자원 · 환경경제연구 제 21 권 제 1 호
Environmental and Resource Economics Review
Volume 21, Number 1, March 2012: pp. 157~173

Water Quality and Environmental Treatment Facilities

Geum Soo Kim*, Young Jae Chang and David S. Kelleher*****

〈Abstract〉

It has been argued that investment in basic treatment facilities could have both a direct improvement effect and an indirect diversion effect on water quality. The reason why the investment in basic treatment facilities could have a negative diversion effect is that the investment in treatment facilities could affect a budget-constrained regulatory agency's choice in a way that would perversely encourage the regulated firms' emissions, giving a negative result in terms of water quality. We have reviewed the Korean experience and tested if the treatment facilities have improved water quality since 1991. Using a two-stage least-squares method we have shown that building treatment facilities has contributed to improving the water quality even with consideration of the negative effect through reduced

* Professor, Division of Economics and Commerce, Hoseo University (First and Corresponding Author).

** Professor, College of Business Administration and Institute for Industrial Management, Inje University (Second Author).

*** Professor, Department of Public Administration, Hoseo University (Third Author).

enforcement effort. The model and results draw attention to the importance of optimally balancing efforts to build wastewater treatment facilities with efforts to set and enforce regulatory standards.

Keywords : basic treatment facilities, water quality, enforcement, regulation

◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆

본 논문은 환경기초시설에 대한 투자가 수질을 직접 개선하는 효과와 더불어 결과적으로 수질을 악화시킬 수도 있는 가능성을 제기하였다. 환경기초시설에 대한 투자가 수질에 부정적인 효과를 낳는 이유는 그것이 예산제약하에 있는 규제당국의 선택에 영향을 미치고 결과적으로 피규제 기업의 오염배출량을 증가시켜 수질을 악화시킬 수 있기 때문이다. 본 논문에서는 한국의 경험을 살펴보고 특별히 1991년 이후 환경기초시설의 투자가 과연 4대강의 수질을 개선했는가를 점검하고자 하였다. 우리는 2단계 최소자승법을 사용하여 기초시설의 건설이 단속활동의 감소를 통해 부정적인 효과를 가졌지만 종합적으로 수질개선에 기여했음을 실증적으로 보였다. 본 논문이 갖는 중요한 정책함의는 환경기초시설의 건설이 수질개선에 기여하기 위해서는 그것과 더불어 환경기준을 설정하고 이를 강제하는 단속활동이 적절히 배합되어야 한다는 것이다.

주제어 : 환경기초시설, 수질, 단속, 규제

JEL Classification : K42, Q53, Q58

Ⅰ. Introduction

Water quality in natural waterways is a public good. Once one party in a society exerts an effort to improve the water quality in lakes, rivers, etc., other parties will enjoy the benefits with no additional cost. Due to this non-rival and non-excludable attribute of public goods, they tend to be under-provided from the society's point of view. This is one of the rationales for government intervening in the market. To attain a socially optimal level of water quality, a government may impose a regulation on potential polluters that guides their behavior in accordance with the socially optimal level of pollution. At the same time, the government may also attempt to ensure the desired water quality by directly treating wastewater or having private treatment firms do the job before the wastewater is discharged into the river. As in many countries, the Korean government makes both efforts to ensure water quality. In the 1980s, the Korean government introduced new water quality standards and increased enforcement efforts. In the 1990s, the government significantly expanded its so-called basic treatment facilities, which includes facilities for treating municipal wastewater, industrial wastewater and livestock wastewater. As of 2009, there were approximately 600 treatment facilities in operation throughout the country.

Thus, water quality is determined by efforts to regulate the amount and composition of wastewater emitted by households and firms as well as being determined by government efforts to directly treat these emissions. However, most analyses focus on only one part of this situation at a time(Garvie and Keeler, 1994 ; Neilson and Kim, 2001 ; Kwak and Kim, 1995; Kang, 2003). Kim and Chang (2007) have provided a theoretical model for a budget-constrained environmental regulatory agency, whose budget is allocated towards operation of basic treatment facilities as well as for monitoring and punishment. In this paper we examine whether increased investment in basic treatment facilities has improved water quality in Korea, within the framework of Kim and Chang (2007).

