, the questions ask the respondent to choose the preferred option on behalf of the household. If someone is not the head of household, she or he may not have responsibility for the answer. In this case, the answer might be less reliable. Therefore, if estimates are needed for a household unit, it would be reasonable to restrict the sample group to heads of households.

A non-parametric analysis might be an alternative approach to analysing and measuring the levels of drinking water quality. This research uses parametric analysis in evaluating the coefficients. Consumers might perceive the levels of drinking water quality as grades of quality. In this case, the independent variables would be nominal and ordinal, because people prefer one attribute to the other categorically. The non-parametric analysis may be more appropriate to the case. As a result, the ratio of other attributes by cost attribute would change unlike the result of this research. In this case, the benefits of the two alternatives would also change.

In conclusion, this research aims to test the feasibility of the two advanced water treatment facilities in the target area in South Korea. However, the decision on the investment needs to be made by taking into consideration a broader view, such as a more comprehensive approach including improvement of the raw water quality in the water catchment and (or) prevention of water pollution upstream of the basin. This research is a first step toward more rational decision –making for a public investment.

9.5 Discussion of Wider Policy Prospects for the Future

Even though this research mainly focuses on testing the feasibility of installing advanced water treatment systems in the target area, wider policy prospects for the future can also be taken into account. This subsection will review the approaches discussed in the thesis.

9.5.1 Ways to Protect the Catchment Area

As discussed in Chapter 1, many different approaches can be used to provide people with safer and cleaner water. At the moment, Korean people have already sought alternatives such as purchasing bottled water and in-line filers. The amount of spending on these two alternatives shows how much people are able to pay additionally for safer and cleaner water. In addition, Korean people don't have trust in the water industry and the people's distrust may play a negative role in improving drinking water quality. Therefore, it is necessary to recover the people's trust in the organizations related to supplying drinking water. If the government actively pursues several environmental projects to protect the river basin from pollution and takes measures to improve the water quality in the catchment area, people's trust may be restored.

To protect the water environment in the upstream areas, water pollution caused by pollutants such as domestic and industrial sewage, fertilizers for farming and livestock excrement should be prevented. Through the process of preventing water pollution, the raw water will be improved. Several solutions can be considered to prevent pollution. The solutions can be divided into two main groups; one focuses on the causes and the other on the effect.

First, to overcome the causes of water pollution, several solutions can be applied. Even though private negotiation is discussed as a solution in terms of environmental economics, enhanced administrative regulations on pollutant discharge are regarded as a powerful practical method. If the government intensifies the punishment for violating the law on water pollution, the discharge of pollutants will be reduced. Taxation and (or) subsidy systems are also important governmental approaches. Tax relief for organic fertilizers or farming materials is an example. Subsidies can be given to farmers who reduce the use of chemical fertilizer or install new facilities to treat livestock manure. Organic production is strongly recommended to prevent the pollutants. Other governmental approaches are not explored in this research.

Second, enhancement of treatment of pollutants focuses on the effects such as domestic and industrial sewage, fertilizers for farming and livestock manure. Introduction of new wastewater treatment facilities would offer a direct solution for reducing the inflow of pollutants. In particular, livestock manure is pointed out as the main pollution source in the catchment. Therefore, new livestock manure treatment systems would directly help reduce pollutants. Taxation and subsidy systems for organic farming, such as no-till system, could also help to reduce the wastewater associated with manure. If the government subsidises farmers who recycle the livestock manure, it could also reduce the amount of pollution. The tax system can work in the same way.

In addition to the two solution -categories, voluntary reduction of pollution by farmers is anticipated. In this respect, corporate social responsibility (CSR) is mentioned as a hopeful effort for the goal. CSR is a self-regulatory mechanism whereby a business monitors and ensures its active compliance with the law, ethical standards and national or international norms. Studies have shown that reducing the level of pollution in accordance with the law, or even below the level required by the law, can be profit-maximizing (Besley and Ghatak, 2007). All of the approaches can assist in the prevention of pollutants. However, the approaches focusing on the causes are more desirable because they are expected to be more cost-efficient than the approaches based on the effects.

9.5.2 Ways to Improve the Raw Water Quality in the Basin

Direct treatment of the raw water in the catchment is nearly impossible because the costs would be tremendous. However, it is possible to think over the efforts for controlling the raw water quality inflowing to the catchment. Several solutions can be considered.

