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An empirical study on effective pollution enforcement in Korea

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ABSTRACT. It has been recognized that extra incentives for firms' compliance with pollution regulations would be created under state-dependent enforcement as Harrington (1988) has shown theoretically. However, the extent of the overall improvement in compliance is expected to be different according to the pollution control costs and industrial structures of any given country. This paper empirically examines, for the first time, the effectiveness of an imposition of higher fines for repeated violations and state-dependent enforcement in terms of the reduction of violation days, by simulating emitting behavior for 65 sub-industries in the Korean manufacturing industry over the period 1987–1989. State-dependent enforcement was found to be more effective than an imposition of higher non-compliance fines for repeated violations in regard to the number of sub-industries exhibiting persistent non-compliance. However, the number of fully complying sub-industries was found to be slightly higher under an imposition of higher non-compliance fines for repeated violations. In Korea, it would therefore be desirable to discriminate against certain industries with enforcement systems of different intensity based on their abatement cost structures rather than uniformly introducing a state-dependent approach.

1. Introduction

Before the 1980s, mainly concerned with achieving rapid economic development with little or no consideration for the environment, Korea's use of its human and physical resources resulted in considerable environmental damage. A number of pollutants produced by industrialization were indiscriminately released into the environment, causing environmental degradation and threatening people's health. It was not until the early 1980s that the Korean government began to recognize the seriousness of the effects of pollution and established an independent regulatory agency, the Ministry of Environment, directing it to set emission standards for major pollutants.

Even in the 1980s, economic performance took precedence over environmental quality in terms of policy. As a result, investment in

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environmental conservation efforts was insignificant, and the quality of the environment continued to deteriorate. By the 1990s, the regulatory agency realized the need for more stringent standards in enforcing regulations. In order to attain satisfactory outcomes, the regulatory agency began to monitor compliance to these standards and, now, when a firm is discovered to be violating the set standards, it is subject to penalties.

As shown in table 1, the number of firms emitting effluents increased annually by about 20 per cent from 1980, such that the number in 1992 was fourfold that of 1980. Prior to 1985, the regulatory agency, on average, did not inspect each firm more than once a year. Since 1985 the frequency of inspections increased. However, the fraction of firms detected to be violating the standards has not changed significantly. This finding might imply that the non-compliance penalties were not high enough, so, for some firms, the expected non-compliance penalties were lower than the costs incurred from meeting the standards. In reality, more than half of the firms found in non-compliance were punished with an amount that corresponded to the lowest level amongst several types of penalties.[1] Even though a high level of penalties does not necessarily guarantee high compliance rates,[2] an increase in the level of penalties may be effective in improving environmental outcomes in Korea. For instance, repeated violations would be subject to higher non-compliance fines.

Enforcement issues on environmental regulation have been addressed since the beginning of the 1970s. Downing and Watson (1974), Buchanan and Tullock (1975), Harford (1978), and Beavis and Walker (1983) analyzed efficient enforcement policies in static models where violating firms would optimize their behavior keeping in mind pollution control costs and fines.

According to Harrington (1988), extra incentives for compliance would be created under state-dependent enforcement[3] in which the regulatory agency's policy depends upon the firm's past performance. The basic idea is that firms are assigned to two groups, group 1 and group 2, based on their previous compliance status. Firms found to be in compliance up to the last inspection are placed into group 1, and firms found to be in violation are placed into group 2. Group 2 is subject to a tougher regulatory system, which includes more stringent standards, a higher probability of inspections, and more severe penalties, than group 1.

The extent of the overall improvement in compliance, however, is expected to be different according to the pollution control costs and industrial structures of any given country. In this paper, we simulate the emitting behavior of 65 sub-industries in the Korean manufacturing industry over the period from 1987 to 1989. Firstly, we empirically examine the

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[1] In the development-oriented government, the agency hesitated to impose severe punishments except for polluting accidents that caused serious hazards.

[2] Harford (1987) showed a model in which more frequent monitoring increased the level of compliance without imposition of fines.