Kwak and Kim (1995) and Kang (2003) have already reviewed the Korean experience and argued that investment in basic treatment facilities has been quite effective in improving water quality. However, their analysis is limited in the sense that they did not use the real water quality data for the dependent variable in their regression analysis, but rather used an estimate of water quality difference ; also, the treatment facility is assumed to be the only factor determining the water quality. They begin by estimating a counterfactual trend in water quality that they presume would have obtained in the absence of treatment facilities. Then they compare this counterfactual trend with the real water quality trend, and assess whether investments in basic treatment facilities adequately explain the resulting differences in water quality. They simply assume that without the basic treatment facilities the water quality would have deteriorated in accordance with the preexisting trend. In contrast, we will run a regression on real water quality data wherein we allow both treatment facilities and regulation to affect the water quality.

In the next section we are going to reproduce briefly Kim and Chang's (2007) model, which argues that the investment in basic treatment facilities has both a direct improvement effect on water quality and an indirect diversion effect on water quality. The reason why the investment in basic treatment facilities could have a negative diversion effect is that the investment in treatment facilities could affect a budget-constrained regulatory agency's choice in a way that would perversely encourage the regulated firms' emissions, giving a negative result in terms of water quality. In the third section, we have tested this hypothesis with the Korean experience. Since investment in treatment facilities is one of the important explanatory variables for water quality while at the same time being endogenously determined within the regulatory framework, we have run a two-stage least squares regression. We find that investment in basic treatment facilities has been effective in improving water quality even with its indirect, negative enforcement effect. In the last section, we provide a summary of our main arguments and draw attention to limitations to be addressed in the future work.

Ⅱ. Theory

A strategic interaction between a regulatory agency and n homogeneous regulated firms is considered. With a given budget and a given level of treatment facilities the agency first sets enforcement parameters, and then the firms respond to the agency's choice by choosing an amount of emissions. In other words, the agency behaves like a Stackelberg leader and the firms as a whole act like a Stackelberg follower. So the analysis begins with a representative regulated firm. The firm is assumed to minimize its abatement cost C plus expected fine pf by choosing its emission level x as indicated below.

$$Min_x \; C(x) + pf(x-s, E)$$

Those two factors C and pf depend on the firm's emission level x, and the fine f depends also on an environmental standard s and the strength of the agency's enforcement will E.[1] The probability of violators getting detected is denoted by p and the fine schedule f is exogenously determined; thus, the monitoring probability p coupled with the fine f constitute an expected fine pf. The first order condition for this optimization problem is as follows.

$$-C_x = pf_x \tag{1}$$

Using the second order condition we can show that the optimal choice regarding emission, say x^*, would decrease as the agency increases either p or E(Kim and Chang, 2007).

Knowing this firm's response, the regulatory agency is assumed to minimize so-called net non-compliance with a budget constraint as in the following:[2]

$$Min_{p,E} \; n(x^*(p,E)-s)-g$$
$$s.t. \;\; M(p,E)+A(g) \leq B$$

Here the non-compliance level of a firm is x^*-s and so the total level of non-compliance is $n(x^*-s)$. Now the government treats the waste

1) The detected violator might disagree with the regulatory decision so that the agency is brought into litigation. Thus the agency's enforcement may be expressed by the agency's willingness to pay for litigation (Garvie and Keeler, 1994).

2) The objective function in physical terms may be interpreted as a special form of a damage cost function.

water directly, as reflected by g. Now, the net non-compliance is $n(x^* - s) - g$. $M(p,E)$ represents the agency's expenditure for monitoring and costs such as being involved in a lawsuit with a violator. $A(g)$ represents the operational cost for treatment facilities. The total expenditure cannot exceed the agency's total budget, which is given by a superior agency like the central government. Notice that s, g and B are all given to the agency by a superior agency. Assuming an interior solution, the first-order conditions for this optimization problem are the following :

$$n\frac{\partial x^*}{\partial p} - \lambda M_p = 0 \tag{2}$$

$$n\frac{\partial x^*}{\partial E} - \lambda M_E = 0 \tag{3}$$

$$\lambda[B - M(p,E) - A(g)] = 0 \tag{4}$$

$$B - M(p,E) - A(g) \geq 0, \ \lambda \geq 0$$

Here λ denotes the Lagrange multiplier. The first two equations (2) and (3) are exactly the same as the conditions for the case where the agency's objective is to minimize non-compliance, $n(x^* - s)$, rather than net non-compliance, $n(x^* - s) - g$. This is because the g variable does not depend on p and/or E, but is just given by a superior agency. From these two equations (2) and (3) we can derive the following equation (5) :

$$\frac{(\partial x^*/\partial p)}{(\partial x^*/\partial E)} = \frac{M_p}{M_E} \tag{5}$$

