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# The Economic Valuation of Water Quality Degradation from River Algae Blooms: Evidence from the Han River\*

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Abstract: Amid a range of growing environmental concerns, water quality degradation coupled with excess concentrations of nutrients in regulated rivers and streams have become problematic at not only the local but a national level. Aiming to revitalize a healthy and self-sustaining river system, the Korean government implemented a massive river restoration project, approximately USD 71.3 billion, and ironically exacerbated algae blooms. The Han River is a restoration project river and the only drinking water source for almost the half the Korean population, including the capital, Seoul, thus impacts of algae blooms were severe. To elicit aggregate economic cost of algae blooms in the Han River, ex-ante and ex-post economic assessment was applied to survey data from 2012 and 2015, using a Spike model and difference-in-differences (DID) analysis. The aggregated cost of algae blooms was estimated to be KRW 84.44 billion (USD 76.76 million). Based on the DID results, the pure aggregate economic cost of removing algae in the Han river were calculated to be KRW 2.56 billion (USD 2.33 million), annually. Although the initial river restoration plan to revitalize rivers was optimistic and promising, consequences might burden the nation.

Key Words: Economic Valuation, Spike Model, Difference-In-Differences Analysis, Aesthetic Value, Algae Bloom

## I. Introduction

In recent decades, water quality degradation has become one of the problematic social issues for developed countries and for less developed

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countries. Of several possible causes that aggravate water quality, anthropogenic activities have played a significant role in excess concentrations of nitrogen and phosphorus, causing eutrophication in many rivers and streams (Dodds, 2006). Excess nutrients impair water quality, causing negative externalities, including toxic algal blooms that reduce economic as well as aesthetic values for water (Nelson et al., 2015). Although eutrophication of surface waters can occur naturally, anthropogenic activities upstream coupled with climate change can accelerate algal blooms, because higher temperature drives physiological processes in phytoplankton, increasing the frequency and severity of algal blooms (Wells et al., 2015). Moreover, slowing water flow in rivers and streams by introducing dams and weirs that conventionally increase the availability and therefore the value of water can ironically worsen water quality and decrease the value of water, particularly due to a more frequent appearance of algal blooms. Man-made structures in rivers and streams require massive public expenditures to construct and maintain. Adding to these costs negative externalities that result from combining these structures with recent changes in hydrologic patterns due to climate change, suggests a need to carefully assess the net impact of water infrastructure investments. Unfortunately, in many parts of the world, most negative effects from eutrophication are non-stationary, so it can be easy to neglect the costs of nitrogen and phosphorus concentrations (Nelson et al., 2015).

Since the use of algaecides should be avoided so as not to compromise drinking water quality, there are limited number of management options to remove algae blooms in regulated rivers and streams. Biochemical removal of algae such as coagulationflocculation and dissolved air floatation are well-known and widely adopted options. However, those methods require labor-intensive and costly cleaning operations, imposing a capital burden on water service providers (MacArthur et al., 2009). Another method is mechanical removal using granular media filtration and intermittent sand filtration. As with the high-management schemes. the mechanical algae removal options may demand capital-intensive inputs, which burden water treatment facilities. Last but not least, flushing flows are a strategic option, in particular for sediment removal, and can eliminate algae blooms and potentially limit periphyton (Flinders and Hart, 2009). However, a hydraulic strategy for benthic algae removal is likely to decrease water availability in the short run and must be applied in a timely manner (Lee et al., 2011). Of these algae removal schemes, it should be possible to select a feasible option with respect to cost effectiveness. In the absence of information on the benefits of algae removal in natural rivers and streams, applying a homogeneous management scheme may result in unexpected consequences, because benefits are affected by location and time constraints. It may be best for policy maker to begin from an economic perspective rather than a default management strategy.

However, the benefit from algae removal sometimes combine with increasing water quality and the aesthetic value of water. Lee et al. (2017) indicates that a heterogeneous value of water is a key element in identifying the success of water projects. In addition, the value of clean and safe water can change with seasons and differs according to user needs. Given these factors, the benefits of algae removal will vary with conditions, and when monitoring sites with periodically sever algae blooms decision makers seeking the best economic solution need to understand how benefits change with conditions and with the removal method. A comprehensive cost-benefit analysis should be adopted wherever possible that respects site-specific constraints.