[3] Adapting the model of income tax enforcement originated by Landsberger and Meilijson (1982), Harrington (1988), Harford and Harrington (1991), and Harford (1991) tried to explain the phenomenon of high compliance in the lack of strict enforcement, what is called 'voluntary compliance.'

Table 1. *Enforcement of effluent firms in Korea (unit: no. of firms)*

		Inspection		*Types of penalties*						*Rate*		
Year	*Total (a)*	*Number inspected (b)*	*Number detected (c)*	*Correction*	*Operation prohibition*	*Permission withdrawal*	*Indictment*	*Order of removal*	*Others*	*(b)/(c)*	*(e)/(b)*	*(c)/(a)*
1980	5,097	4,801	1,886	1,106	118	25	154	116	367	0.94	0.39	0.37
1981	5,819	5,613	2,459	1,389	145	37	175	62	651	0.96	0.44	0.42
1982	6,526	5,459	2,541	1,414	78	52	115	19	863	0.84	0.47	0.39
1983	7,022	5,386	2,461	1,333	226	51	228	7	616	0.77	0.46	0.35
1984	7,719	6,355	2,863	1,658	324	42	300	8	531	0.82	0.45	0.37
1985	8,457	7,631	3,275	1,848	432	49	374	7	565	0.90	0.43	0.39
1986	9,916	11,053	3,427	2,159	278	53	410	10	517	1.11	0.31	0.35
1987	11,587	16,551	2,826	1,723	90	64	266	2	681	1.43	0.17	0.24
1988	14,214	25,624	4,917	2,929	290	26	220	7	1,445	1.80	0.19	0.35
1989	14,744	32,471	7,524	3,808	1,005	61	566	35	2,049	2.20	0.23	0.51
1990	17,375	61,639	11,015	4,303	1,917	91	849	14	3,841	3.55	0.18	0.63
1991	20,731	73,895	8,575	3,451	1,339	70	317	22	3,376	3.56	0.12	0.41
1992	24,980	63,053	6,428	3,172	593	50	105	1	2,507	2.52	0.10	0.26

effectiveness of an imposition of higher fines for repeated violations in terms of a reduction in violation days. Secondly, we also explore the extent of the overall improvement in compliance under state-dependent enforcement. In particular, we classify the data set into 12 mid-industries to grasp the responses of individual industries to different regulatory systems.

In the next section, we provide the theoretical model with which to investigate a firm's behavior under static and state-dependent enforcement. The simulation process for empirical analysis and our results are discussed in section 3. Section 4 contains concluding remarks.

2. Analysis of firm's behavior

For simplicity, it is assumed that a firm's production process is separate from its choice of emission control. In investigating a firm's behavior in response to the regulatory agency's enforcement, most previous studies have used the quantity of pollution as a choice variable in the cost minimization problem. Here, we regard the number of violation days as the choice variable.[4]

The cost function of the firm's emission control for an arbitrary period t is $C_t = C[n_t, S]$, where n_t is the firm's violation days for period t and S is the legal discharge allowance. An increase in the violation days leads to a decrease in costs: $C_n (\equiv \partial C_t / \partial n_t) < 0$. Lowering S means that the standard is made more stringent: $\partial C_t / \partial S < 0$. For simplicity it is assumed that $\partial^2 C_t / \partial n_t^2 = 0$. If a unit period of monitoring lasts for M days, C_n is calculated by $-(1/M)[C(n_{t0}, S) - C(n_{tM}, S)]$, where $C(n_{t0}, S)$ is the cost under no violations and $C(n_{tM}, S)$ is the cost when violations are made on a daily basis during a unit period of monitoring. Thus, $[C(n_{t0}, S) - C(n_{tM}, S)]$ is the cost incurred by meeting the standards for a unit period.

The regulatory agency monitors whether firms are observing the legal standards for emission control. If some firms are found to be violating the standards, they end up with lump-sum fines, f. The probability of detecting violations for period t is $P_t = P(n_t, S)$, where $\partial P_t / \partial n_t > 0$ and $\partial P_t / \partial S < 0$. Naturally, $\partial^2 P_t / \partial n_t^2 > 0$.