The left hand side of equation (5) represents the slope of an iso-non-compliance curve, while the right hand side represents the slope of the agency's budget line. This is analogous to a rational consumer's optimization problem. Like a rational consumer, the agency tries to equalize the marginal contribution towards non-compliance of both monitoring expenditures and expenditures associated with litigation. This raises an interesting question, namely, does the variable g make any difference to the agency's choice? The answer is not simply "no" because, even though with g the way the agency makes a choice remains the same, g affects the position where the choice is made. In other words, the variable g does not enter into the above equation (5), but it enters into the agency's objective function and its budget constraint. The variable g does reduce the net non-compliance level directly but with a reduced enforcement budget. The net effect is not clear. That is, introducing g may or may not reduce the non-compliance. In other words, introducing g may or may not improve the water quality.[3)]

Ⅲ. Estimation Equation and Data

Since the treatment facilities may or may not improve the water quality from a theoretical point of view, we are going to review the Korean experience and test if the treatment facilities have improved

3) The higher-level agency who provides with the facility could adjust g so that the water quality could always improve. However, our focus in this paper is on the choice of a lower level agency to which g and B are just given. Kim and Chang (2007) do a comparative statics analysis with respect to g or B to find a condition for water quality improvement.

water quality since 1991.[4] In order to test the hypothesis we specify the following simultaneous equation system, as depicted in (6) and (7). The reason why we have a simultaneous system is that the water quality is not only determined by treatment facilities, but also by regulatory activities, and the treatment facilities are interrelated to regulatory variables as implied by the theoretical model in the previous section.

$$WQ_i = \beta_{10} + \beta_{11} BEF_i + \beta_{12} WW_i + \beta_{13} PRE_i + \epsilon_{1i} \tag{6}$$

$$WQ_i = \beta_{20} + \beta_{21} BEF_i + \beta_{22} ENF\_PUNS_i + \epsilon_{2i} \tag{7}$$

The first equation (6) says that the capacity of basic environmental treatment facilities, the amounts of waste water, and precipitation are the factors that directly determine the water quality. The second equation (7) says that the water quality is also affected in the relationship between the regulatory authorities' efforts of both building basic environmental treatment facilities and monitoring and punishing violating firms. In light of (7), we know that BEF and the error term in (6) is statistically correlated. So we need to estimate the equations simultaneously in two stages. The following reduced form equation (8) for BEF can be easily obtained by removing WQ from the above equations, (6) and (7).

$$BEF_i = \gamma_1 + \gamma_2 WW_i + \gamma_3 PRE_i + \gamma_4 ENF\_PUNS_i + \epsilon_{3i} \tag{8}$$

---

4) One referee has indicated that in Korea the facilities are operated based on user fees paid by private firms, which is different from the assumption of our model. Notice, however, that the focus of our model is on the possibility of the change in governmental regulatory choice due to the existence of basic environmental facilities, irrespective of how to finance its operation. Even with a private operation, the government regulator could strategically reshape its choice, taking into account the option of basic environmental facility.

where $\gamma_1 = -(\beta_{10} - \beta_{20})/(\beta_{11} - \beta_{21})$, $\gamma_2 = -\beta_{12}/(\beta_{11} - \beta_{21})$, $\gamma_3 = -\beta_{13}/(\beta_{11} - \beta_{21})$, and $\gamma_4 = \beta_{22}/(\beta_{11} - \beta_{21})$. We estimate this equation first, and then using the result we estimate the coefficient for BEF in (6) in a statistically innocuous way, which will be explained in more detail in the next section.

We use data regarding the four main rivers in Korea covering 1991 through 2006, but the data is not river-specific, but yearly aggregate data. These data are available at the Korea Ministry of Environment web page (www.me.go.kr) which provides access to the Environmental Statistics Yearbooks, the only data source we have relied upon. The dependent variable is water quality (denoted by WQ) and there are many indicators for water quality, among which we are going to use BOD (biological oxygen demand) for the sake of convenience. The explanatory variables are BEF, ENF_PUNS, WW, and PRE. BEF represents Basic Environmental Treatment Facilities which includes municipal sewage, industrial wastewater, and livestock wastewater treatment facilities. BEF is a stock variable (unlike investment in treatment facilities, which is a flow variable). BEF is an accumulated investment measured in terms of tons per day of wastewater treatment capacity. The unit of measurement is 1,000s of ton per day. ENF_PUNS is an enforcement variable. It is the product of ENF and PUNS. ENF represents the average number of inspections per year per wastewater-discharging firm; PUNS represents the strength of punishment imposed on violating firms. There are six different types of punishment: Warning, Improvement Order, Temporary Operation Stoppage, Operation Expiration, Plant Closure, and Prosecution. We have given an arbitrary point value to each of these different types of punishment with a higher value assigned to a harsher punishment type