In 2008, the president of the Republic of Korea (Korea) implemented a national-level development strategy, called "Low-Carbon Green Growth". This policy aimed to reform Korea's economy from conventional development to an environmental-friendly approach. Sound natural resource management for water scarcity coupled with a climate change impact assessment emphasized a new growth pathway, with USD 17.3 billion dedicated to constructing 16 weirs on natural rivers and streams (Jones and Yoo, 2011). This mega-project intended to prevent flooding, water quality degradation, and water scarcity. In spite of its aspiration, critics including water resource experts and economists (e.g., Lee et al. (2015)) contended that the project neglected various stakeholder demands and disturbed natural interactions, possibly causing benthic algae development in those rivers. Although algae blooms were monitored intermittently at many sites in Korea, their density and intensity continued to accelerate after the mega-project began, becoming a problematic social issue recently in Korea. In this sense, exploring the cost and the benefits of algae has become a critical research questions relating to water availability and use.

Many economists have investigated methods to estimate the value of water and have conducted empirical analyses of overall water quality. For instance, Steinnes (1992) and Bergstrom et al. (2001) studied the value of water quality improvement by applying various valuation techniques in the U.S. However, the majority of prior economic literature has assessed the benefits of reducing overall sources of water pollutants at different levels (e.g., Larson et al. (2001)). On the contrary, only a handful of studies have focused on nutrient concentrations, mainly concerning algae development at a state-level. This research motivated our work to estimate the value of reducing the nutrient concentration in Korea. Stumborg et al. (2001) applied the contingent valuation method (CVM) to calculate the public's willingness to pay (WTP) to reduce the chance of algae blooms at Lake Mendota, Wisconsin. Recently, Van Houtven et al. (2014) and Nelson et al. (2015) introduced the cost of water quality impairment due to excess nutrients in southern U.S. lakes. Although the valuation methods used in those articles are applied to estimate the total economic value of water quality degradation or the economic cost of polluted water in an area, to our knowledge there is no economic literature investigating the value of nutrient reduction for the major fresh water source such as the Han River.

Our study investigates one of the four major rivers in Korea where severe water quality impairment has been frequently monitored following construction of new weirs, indicating a major failure in the hydraulic cycle. In addition, our analysis employs two national-level water value surveys, allowing us to conduct statistical analyses, e.g., a contingent valuation method and a difference-in-differences (DID) approach similar to those done in previous studies (e.g. Stumnorg et al. (2001) and Nelson et al. (2015)). The rest of the paper is organized as follows. Section 2 describes the background for our case study, i.e., the restoration project covering the Han River in Korea, with general water-related data, and the survey design for measuring the value of reducing nutrient concentrations in the Han River. Section 3 provides an overview of theoretical approaches for prioritizing and characterizing water users' behavior. Section 4 elaborates empirical results from the case study, and in the last section, we conclude with a summary of the main findings, and a brief suggestion for policy makers.

## II. Case Study and Application

### 1. The Han River

On the Korean Peninsula, annual average precipitation is approximately four times greater than the world average, but about 70 percent of Korea's rain falls during the rainy season (i.e., June to September). In this regard, Korea is categorized as a water-stressed country, and suffers frequent water-related disasters (e.g., droughts and floods) (Normile (2010). Furthermore, due to rapid industrialization coupled with a myopic river development project (i.e., the four major rivers restoration project), water quality degradation in the form of algae blooms has become a social concern. Initially, the "four major rivers restoration project" was implemented to enhance water security, flood control, and ecosystem vitality as a part of Korea's "Green New Deal" policy. To achieve its river project objectives, the Korean government, with good intentions, constructed 16 consecutive weirs by dredging 570 million m3 of sediment and graveling almost 700 km of riverbed in the four major rivers (the Han River, the Nakdong River, the Yeongsan River, and the Geum River, in Figure 1) (Cha et al., 2011). The total cost of this mega-construction project was approximately USD 71.3 billion, but this investment failed to supply clean water to the greater population because it also caused an eutrophication. Lee et al. (2015, 2017) concluded that a myopic view and ignoring various stakeholders' demands may have resulted the severe environmental damage in Korea that could las for decades.





### 2. Survey Design and Data Collection

Two separates but consecutive surveys were conducted to collect data on consumer welfare from river restoration projects. From August to November 2012 before the completion of the four major rivers restoration project, the first water demand and value survey was carried out, gathering information from 5 cities along the Han River and its major tributaries (Incheon, Seoul, Yangpyeong, Namyangju, and Yeoju). Since almost half of the Korean population lives near the Han River, a deterioration in water sourcing or quality may significantly impact consumers' WTP for improvements. From July to August 2015, we conducted a second survey within the Han River watershed to compare how people's perceptions changed with changes in water quality and its aesthetic value after completion of the project, particularly focusing on effects from algal blooms. Adjusting for demographic characteristics, 500 and 301 responses were collected from the first and the second survey respectively, by a professional survey company (the Korea Environmental Economics Research Institute). Highly trained interviewers conducted face-to-face interview surveys during a designated time, informing interviewees about algae blooms and discussing relevant aesthetic values of water. Within two consecutive surveys, we introduced how the algae bloom happened and how it related with water quality degradation. In this sense, the willingness to pay for users will include not only direct use value but also option value and indirect use value.