Consider a two-period model where a risk-neutral firm chooses its optimal number of violation days during each period to minimize the present value of pollution abatement costs and expected penalties. Under static enforcement where the variables such as P_t, f, and S are constant over the two periods,[5] an objective function can be defined as

$$E_t = C(n_t, S) + P(n_t, S) f + d E_{t+1} \tag{1}$$

where E_t and E_{t+1} are the present values of the expected cost in period t and $(t + 1)$, respectively, where d is the discount factor.

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[4] All of the action is to determine whether the pollution control equipment is turned on or off. On violation days it is turned off and on compliance days it is turned on. Therefore, partial compliance is not considered.

[5] Static enforcement is a system where the regulatory intensity is totally independent of previous performance.

In a steady state, where $n_t = n_{t-1} = n$ and $E_t = E_{t-1} = E$, the first-order condition for the minimization of the present value of expected cost will be

$$\frac{\partial E}{\partial n} = \frac{1}{1-d}\left(C_n + \frac{\partial P}{\partial n}\cdot f\right) = 0 \tag{2}$$

From equation (2), which is exactly the same as the one derived from the one-period model, a choice of the number of violation days is such that the marginal abatement cost saved by violating one additional day is equal to the marginal expected penalty.

Now, let us introduce a state-dependent enforcement system. Firstly, firms are divided into two groups, G1 and G2. The firms that are either observing the standards or not being inspected in period t remain in group G1 in period $(t+1)$, but the firms found not complying in period t transfer to group G2 in the period $(t+1)$. The firms belonging to group G2 that exhibit compliance move into group G1 in the next period. Enforcement variables are different for each group such that $P_1 < P_2$, $f_1 < f_2$, and $S_1 > S_2$, where the subscripts represent each group. This implies that group G2 is under tighter regulations than group G1.

Under state-dependent enforcement, it is possible for the firms and the regulatory agency to have mutual strategic correspondence over the periods under question. The firms belonging to group G1 in period t go to G2 with probability P_1 and remain in G1 with probability $(1 - P_1)$ in period $(t+1)$. Likewise, the firms belonging to G2 in period t go to G1 with probability $(1 - P_2)$ and remain in G2 with probability P_2 in the next period. Then, the present values of expected cost for G1 and G2 will be, respectively

$$E_{1t} = C(n_{1t}, S_1) + P_1(n_{1t}, S_1)f_1 + P_1 d E_{2(t+1)} + (1 - P_1) d E_{1(t+1)} \tag{3}$$

$$E_{2t} = C(n_{2t}, S_2) + P_2(n_{2t}, S_2)f_2 + P_2 d E_{2(t+1)} + (1 - P_2) d E_{1(t+1)} \tag{4}$$

In a steady state, where $n_{it} = n_{i(t+1)} = n_i$ and $E_{it} = E_{i(t+1)} = E_i, i = 1, 2$, the first-order conditions for the minimization of the present value of expected cost with respect to n_1 and n_2 will be[6]

$$\frac{\partial E_1}{\partial n_1} = \left\{C_{n_1} + (\partial P_1/\partial n_1)(f_1 + d(E_2 - E_1))\right\}H_1 = 0 \tag{5}$$

$$\frac{\partial E_2}{\partial n_2} = \left\{C_{n_2} + (\partial P_2/\partial n_2)(f_2 + d(E_2 - E_1))\right\}H_2 = 0 \tag{6}$$

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[6] In order to avoid corner solutions where the expected penalty is far less than abatement costs such that optimal violation days exist between 0 and M, the second-order conditions must be satisfied: $\frac{\partial^2 E_i}{\partial n_i^2} = \{C_{n_i n_i} + (\partial^2 P_i/\partial n_i^2)(-C_{n_i}/(\partial P_i/\partial n_i))\}H_i > 0$.

