Water Quality and Environmental Treatment Facilities

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<<Abstract>>

It has been argued that investment in basic treatment facilities could have both a direct, positive effect and an indirect, negative effect on water quality. Using a two-stage least-squares method we have shown that the net effect of investment in basic treatment facilities on water quality in Korea is positive and statistically significant. Nevertheless, the findings also reveal a statistically significant, negative relationship between the volume of wastewater and water quality. These findings can be interpreted to suggest that facilities construction has not kept pace with treatment demands. Alternatively, these findings may also reflect firm behavior regarding wastewater discharge in the face of regulatory enforcement. We thus propose and test a novel model that is capable of simultaneously considering interactive behavior on the part of both firms and regulators and the resulting water quality this interaction gives rise to. 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.

Key Words : Basic Treatment Facilities, Water Quality, Enforcement, Regulation,

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1. 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 optimum level of pollution. At the same time, the government may also attempt to ensure the desired water quality by directly treating wastewater before it 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 through government efforts to directly treat these emissions. However, most analyses focus on one part of this situation by, for example, attempting to model the decision-making behavior of the regulatory agency or focusing on the determinants of water quality as an environmental outcome (Garvie and Keeler, 1994; Neilson and Kim, 2001; Kwak and Kim, 1995; Kang, 2003). To our knowledge, the only exception thus far was provided by Kim and Chang (2007). They 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 fact, local autonomous governments in Korea are responsible for monitoring and imposing fines on the violators and they are also charged with the operation of most basic treatment facilities, while a superior agency like (in this case, the central government) is mostly responsible for constructing the treatment facilities and providing the overall budget to autonomous governments. In this paper we examine whether increased investment in basic treatment facilities has improved water quality in Korea, with the analysis conducted within the framework provided by 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 have not used the real water quality data for the dependent variable in their regression analysis, but rather used estimated data; 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. To some extent, they have assumed away the problem by positing that these investments are predominantly responsible for (presumed) changes in water quality levels. At most, we can say that such investments are positively correlated with improvements in water quality. 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 Kim and Chang's (2007) model briefly, which argues that investment in basic treatment facilities has both a direct, positive effect on water quality and an indirect, negative effect on water quality. The reason why the investment in basic treatment facilities could have a negative 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 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 quite effective in improving water quality and its indirect, negative effect is almost negligible. In the last section, we provide a summary of our main arguments and draw attention to limitations to be addressed in future work.

2. 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 act like Stackelberg followers. So the analysis begins with the regulated firms. We are going to focus on the choice of a representative firm. The firm is assumed to minimize its abatement cost C plus expected fine pf by choosing its emission level x as indicated.

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

Those two factors C and pf all 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. The fine would increase as either the emission increases relative to an environmental standard, or the agency takes a stronger posture for enforcement. The probability of violators getting detected is denoted by p and the fine 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 $-C_x = pf_x$, which means that as a rational firm increases a marginal unit of emission, the saved abatement cost should equal the increase in expected fine. Also, using the second order condition we can easily show that the optimal choice regarding emission, say x^* would decrease as the agency increases either p or E.

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:

$$\begin{aligned} &Min_{p,E}\ n(x^*(p,E)-s)-g \\ &s.t.\ M(p,E)+A(g)\le B \end{aligned}$$

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 water directly, as reflected by g. The actual amount of g depends on the capacity of government constructed treatment facilities and we just assume for simplicity that g equals that capacity. 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. $A(g)$ stands for 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:

$$\begin{aligned}
&n\frac{\partial x^*}{\partial p} - \lambda M_p = 0 \\
&n\frac{\partial x^*}{\partial E} - \lambda M_E = 0 \\
&\lambda[B - M(p,E) - A(g)] = 0 \\
&B - M(p,E) - A(g) \geq 0,\ \lambda \geq 0
\end{aligned}$$