Kim et al. (2013) suggest solutions with respect to the process of treating the inflow of pollutants. As shown in Table 1.6, they list solution for preventing water pollution in Lake Daecheong. Among them, artificial swamps, planting waterways and detention ponds are examples of treating the inflow of pollutants into the catchment. Filter strips as a buffer of unfertilized permanent grass use a similar approach. In this sense, programs of the Committee for Managing the Geum River Basin are implementing approaches such as building a buffer. The Committee is also conducting a program of afforestation in the upstream site of the basin. The afforestation includes reforestation, which means planting trees in an area where there is no tree cover. Forests rebuilt by the program can also reduce the direct inflow of pollutants into the catchment. All these types of approaches can work independently or together for prevention of water pollution.

9.5.3 Questions Surrounding the Balance of Policy in the Long-Run

The advanced water treatment systems for supplying clean water have business lives based on their technical properties. The business lives of the two alternatives are presumed to be 20 years and the construction period is assumed to be 5 years, even though several different values are tested in the sensitivity analysis. Therefore, questions about what will and should follow after 25 years can be asked.

In this regard, the advanced water treatment systems can be regarded as the short-term solution. In the long-run, the water treatment systems will wear out and not work well in supplying clean water. However, if the raw water quality is improved by that time, new investment will be unnecessary. In the same context, if the raw water quality is improved earlier than the period, 25 years, the value of the advanced systems will depreciate more quickly. However, if the raw water quality constantly worsens, the present treatment systems will not work. In this case, new technology will be necessary to produce drinking water and the costs cannot be measured at the moment.

The people upstream might be more interested in economic development or profit than in the protection of the environment. If the residents upstream continue to use the same production and consumption style, the water environment will worsen, and it will not be sustainable in the long-run. In this regard, the people have to understand that economic development need not exclude protection of the environment. As discussed in an example of CSR above, people should and can know that environmental protection does not exclude profitability and growth. Therefore, it may be necessary to change people's perception of environmental protection. The Korean government could use the education system as a policy measure to develop the people's way of thinking. Also, other different environmental projects can be considered. Encouraging citizens' voluntary attempts to conserve natural areas is an alternative. For example, the National Trust is continuing its role as a typical private non-profit organisation. The National Trust is a charity founded in England, in 1895 and has been trying to preserve nation's heritages and open spaces for everyone to enjoy. Also, in 2000, the National Trust of Korea was established to preserve heritages and nature places in South Korea and it could take a more active role in raising environmental awareness among the population. For example, the U.K. National Trust has evoked citizens' spontaneous participation by implementing various training programs and campaigns[29]. The National Trust of Korea can follow the previous trials.

All the solutions noted here should march forward together to prevent pollution and improve water quality in South Korea. Some of the environmental approaches are already in the process of implementation however, in the future, all approaches should be employed to work together to achieve a more effective and efficient outcome. In the long-run, organic farming may be one of the most important and practical solution for protecting the water environment in the basin but other solution should also be considered.

[29] For example, the U.K. National Trust continues a campaign, named Neptune Coastline campaign. In the campaign, over the past 50 years, the people-powered Neptune Coastline campaign has been enabled to buy 574 miles of glorious coastline; securing these special places for all to enjoy. Today 775 miles of coastline around England, Wales and Northern Ireland is looked after (https://www.nationaltrust.org.uk/appeal/fifty-years-of-neptune-coastline-campaign).

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

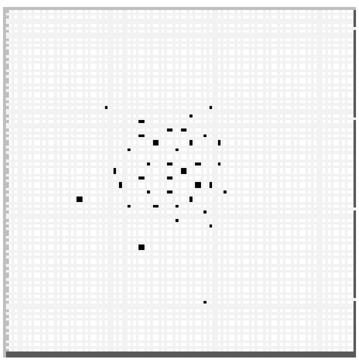
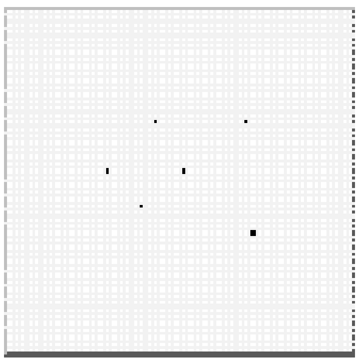
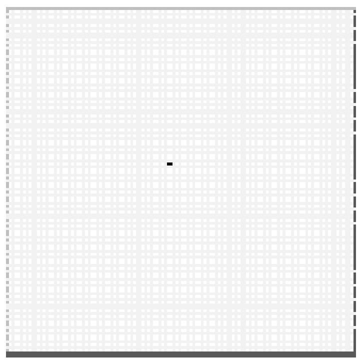
This survey presents you with each picture for describing the levels of