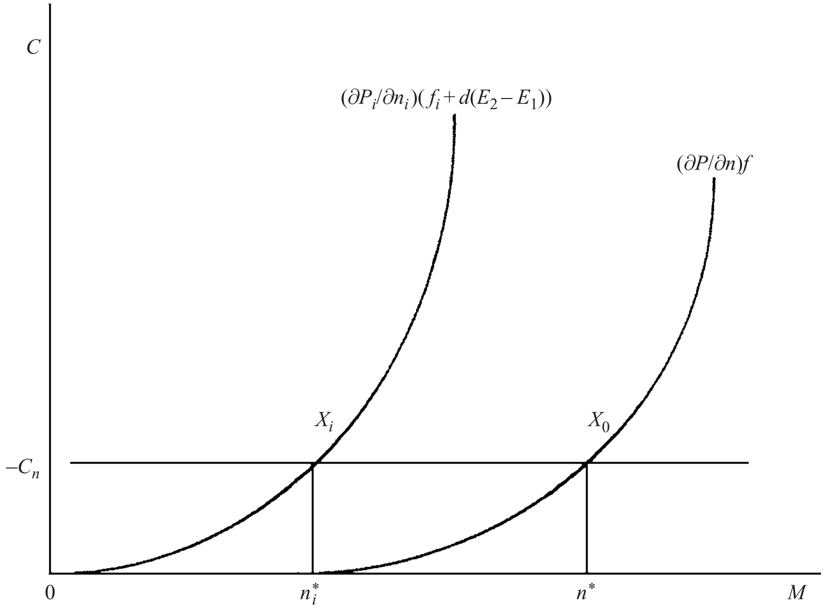

Figure 1. *Optimal number of violation days*

where $H_1 = (1 - P_2d)/\{(1 - d)[1 - d(P_2 - P_1)]\} > 0$ and $H_2 = \{1 - (1 - P_1d)\}/\{(1 - d)[1 - d(P_2 - P_1)]\} > 0$.

The optimal conditions under state-dependent enforcement will be such that the marginal abatement cost for each group is equal to the marginal expected penalty including the difference in the present value of expected cost between group G1 and G2, $\{d(E_2 - E_1)\}$. If the regulatory agency does not distinguish one group from the other, so that $E_1 = E_2$, these conditions boil down to equation (2), which is the optimal condition under static enforcement. As shown in figure 1, the equilibrium point will be X_0 associated with n^* under static enforcement. As the expected penalty increses as much as $\{(\partial P_i/\partial n_i) \cdot d(E_2 - E_1)\}$ under state-dependent enforcement, the equilibrium points for each group will be $X_i, i = 1, 2$, where the optimal numbers of violation days are n_i^*. Accordingly, the number of violation days under state-dependent enforcement will be less than the one under static enforcement by $(n^* - n_i^*)$.

3. Simulation and results

The waste-water discharge intensity data were obtained from the National Environmental Institute's reports, which surveyed 1,231 effluent wastes firms in 134 sub-industries over the period 1987–89.[7] They measured the

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[7] Though the Korean Ministry of Environment has been publishing annual reports on effluent wastes sources of 24 industries since 1986, information on effluent waste intensity is not included.

Table 2. *Classification of 65 sub-industries by mid-industry and the class*

	Class					
Mid-industry	*No. of sub-industries*	*1st*	*2nd*	*3rd*	*4th*	*5th*
Industrial chemicals	7	2		2	3	
Other chemicals	5				5	
Rubber and plastics	2				2	
Primary metals	1	1				
Fabricated metal and machinery	10				4	6
Leather and fur	4				3	1
Food	11		2	1	7	1
Beverages	5	1		1	3	
Textile	10				10	
Paper and tobacco	6	1	5			
Non-metallic minerals	2					2
Livestock raising	2				1	1
Total	65	5	7	4	38	11

intensity of effluent wastes using a method designed in conjunction with the Ministry of Environment. In the present study, 40 sub-industries have been excluded due to a deficiency in information on the BOD density before and after waste treatment, and 29 sub-industries have also been ruled out due to their constant compliance.

This survey includes the amount of effluent waste (m^3/day) and the average density of BOD and COD. The abatement costs for BOD (won/kg) and non-compliance fines are constructed based on the average values of the data obtained.