〈Table 1〉 Summary Statistics

Variable	Obs.	Mean	Stand. Dev.	Min.	Max.
WQ	16	3.45125	0.4625131	2.58	4.3
BEF	16	15856.94	6469.331	5525	24157
ENF_PUNS	16	7520.75	928.8885	5656	8926
WW	16	31178.89	26346.41	8036.842	101625.1
PRE	16	19413.38	24966.53	8893	112564

and then we have summed them up into a measure, PUNS.[5] So ENF_PUNS reflects both monitoring frequency and punishment strength. ENF_PUNS does not have a special unit, but is simply a number.

WW represents wastewater, the unit of which is 1,000 cubic meters per day. There are different types of wastewater, i.e., municipal sewage, industrial wastewater and livestock wastewater, but we use only the data for industrial wastewater due to gaps in availability. Municipal sewage is relevant to our analysis, but it's not been reported since 1994. Moreover, the data for industrial waste water in 1999 and 2000 are absent and so we have interpolated estimates based on the yearly trend. PRE stands for the national average of precipitation. Summary statistics for the data we use in the empirical analysis are provided in <Table 1>.

5) Arbitrary weights are given to components. Warning is assigned one point, while Improvement Order, Temporary Operation Stoppage, Operation Expiration, Plant Closure and Prosecution are assigned two, three, four, five and six points, respectively. The size does not have any meaning but reflects the stringency of punishment methods.

IV. Empirical Results

As already noted, BEF is not statistically independent of WQ because WQ is a function of BEF and BEF is governed in another equation together with ENF_PUNS. So we have applied a two-stage least-squares method for estimating the effect of treatment facilities on water quality. In the first stage, the reduced form equation (8) for BEF is estimated. That is, BEF is regressed on all the independent variables of the system, ENF_PUNS, WW and PRE, and the estimation results are given in <Table 2>.

The coefficient of ENF_PUNS is estimated to be negative and statistically significant at the 1% significance level. That is, increases in BEF are associated with decreases in ENF_PUNS with other things being equal.[6] This tells us that building BEF and monitoring efforts

〈Table 2〉 BEF Regression Results

Variable	Coefficient	Stand. Error	t-statistic	P-value
C	-1538.145	8603.53	-0.18	0.861
ENF_PUNS	-.0057105	.0015154	-3.77	0.003
WW	2.99771	1.088967	2.75	0.018
PRE	.0869154	.0402645	2.16	0.052

6) One referee has indicated that the decrease in ENF_PUNS may be due to the introduction of TMS (tele-metering system) technology. However, TMS technology does not refute our hypothesis on the relationship between BEF and ENF_PUNS in a fundamental way but may give the regulator an additional incentive to reduce the traditional enforcement efforts to have the negative relationship look amplified.

〈Table 3〉 2SLS Regression Result

Variable	Coefficient	Stand. Error	*t*-statistic	*P*-value
C	1.804826	.9606914	1.88	0.085
BEF	-.0000886	.0000291	-3.04	0.010
WW	.0004028	.0001572	2.56	0.025
PRE	1.10e-06	4.93e-06	0.22	0.827

move in the opposite direction. The coefficient of WW is positive as expected and statistically significant at the 5% significance level. As WW rises, BEFs are also expanded.

After estimating BEF we have regressed WQ on the estimated BEF, WW and PRE, obtaining the results presented in <Table 3>. The estimation results confirm the previous authors' argument that building treatment facilities has been effective in improving the water quality. The coefficient for BEF implies that other things being equal, an increase in treatment capacity by 1,000 tons per day would lead to the water quality being improved by a 0.0000886 BOD decrease, which is quite a small number, though.