Following Hanemann et al. (1991), double- bounded dichotomous choice questions were used to estimate WTP for the removal of algae bloom in the Han River across five different initial bids (KRW 250, KRW 500, KRW 1,000, KRW 2,000, KRW 4,000). The main questionnaire was consisted of three parts: (1) demographic information; (2) level of perception of water quality associated with algae blooms; and (3) WTP for water quality improvement, i.e., the removal of existing algae blooms caused by the four major rivers restoration project. Prior to executing each survey on the WTP for algae removal, we provided scientific information about current algae blooms in the Han River, and how this could deteriorate water quality and the aesthetic value of the river. To increase credibility of the research, the data of the first initial bids and responses can be used to estimate WTP from a single-bounded dichotomous choice model.

In our estimation model, we included as covariates: respondents' age (all respondents were over 20), sex, years of formal education,

type of job, an apartment dummy, monthly household real income, and the number of members in the household. The mean and standard error of covariates are illustrated in (Table 1).

Variables	Description		2012	2015	
	Description	Mean	Standard error	Mean	Standard error
Mean Rate	Mean water rate per month	17410.8	635.24	18803.32	541.88
Sex	1=male, 0 otherwise	0.53	0.022	0.408	0.028
Age	1 = 20's, 2=30's, 3=40's, 4=50's, 5=above 60's	2.486	0.110	2.797	0.073
Job	1=white collar, 0 othersie	0.286	0.020	0.388	0.028
Education	1= college educated or above, 0 = below college	0.654	0.021	0.093	0.016
Household Income (per month)	<pre>{\$2000 1, {\$3000 2, {\$4000 3, {\$5000 4, {\$6000 5, {\$7000 6, {\$8000 7, }\$8000 8, Otherwise 9</pre>	2.938	0.068	3.205	0.078
# in Household	Number in household	3.222	0.061	3.488	0.058
Apartment	1 = apartment, 0 otherwise	0.50	0.022	0.388	0.028
Sample	1=Namyangju, 2= Yangpyeong, 3=Yeoju 4=Seoul & Incheon		101 104 52 243		53 50 97 101

(Table 1) Variable description and summary statistics

## III. Theoretical Model Specification

## 1. The State Preference Approcah to Environmental Valuation

For more than four decades, economists have established numerous knowledge on certain goods and services that are unable to trade in

the market system. The CVM is a well-known standard valuation method for estimating a conceptual demand curve for non-market goods and services (Hanemann et al., 1991). Since this method was developed by Ciriacy-Wantrup (1947), various statistical approaches for eliciting individual preferences have been investigated by many economists. Of those statistical methods, single-bounded (SBDC) and double-bounded dichotomous choice (DBDC) models have been widely applied (Venkatachalam, 2004). Both methods involve asking an individual whether he or she would pay some given amount, B, to secure given level of environmental quality. For a SBDC model, the probability of obtaining a "no" or a "yes" response can be written, respectively, as follows:

$$\pi^n(B) = G(B;\theta) \tag{1}$$

$$\pi^{\nu}(B) = 1 - G(B;\theta) \tag{2}$$

where  $G(\bullet;\theta)$  is a cumulative distribution function (e.g. normal or logistic) with parameter vector  $\theta$  that is interpreted as the individual's true maximum WTP (Hanemann et al., 1991). Where N number of respondents in a SBDC survey and  $B_i^s$  is the bid offered to the ith respondent, the log-likelihood function can be represented as follows:

$$\ln L^{S}(\theta) = \sum_{i=1}^{n} \{ d_{i}^{y} \ln[1 - G(B_{i}^{S}; \theta)] + d_{i}^{n} \ln G(B_{i}^{S}; \theta) \}$$
(3)

here  $d_i^y$  is 1 if the ith response is "yes" and 0 otherwise,  $d_i^n$  is 1

if the ith response is "no" and 0 otherwise. In this case, we can estimate the individual's WTP as follows (Jeanty, 2007):

$$WTP = \frac{-\bar{X}\beta'}{\beta_0} \tag{4}$$

where  $\overline{X}$  is a row vector of sample means including 1 for the constant term,  $\beta'_{(k-l\times l)}$  is a column vector of estimated coefficients, and  $\beta_0$  is a coefficient on the bid variable.