- 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

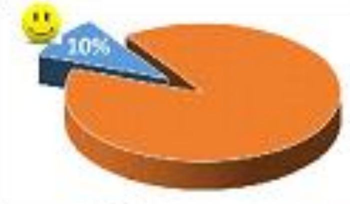
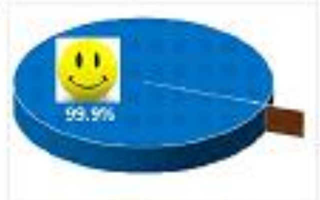
The safety of drinking water informs about the probability of how many people are diagnosed with cancer from drinking water all one's life according to the amount of THMs (Trihalomethanes). The current national criterion about THM is 0.1 mg/L meaning that cancer risk is probably 40 persons per 10 million.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

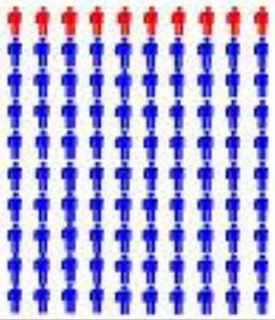
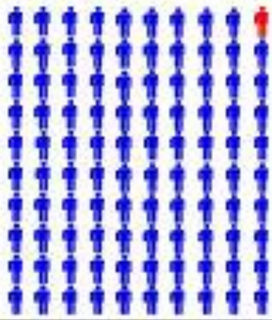
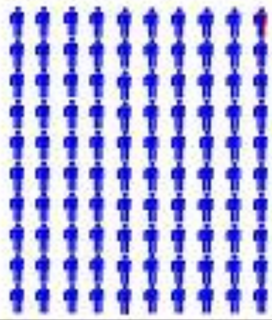
2. The taste and odour

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.**

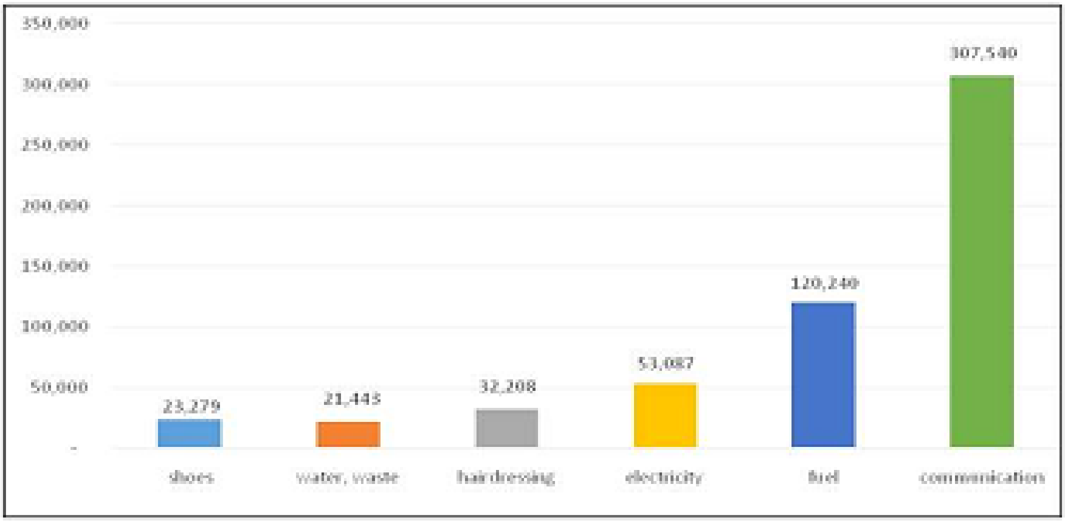
For your information, it is shown the average bill of 1 ㎥ water of some countries over the world in the next table.

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

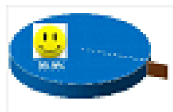
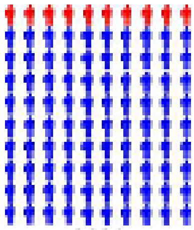
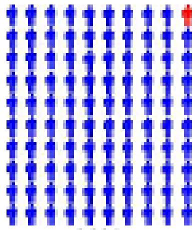
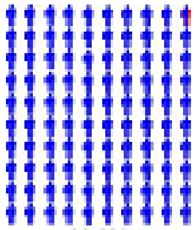
Nation	S, Korea	Japan	The U.S	The U.K	Germany	France
bill	619.3	1,646	1,446	2,357	3,236	2,491

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.