It is also shown that the increase in wastewater has deteriorated the water quality. The corresponding coefficient is statistically significant at 5% level. The increase in waste water by 1,000 tons per day, other things being equal, would lead to a 0.0004028 BOD increase. The size of the coefficient looks small, but is 5 times as large as that of BEF in absolute terms. This has important policy implications insofar as the building of treatment facilities, by itself, will not guarantee a given level of water quality in the absence of sufficient regulation and enforcement. This might imply the possibility that the waste water has been getting more toxic because of loosened regulatory efforts. Notice that WW measures just the volume of wastewater. But the pollutant concentration of wastewater is also critical in determining the extent to which treatment is effective and results in adequate water quality, and the firms' emissions and the pollution concentration in wastewater are affected by regulatory variables.[7] So WW, being a measure of quantity, does not capture potentially important quality considerations. Lastly, the sign of the estimated coefficient for PRE does not conform to our commonsense reasoning, but it is not statistically significant. This may be due to the fact that there has not been much variation in the national average precipitation.

One important question that we have asked is the extent to which the positive effect on water quality associated with increased investments in basic treatment facilities is offset by the indirect, negative effect of reduced potential enforcement activities. For the sake of this, we provide the OLS regression results in <Table 4>, in which the perverse effect

〈Table 4〉 OLS Regression Result

Variable	Coefficient	Stand. Error	*t*-statistic	*P*-value
C	2.233893	0.818156	2.73	0.018
BEF	-0.0000539	1.89E-05	-2.85	0.015
WW	0.0000280	0.000124	2.26	0.043
PRE	-1.57E-06	4.17E-06	-0.37	0.713

7) One important caution with this argument is that the water quality may have been affected by general economic conditions like industrial structure change and urbanization as well as regulatory variables and BEF. Thus the above argument indicates just one possibility at most.

through a reduced regulatory effort is not considered. As you can see when comparing <Table 3> and <Table 4>, the absolute value of the coefficient for BEF in 2SLS is greater than the one in OLS. This might imply that there has been a negative effect through a reduced regulatory effort. In summary, if a policymaker uses OLS estimation results to evaluate the effectiveness of BEF and WW on WQ, he will end up with underestimating the effectiveness of BEF on WQ.

Ⅴ. Concluding Remarks

The main question of this paper is whether building treatment facilities has improved water quality. Previous authors have argued that the facilities have been quite effective in improving the water quality. However, their analyses have been limited in the sense that they have not used real water quality data for the dependent variable in their regression analyses, but rather estimated data, and also the treatment facility is assumed to be the only factor determining the water quality. In contrast we have provided a theoretical model where the water quality is determined by regulatory efforts as well as the treatment facilities. Based on the theory we have run regressions on real water quality data.

With a structural equation model we have run a 2SLS regression and compared the results with those of an OLS regression to find that there has also been a counteracting negative effect on water quality through building BEF, even though it is small. The OLS regression results tells us that building treatment facilities has contributed to improving the water quality even with consideration of the negative effect through reduced enforcement effort. It is also shown that an increase in wastewater has deteriorated water quality. The absolute value of the estimated coefficient for WW is greater than the one for BEF, which might imply that WW emissions by firms have been becoming more toxic. An important policy implication is that building treatment facilities alone does not guarantee water quality, but depends in addition on proper regulation and enforcement. With this trade-off in mind, the higher-level agency that provides with BEF and enforcement budget should pursue an optimal allocation of public funds among those two options.[8)]

One critical limitation with this paper is that the number of observations in the empirical analysis is limited. With an expanded data set including river-specific data for all the variables, which does not exist in a well-ordered form yet, and longer time coverage, we could conduct a more meaningful analysis to get statistically robust results. This is left for future research.

8) The equation (7)~(9) in Kim and Chang (2007) present the optimality condition.

◎ References ◎

1. Garvie, D. and A. Keeler, "Incomplete Enforcement with Endogenous Regulatory Choice," *Journal of Public Economics*, Vol. 55, 1994, pp. 141～162.
2. Kang, M., "A Research on Reforming Korean Environmental Budget," RE-08, Korea Environment Institute, 2003. (in Korean)
3. Kim, G. and Y. Chang, "Investment in Basic Treatment Facilities and Environmental Regulation," *Journal of Regulation Studies*, Vol. 16(2), 2007, pp. 175～193. (in Korean)
4. Korea Ministry of Environment, *Environmental Statistics Yearbooks*, All Relevant Issues. (in Korean)
5. Kwak, T. and H. Kim, "A Study on Improving Korean Environmental Budget Policy," WO-04, Korea Environmental Technology Research Institute, 1995. (in Korean)
6. Neilson, W. and G. Kim, "A Standard-Setting Agency and Environmental Enforcement," *Southern Economic Journal*, Vol. 67(3), 2001, pp. 757～763.

접수일(2011년 11월 9일), 수정일(2012년 3월 9일), 게재확정일(2012년 3월 12일)