Unlike the SBDC model, the DBDC format offers two sequential bids to respondents. An initial bid  $B^1$  is acceptable or not, and  $B^2$  (i.e.,  $B^2 = 2B^1$ ) is asked on the condition that a respondent accepts  $B^1$ ; otherwise  $B^3$  ( $B^3 = 0.5B^1$ ) is offered. In this sense, there are four possible responses sets - "yes-yes", "yes-no", "no-yes", "no-no"- with respective likelihoods of  $\pi^{yy}$ ,  $\pi^{ym}$ ,  $\pi^{ny}$ , and  $\pi^{nm}$  (Hanemann et al., 1991). When there are N respondents, the log-likelihood can be illustrated as follows:

$$\ln L(\theta) = \sum_{i=1}^{N} \left[ d_i^{yy} \ln \pi^{yy} (B_i^1, B_i^2) + d_i^{yn} \ln \pi^{yn} (B_i^1, B_i^2) + d_i^{yn} \ln \pi^{ny} (B_i^1, B_i^3) + d_i^{nn} \ln \pi^{nn} (B_i^1, B_i^3) \right]$$
(5)

Following Hanemann (1984), the mean WTP with covariates can be rewritten as follows:

$$WTP^* = \frac{a + X_i'\beta}{b} \tag{6}$$

where  $X_i$  is the covariate vector for respondents' socio-economic

characteristics, and  $\beta$  is the parameter vector to be estimated. In addition, WTP is directly derived from the maximum likelihood (ML) estimates which are asymptotically normal with variance-covariance matrices. We can apply the Krinsky and Robb (1986) simulation technique to obtain confidence intervals for the point estimates of WTP.

If there are a substantial number of "zero bid" responses, the Spike model is an appropriate method for estimating WTP (Kriström, 1997). "No-no" respondents are divided into two categories – those with a zero WTP, and those with a positive WTP less than  $B^3$ . Therefore, a third follow-up question was offered to "no-no" respondents. In this process, respondent subgroups are divided into five categories in order to distinguish true-zero WTP from "protest"-zero WTP. For each respondent *i*, therefore, a binary-value indicator that states where the individual belongs among those five subgroups can be written as follows:

$$d_{i}^{YY} = 1 \text{ (if WTP } \ge B_{i}^{2}, 0 \text{ otherwise)}$$

$$d_{i}^{YN} = 1 \text{ (if } B_{i}^{1} \le WTP \le B_{i}^{2}, 0 \text{ otherwise)}$$

$$d_{i}^{NY} = 1 \text{ (if } B_{i}^{3} \le WTP \le B_{i}^{1}, 0 \text{ otherwise)}$$

$$d_{i}^{NNY} = 1 \text{ (if } 0 \le WTP \le B_{i}^{3}, 0 \text{ otherwise)}$$

$$d_{i}^{NNN} = 1 \text{ (if } WTP \le 0, 0 \text{ otherwise)}$$
(7)

The log-likelihood function of equation (7) can be represented for n respondents as follows:

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$$\ln L(\theta) = \sum_{i=1}^{n} \{ d_i^{YY} \ln[1 - G_Y(B_i^2)] + d_i^{YN} \ln[G_Y(B_i^2) - G_Y(B_i^1)] + d_i^{NY} \ln[G_Y(B_i^1) - G_Y(B_i^3)] + d_i^{NNY} \ln[G_Y(B_i^3) - G_Y(0)] + d_i^{NNN} \ln[G_Y(0)] \}$$
(8)

When the cumulative density function,  $G_{Y}(B_{i})$ , is assumed to follow a logistic distribution, we have:

$$G_{Y}(B_{i}) = \begin{cases} 0 & \text{if } B_{i} < 0\\ [1 + \exp(\alpha + \beta X_{i})]^{-1} & \text{if } B_{i} = 0\\ [1 + \exp(\alpha - \beta_{P}B_{i} + \beta X_{i})]^{-1} & \text{if } B_{i} > 0 \end{cases}$$
(9)

By maximizing equation (8), parameters  $\alpha$  and  $\beta$  can be estimated and the share of true-zero WTP in the sample can be defined as follows:

$$Spike = \frac{1}{[1 + \exp(\alpha + \beta X_i)]}$$
(10)

Finally, the mean WTP under the Spike model can be rewritten as follows:

$$WTP^* = \frac{\ln[1 + \exp(a + X'_i\beta)]}{b}$$
(11)