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.

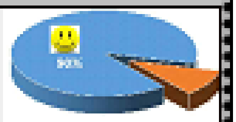
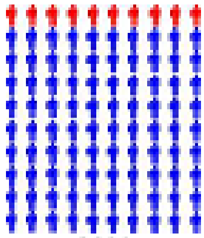
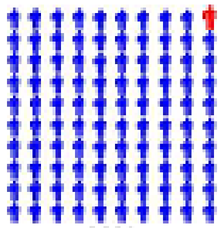
Now have a go at the following sentences:

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**)

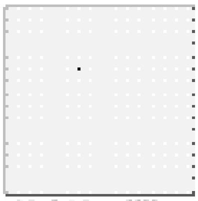
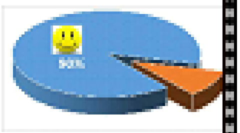
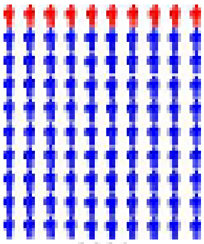
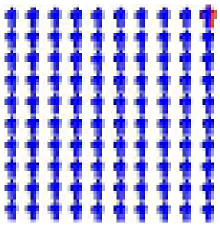
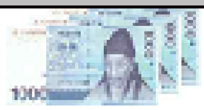
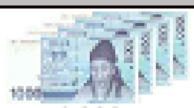
Part C. Eight Choice Cards

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.

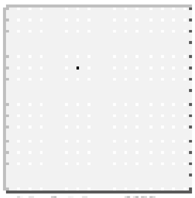
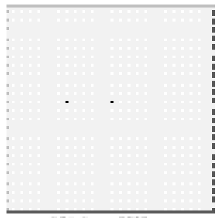
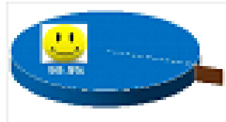
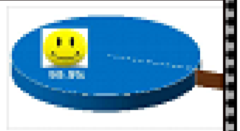
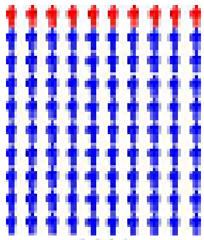
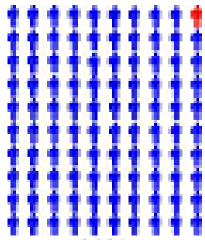
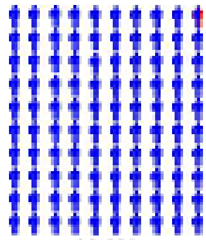
Choice Card 1

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 (%)

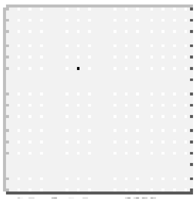
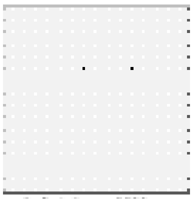
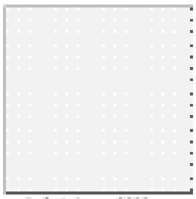
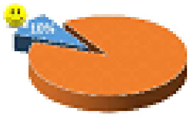
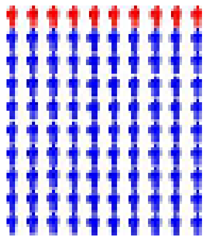
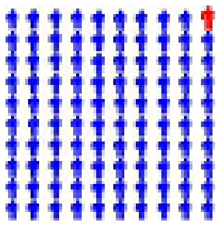
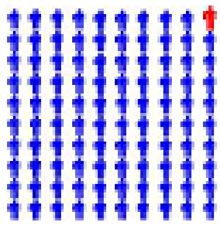
Choice Card 2

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 ☐

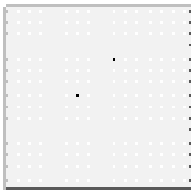
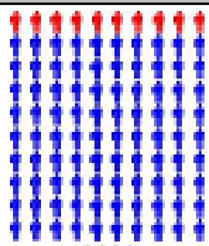
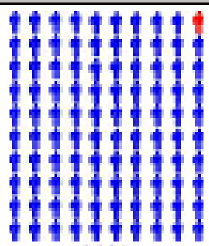
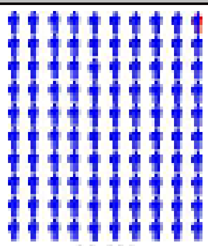
Choice Card 3