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

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

The left hand side represents the slope of an iso-non-compliance curve at the optimum, while the right hand side represents the slope of the agency's budget line at the optimum. 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, but it enters into the agency's objective function and its budget constraint. The variable g does reduce the 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. 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 water quality since 1991. In order to test the hypothesis we specify the following simultaneous equation system. 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 endogenously determined by regulatory variables.

$$WQ_i = \beta_{10} + \beta_{11} BEF_i + \beta_{12} WW_i + \beta_{13} PRE_i + \varepsilon_{1i}$$
$$BEF_i = \beta_{20} + \beta_{21} ENF\_PUNS_i + \varepsilon_{2i}$$

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 types with a higher value assigned to a harsher punishment type and then we have summed them up into a measure, PUNS. 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 square 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. 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 the following table.

<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

4. Empirical Results

BEF is not independent of WQ because it is influenced by ENF_PUNS and WW. So we have applied a two-stage least-squares method for estimating the effect of treatment facilities on water quality. The instrument variables for estimating BEF are ENF_PUNS, WW and PRE. After estimating BEF we have regressed WQ on the estimated BEF, WW and PRE, getting the result in <Table 2>. The estimation results confirm the previous authors' argument that building treatment facilities has been quite 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 0.0544 BOD decrease.

<Table 2. 2SLS Regression Result>

Variable	Coefficient	Stand. Error	t-statistic	P-value
C	2.223159	0.8259682	2.69	0.020
BEF	-0.0000544	0.0000191	-2.86	0.014
WW	0.0002819	0.0001251	2.25	0.044
PRE	-1.49E-06	4.18E-06	-0.36	0.728

It is also shown that the increase in wastewater has deteriorated the water quality. The corresponding coefficient is statistically significant. This result implies that the wastewater has been increasing in excess of total treatment capacities or actually utilized capacities. Otherwise, the variation in wastewater would not have affected the water quality in a statistically significant way. The size of the coefficient is small, though. The increase in waste water by 1,000 tons per day, other things being equal, would lead to only a 0.0001251 BOD increase. 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. So WW, being a measure of quantity, does not capture potentially important quality considerations. 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. Lastly, the sign of the estimated coefficient for PRE conforms to our commonsense reasoning, but it is not statistically significant.

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. The above result tells us that the net effect was positive on water quality, i.e., we can say that building treatment facilities has contributed to improving the water quality even with consideration of the negative effect through reduced enforcement efforts. Just for a reference we provide the OLS regression results. As you can see in <Table 3>, the negative effect can be thought to be small.

<Table 3. 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

5. 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 analysis is 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. This paper is different in that we have run a regression on real water quality data and we have allowed both treatment facilities and regulation to affect the water quality.

With a structural equation model we have run a 2SLS regression and shown 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. This result implies that WW might have deteriorated the water quality through the induced firms' emissions. An important policy implication is that building treatment facilities alone does not guarantee water quality, but depends in addition on proper regulation and enforcement. 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 we could conduct a more meaningful analysis. This is left for future research.

References

Garvie, D. and Keeler (1994), “Incomplete Enforcement with Endogenous Regulatory Choice,” *Journal of Public Economics*, Vol. 55, pp. 141-162.

Kang, M. (2003), “A Research on Reforming Korean Environmental Budget,” RE-08, Korea Environment Institute. (in Korean)

Kim, G. and Y. Chang (2007), “Investment in Basic Treatment Facilities and Environmental Regulation,” *Journal of Regulation Studies*, Vol. 16(2), pp.175-193. (in Korean)

Korea Ministry of Environment, *Environmental Statistics Yearbooks*, all relevant issues. (in Korean)

Kwak, T. and H. Kim (1995), “A Study on Improving Korean Environmental Budget Policy,” WO-04, Korea Environmental Technology Research Institute. (in Korean)

Neilson, W. and G. Kim (2001), “A Standard-Setting Agency and Environmental Enforcement,” *Southern Economic Journal*, Vol. 67(3), pp.757-763.