### 2.. Difference-in-Differences Approach

The difference-in-differences (DID) estimator is one of the most well-known approaches for examining the effects of a policy when distinguishing two groups (i.e., pre-treatment and post-treatment period, with and without public intervention). The DID framework applies in our analysis as follows. Let Y(i,t) be the outcome (e.g., water quality improvement) of weir construction for individual i at time t. Two samples are collected in a pre-construction of weir period t=0, and in a post-construction of weir period t=1. Between these time periods, a certain fraction of population experiences weir construction in its neighboring river. We denote D(i,t)=1 if individual i has a weir in his/her neighboring river at t=1, D(i,t)=0 otherwise. Therefore, of those individuals, we can rename D(i,1)=1 a "treated", and D(i,1)=0 a "untreated". Following Ashenfelter and Card (1984), the DID model can be written as follows:

$$Y(i,t) = \delta(t) + \alpha \cdot D(i,t) + \eta(i) + \upsilon(i,t)$$
(12)

where  $\delta(t)$  is a time-specific component,  $\alpha$  indicates the impact of weir construction,  $\eta(i)$  is an socio-demographic component, and  $\upsilon(i,t)$  is an individual-transitory shock ( $\overline{\upsilon} = 0$  at time t), correlated within individuals.

In this model, we only monitor Y(i,t) and D(i,t). Since the sufficient condition for selecting weir construction does not rely on v(i,t), adding and subtracting  $E[\eta(i)|D(i,1)]$  in equation (12) we obtain:

$$Y(i,t) = \delta(t) + \alpha \cdot D(i,t) + E \lfloor \eta(i) \rfloor D(i,1) \rfloor + \varepsilon(i,t)$$
(13)

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where 
$$\varepsilon(i,t) = \eta(i) - E[\eta(i)|D(i,t)] + \upsilon(i,t)$$

We can modify equation (13) to produce the following equation:

$$Y(i,t) = \mu + \tau \cdot D(i,1) + \delta \cdot t + \alpha \cdot D(i,t) + \varepsilon(i,t)$$
(14)

where  $\mu = E[\eta(i)|D(i,1) = 0] + \delta(0)$ ,  $\tau = E[\eta(i)|D(i,1) = 1] - E[\eta(i)|D(i,1) = 0]$ , and  $\delta = \delta(1) - \delta(0)$ .

Since we have a sample with repeated pre- and post-weir construction, Y(i,1) and Y(i,0), the effect of weir construction,  $\alpha$ , can be estimated as follows:

$$\alpha = E[Y(i,1) - Y(i,0)|D(i,1) = 1] - E[Y(i,1) - Y(i,0)|D(i,1) = 0]$$
(15)

In our DID analysis, we used individual's WTP as a proxy for water quality improvement due to weir construction on the Han River. This analysis leads us to calculate the pure impacts of weir construction from the project, and allows us to verify any welfare loss to society.

## **IV. Empirical Results**

In the preliminary analysis, estimates from SDBC and DBDC models were not reliable due to a substantial number of "zero" responses. We therefore conducted the Spike model to adjust for this econometric problem.  $\langle Table 2 \rangle$  illustrates estimates from the Spike models across three different data sets: 2012, 2015, and aggregate (2012 and 2015) data. Each model had two separate estimates (with and without explanatory variables). We checked the variance inflation factor (VIF) and correlation matrix, concluded that there are no multicollinearity problems in the dataset.

Variablaa	Spike 1		Spike 2		Spike 3	
Valiables	Aggregate data (2012 & 2015)		2012 dataset		2015 dataset	
Constant	0.2250(0.0697)**	0.2533(0.0706)**	0.0283(0.8765)*	0.0511(0.0885)*	0.5683(0.1175)**	0.6094(0.1206)**
Bid	0.0015(0.0001)**	0.0010(0.0001)**	0.0016(0.001)**	0.0011(0.0002)**	0.0014(0.0001)**	0.0009(0.0002)**
Mean rate		0.0000(0.0000)		0.0000(0.0000)		0.0000(0.0000)
Sex		0.0092(0.1370)		-0.0112(0.1777)		-0.0549(0.2365)
Age		-0.0317(0.0521)		-0.0367(0.0750)		-0.0202(0.0755)
Job		0.3388(0.1705)**		0.5516(0.2683)**		0.2042(0.2401)
Education		0.3441(0.1479)**		0.1587(0.1983)		0.2754(0.4175)
Income		0.0186(0.5799)		0.0353(0.0775)		-0.0542(0.1027)
# in Household		0.1484(0.0621)**		0.0737(0.0766)		0.2381(0.1146)
Apartment		-0.3702(0.1582)**		-0.1795(0.2232)		-0.0687(0.2301)
Year dummy		-0.2102(0.1684)*				
Spike	0.4439(0.0172)**	0.4369(0.1739)**	0.4929(0.0219)**	0.4872(0.0221)**	0.3616(0.0271)**	0.3521(0.0275)**
Wald-x2	323.36	342.78	188.76	199.36	135.81	142.79
Prob. > x2	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**	0.0000**
LL	-851.776	-837.617	-523.060	-515.909	-319.313	-313.698
Mean WTP (KRW)	530.32(32.23)**	779.04(110.56)**	436.12(32.82)**	654.70(130.27)**	691.92(61.23)**	1014.11(214.00)**
# of Obs.	801		500		301	