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 (%)

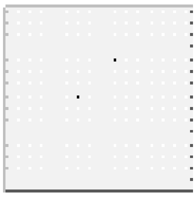
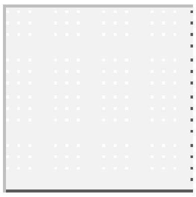
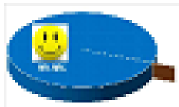
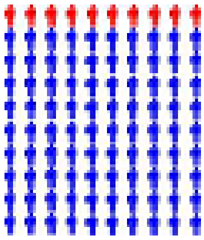
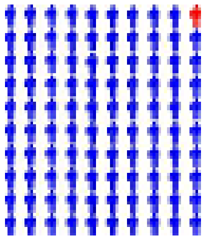
Choice Card 4

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 ☐

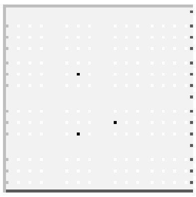
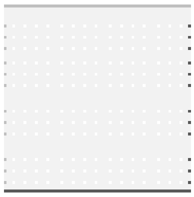
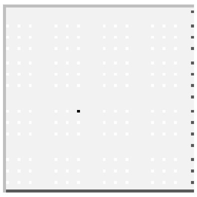
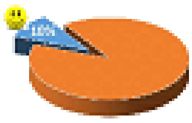
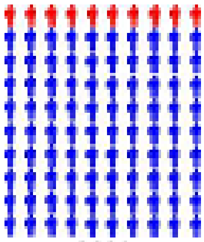
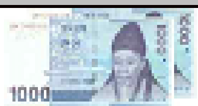
Choice Card 5

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 ☐

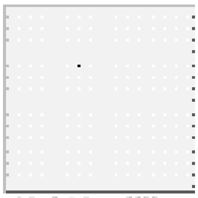
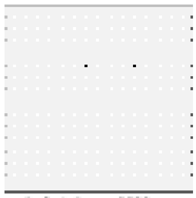
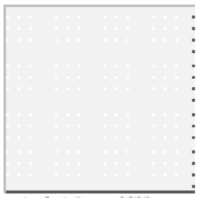
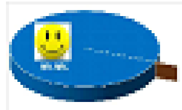
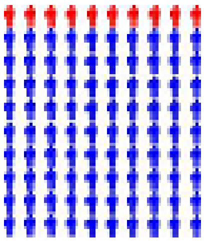
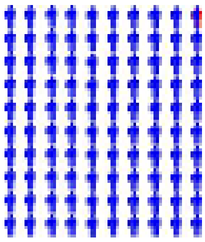
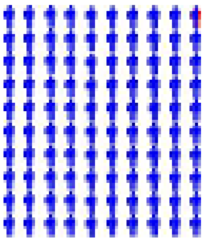
Choice Card 6

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 (%)

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 ☐

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 ☐

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 ☐

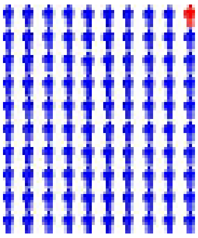
② Taste and Odour ☐

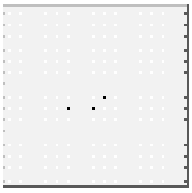
③ Colour ☐

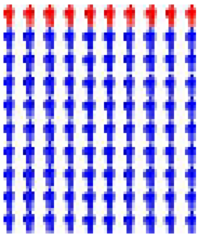
④ Price ☐

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?

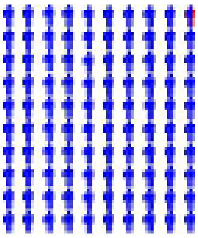
 ☐

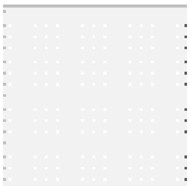
 ☐

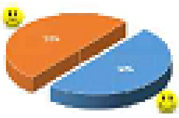
 ☐

 ☐

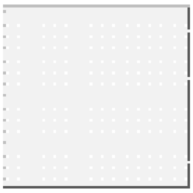
 ☐

 ☐

 ☐

 ☐

 ☐

 ☐

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. A code for generating a space of MWTPs of an LCM

Nlogit code for producing the space of the median MWTPs 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)$
```

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** means that the works are written in Korean.*