(Table 2) Spike model estimates across three different data sets

Note: \*\* and \* indicate significance at the 1% and 5% level, respectively Numbers in parentheses are standard errors

Although some explanatory variables (e.g., job, education, number in household, and apartment) are statistically significant at the 1% level, for all three data sets, model goodness-of-fit tests are better without explanatory variables. To elicit the WTP for algae removal in the Han River to increase water quality and its aesthetic value, we provided five different initial bids to each of five subgroups of respondents. The estimation results of the Spike model based on Eqs. (8) to (11) indicates that respondents prefer low bid amounts for algae removal even though there are negative effects from water quality degradation. For two different surveys, the estimated constants are statistically significant and positive. This confirms a positive WTP across all models. The monthly mean WTP for algae removal in the 2012, 2015, and the aggregated model is estimated to be KRW 436.12 (USD 0.39), KRW 691.92 (USD 0.62), and KRW 530.32 (USD 0.47), respectively. As shown in  $\langle$ Table 3 $\rangle$ , we conducted additional marginal analysis to capture respondent heterogeneity across socio-demographic characteristics.

Variables	Spike1		Spike2		Spike3	
	Mean	Elasticity	Mean	Elasticity	Mean	Elasticity
Job	0.3245	0.0632	0.2860	0.0568	0.3887	0.0468
Education	0.4431	0.0627	0.6540	0.5686	0.0930	0.0151
# in Household	3.3221	0.3035	3.2220	0.1300	3.4883	0.4907
Apartment	0.5106	-0.1053	0.5000	-0.0491	0.5315	-0.0215

(Table 3) Marginal analysis results of explanatory variables

Note: elasticities are calculated at the mean value of each variable

Although the explanatory variables in Table 3 are statistically insignificant, variables capturing socio-demographic characteristics indicates meaningful results for policy makers. For instance, people with white-collar jobs and higher education indicate relatively higher WTP for algae removal. This implies that people more directly or frequently exposed to environmental problems are likely to pay more WTP to ameliorate water quality degradation. On the contrary, people who are provided clean water from public services and live relatively far from compromised water resources are less likely to pay WTP to improve water quality and its aesthetic value. Since the four rivers restoration project was completed in 2013, we conducted the DID model to calculate WTP to remove algae in the Han River, temporally and spatially. Consequences from the project have accelerated algae bloom in the river, but Incheon, Seoul, and Yangpyeong are likely to be less affected from the weirs than Yeoju or Namyangju. Therefore, responses from these five different watersheds are categorized into four subgroups (pre-treatment, post-treatment, treatment, and control groups). To reflect temporal aspects, pre-treatment and post-treatment subgroups are separated as before or after 2013. Watersheds that are less likely to be affected by weir introduction are treated as a control subgroup (Incheon, Seoul, Yangpyeong). With these clarifications, the DID estimates of repeated cross-section analysis are illustrated in  $\langle Table 4 \rangle$ .

	•		
Variables	Coefficient	t-value	
Year dummy	247.7913 (91.1323)	2.72**	
Control dummy	-260.9757 (86.6675)	-3.01**	
DID dummy	20.7549 (136.2658)	0.15	
Constant	791.4244 (51.1946)	15.46**	
F-test	8.22		
Prob. > F	0.0000**		
Root MSE	935.54		
# of Obs	801		

(Table 4) DID estimates of repeated cross-section data

Note: \*\* indicates the significance at the 1% and numbers in parentheses show the standard errors

According to DID estimates, respondents more affected by the four major rivers restoration project demonstrate a higher WTP, KRW 20.75, to address current algae blooms in the Han River. Although the DID dummy is not statistically significant, this result implies that people suffering a decrease in water quality and aesthetic water value are willing to pay more for their monthly water bills. This amount is equivalent to approximately 0.25% of the average monthly water rate.

Since this research employed representative sampling frame and had a high survey response rate, the estimated mean WTP can be expanded to analyze the aggregate benefit of algae removal in the Han River. Therefore, we multiplied the mean monthly per-household WTP by the total number of households in the Han watershed in 2017 (i.e., 10.17 million) and then annualized this result. For 2015 the aggregate economic benefit of removing algae from the Han River, to improve water quality and aesthetic value, is estimated to be approximately KRW 84.44 billion (USD 76.76 million). Based on the DID estimates, the aggregate economic cost of removing algae across the waters of the Han River is approximately KRW 2.56 billion (USD 2.33 million), annually.

## V. Conclusions

Since the four major rivers restoration project in Korea, abnormal algae blooms much more frequently aggravate water quality and diminish the aesthetic value of water along these major rivers. Almost half of South Koreans live and rely on the Han River, so the negative impacts from algae blooms not only raise environmental concerns but may also degrade quality of life for millions of residents on the Han River water. Although the initial plan for the four major rivers restoration project was optimistic and promising, unintended consequences of the project lower water quality and burden or distress local populations.

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This research investigates the aggregate economic cost of algae removal to partially restore water quality and regain the aesthetic value of the iconic Han River in Korea. Although methods for estimating non-market goods and services are limited mostly to the contingent valuation method, few other authors have attempted to elicit household willingness to pay for consequences of the mega-project in Korea. We jointly conducted a Spike model and a Difference-in-Differences (DID) approach, policy assessment tools, to elicit Korean households' willingness to pay more for their water bills to correct water quality loss that followed the completion of weirs on the Han River in 2013. Based on results from the Spike model, we estimate per-household monthly WTP for algae removal in the Han River using 2012, 2015, and aggregate data (2012 and 2015) to be KRW 436.12 (USD 0.39), KRW 691.92 (USD 0.62), and KRW 530.32 (USD 0.47), respectively. The three Spike model estimates can be expanded to WTP across the entire Han River watershed: KRW 64.72 billion (USD 58.83 million), KRW 53.22 billion (USD 48.38 million), and KRW 84.44 billion (USD 76.76 million). To calculate the aggregate economic cost of cleaning algae in the Han River, we applied a DID approach and differences in WTP were estimated to be approximately KRW 2.56 billion (USD 2.33 million) annually. We also found that higher-educated residents are likely to pay more attention to environmental issues, while residents who live in apartments are less likely to attend to environmental issues than those in less urbanized areas. This implies that people directly exposed to environmental issues are likely to pay more WTP to ameliorate water quality degradation and recover aesthetic value of river. According to Cho et al. (2016), the effect of algal bloom is to be estimated as KRW 4,129 per household. This analysis carried out for all rivers in Korea, thus estimated WTP was higher than our research.

Results from this study can apply to water development policy perspectives in several ways. (1) A myopic and monotonic implementation plan may not only easily fail to achieve its stated objectives, but may also cause significant damage, as observed after the four major rivers restoration project. (2) Regulating and modifying natural rivers may have unintended consequences that are borne solely by later generation. (3) Although excess concentrations of nitrogen and phosphorus that cause an eutrophication may be recognized as local or temporal problems, people are willing to pay more to ameliorate water quality degradation. Results from this study show that the differences between upstream and downstream WTP for amelioration are relatively small. This implies that an upstream-downstream development agenda may not apply in the case of water quality degradation and aesthetic value of a river. (4) The value of algae removal appears to be meaningful to residents, but the high proportion of respondents claiming a zero WTP indicates that many households may prefer not to pay an additional charge for this on their water bills. Suffice to say that the Korean government should conducting further public outreach and continuing to investigate research on water quality degradation, with renewed attention to meeting national water quality standard.

Limitations of this study deserve mention for future research. First, the contingent valuation survey method can be improved by appreciating a potential bias due to correlation between the responses. Improving the question set used to elicit WTP will improve the quality of this type of research. Second, while this research investigates household-level WTP for ameliorating water quality degradation and recovering aesthetic value of a river, additional cost-benefit analysis would be needed in order to calculate the economic value of the four major rivers restoration project in Korea.

#### References

- Ashenfelter, O. C. and D. Card, 1984, Using the longitudinal structure of earnings to estimate the effect of training programs, (Working paper Princeton University, Industrial Relations Section: no.174), Princeton, N.J.: Industrial Relations Section, Princeton University.
- Bergstrom, J. C., K. J. Boyle, and G. L. Poe, 2001, *The economic value of water quality*, Cheltenham, UK ; Northampton, MA: Edward Elgar.
- Cha, Y. J., M. P. Shim, and S. K. Kim, 2011, "The four major rivers restoration project," *Proceedings of the UN Water International Conference*, Zaragoza, Spain.
- Cho, Y., S. Jin, H. Choi, M. Ryu, and S. H. Yoo, 2016, "Estimation of the aesthetic and environmental costs of algal bloom," *Journal of Environmental Policy* and Administration, 24(4), pp.227-246, DOI: 10.15301/jepa.2016.24.4.227.
- Ciriacy-Wantrup, S. V., 1947, "Capital returns from soil-conservation practices," *Journal of Farm Economics*, 29(4), pp.1181-1196, DOI: 10.2307/1232748.
- Dodds, W. K., 2006, "Eutrophication and trophic state in rivers and streams," *Limnology and Oceanography*, *51*(1part2), pp.671-680, DOI: 10.4319/lo. 2006.51.1\_part\_2.0671.
- Flinders, C. A. and D. D. Hart, 2009, "Effects of pulsed flows on nuisance periphyton growths in rivers: A mesocosm study," *River Research and Applications*, 25(10), pp.1320-1330, DOI: 10.1002/rra.1244.
- Hanemann, W. M., 1984, "Welfare evaluations in contingent valuation experiments with discrete responses," *American Journal of Agricultural Economics*, 66(3), pp.332-341, DOI: 10.2307/1240800.
- Hanemann, M., J. Loomis, and B. Kanninen, 1991, "Statistical efficiency of doublebounded dichotomous choice contingent valuation," *American Journal of Agricultural Economics*, 73(4), pp.1255–1263, DOI: 10.2307/1242453.

- Jeanty, P. W., 2007, "Constructing krinsky and robb confidence intervals for mean and median willingness to pay (wtp) using stata," *Sixth North American Stata Users' Group Meeting, Boston,* pp.13-14.
- Jones, R. S. and B. Yoo, 2011, Korea's green growth strategy: Mitigating climate change and developing new growth engines, (Economics Department Working Papers No. 798), Paris, France: Organisation for Economic Co-operation and Development (OECD).
- Krinsky, I. and A. L. Robb, 1986, "On approximating the statistical properties of elasticities," *The Review of Economics and Statistics*, pp.715-719, DOI: 10.2307/1924536.
- Kriström, B., 1997, "Spike models in contingent valuation," *American Journal of Agricultural Economics*, 79(3), pp.1013-1023, DOI: 10.2307/1244440.
- Larson, D. M., D. K. Lew, and Y. Onozaka, 2001, The public's willingness to pay for improving California's water quality," *Annual Meeting of Western Regional Project W*-133, Miami, Florida.
- Lee, Y., T. Yoon, and F. A. Shah, 2011, "Economics of integrated watershed management in the presence of a dam," *Water Resources Research*, 47(10), W10509, DOI: 10.1029/2010WR009172.
- Lee, Y., H. Chang, and Y. Hong, 2015, "Is a costly river restoration project beneficial to the public? Empirical evidence from the Republic of Korea," *Desalination and Water Treatment*, 54(13), pp.3696-3703, DOI: 10.1080/ 19443994.2014.923209.
- Lee, Y., S. Cho, H. Han, K. Kim, and Y. Hong, 2017, "Heterogeneous value of water: Empirical evidence in South Korea," *Sustainability*, 9(10), 1764, DOI: 10.3390/su9101764.
- Nelson, N. M., J. B. Loomis, P. M. Jakus, M. J. Kealy, N. von Stackelburg, and J. Ostermiller, 2015, "Linking ecological data and economics to estimate the total economic value of improving water quality by reducing nutrients," *Ecological Economics*, 118, pp.1–9, DOI: 10.1016/j.ecolecon.2015.06.013.
- Normile, D., 2010, "Restoration or devastation?," *Science*, 327(5973), pp.1568-1570, DOI: 10.1126/science.327.5973.1568.
- MacArthur, R., A. Rabidoux, A. Shvidchenko, L. Anderson, B. Cruey, and J. Pan, 2009, "Developing science-based strategies to manage water conveyance and control weeds and sediment in irrigation and potable water supply canals," *Proceedings of the 61st Annual California Weed Science Society*, pp.37-45.

- Steinnes, D. N., 1992, "Measuring the economic value of water quality," *The Annals of Regional Science*, 26(2), pp.171-176.
- Stumborg, B. E., K. A. Baerenklau, and R. C. Bishop, 2001, "Nonpoint source pollution and present values: A contingent valuation study of Lake Mendota," *Review of Agricultural Economics*, 23(1), pp.120-132, DOI: 10.2307/1349910.
- Van Houtven, G., C. Mansfield, D. J. Phaneuf, R. von Haefen, B. Milstead, and M. A. Kenney et al., 2014, "Combining expert elicitation and stated preference methods to value ecosystem services from improved lake water quality," *Ecological Economics*, 99, pp.40–52, DOI: 10.1016/j.ecolecon.2013.12. 018.
- Venkatachalam, L., 2004, "The contingent valuation method: A review," *Environmental Impact Assessment Review*, 24(1), pp.89-124, DOI: 10.1016/S0195-9255(03) 00138-0.
- Wells, M. L., V. L. Trainer, T. J. Smayda, B. S. Karlson, C. G. Trick, and R. M. Kudela et al., 2015, "Harmful algal blooms and climate change: Learning from the past and present to forecast the future," *Harmful Algae*, 49, pp.68-93, DOI: 10.1016/j.hal.2015.07.009.

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