As presented in table 2, the data set is classified into 12 mid-industries.[8] The highest number of sub-industries is ten, which includes fabricated metal and machinery, and the textile industry. The primary metal industry has only one sub-industry. Examining the data set by class,[9] five sub-industries belong to the first class. The fourth class contains the highest number of sub-industries, with 38.

For the foundation of an empirical two-period model, the following assumptions are necessary. Firstly, the firm violating the standards is risk-neutral in being caught and the two unit periods of monitoring occur at identical intervals. Secondly, the firm is inspected once during the unit period and does not know when it will be inspected. The firm violating the standards is detected without error and the non-compliant fines are

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[8] Classification by mid-industry is more comprehensive in terms of grouping analogous sub-industries.

[9] Based on the amount of effluent waste, emitting sources are classified into five classes. Firms emitting more than 3,000 m^3/day belong to the first class. The firms belonging to the second and third classes emit 1,000–3,000 and 500–1,000 m^3/day, respectively. The firms emitting 50–500 m^3/day and less than 50 m^3/day are included in the fourth and fifth classes, respectively.

levied on the basis of 30 days.[10] Thirdly, the unit periods, M, is composed of 78, 52, and 39 days under static enforcement.[11] Under state-dependent enforcement, M is composed of 78 (52) and 52 (39) days for G1 and G2, respectively. Lastly, the probability of being detected and fined non-compliant penalties in G2 in comparison with those in G1 are $P_2 = 1.5P_1$ and $f_2 = 1.5f_1$, respectively. The probability density function for being detected is the same regardless of the group.

The distribution function of the probability of being detected in the interval from the first day to the inspection day of $X(< M)$ is defined as

$$P(X \leq n) = \int_0^n f(X)\,dX \tag{7}$$

where $f(X) = M \cdot \exp(X/M)/(\exp - 1)$.[12]

Given the probability density function for being detected, the present value of expected cost under static enforcement will be

$$E = \frac{-a(n-M) + \left(\frac{1}{e} - 1\right)\left(e^{n/M} - 1\right) \cdot f}{1-d} \tag{8}$$

where a is abatement cost of BOD (COD) per day and M represents the maximum number of violation days. f is the fine per 30 days of violation, and d is the discount factor, which is assumed to be 0.9.

Similarly, the present values of expected costs for G1 and G2 under state-dependent enforcement will be

$$E_1 = \frac{-a(n_1 - M_1) + \left(\frac{1}{e} - 1\right)\left(e^{n_1/M_1} - 1\right) \cdot f_1}{1 - d\left[1.5\left(\frac{1}{e} - 1\right)\left(e^{n_1/M_1} - 1\right) - \left(\frac{1}{e} - 1\right)\left(e^{n_1/M_1} - 1\right)\right]} \tag{9}$$

$$E_2 = \frac{-a(n_2 - M_2) + \left(\frac{1}{e} - 1\right)\left(e^{n_2/M_2} - 1\right) \cdot f_2}{1 - d\left[\left(\frac{1}{e} - 1\right)\left(e^{n_2/M_2} - 1\right) - \frac{2}{3}\left(\frac{1}{e} - 1\right)\left(e^{n_2/M_2} - 1\right)\right]} \tag{10}$$

where M_1 and M_2 are the unit periods of monitoring for G1 (78, 52 days) and G2 (52, 39 days), respectively. A simulation program was constructed using the Fortran language.

The optimal number of violation days under static enforcement can be obtained from the minimization of equation (8), which is reported in table 3. If the regulatory agency sets 78 days as the unit period of monitoring, 28 out of 65 sub-industries would violate the statically enforceable standards for the entire 78 days. Examination of individual industries showed that all the primary metals and non-metallic minerals industries would never exhibit

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[10] In Korea, firms that are caught are generally punished with not only fines, but also with a suspension of operation for a given period of time. Here, however, we ignore the losses from suspension, because they are very difficult to measure.

[11] The days of 78, 52, 39 as unit periods are derived from the assumption that firms operate for 312 days and the agency inspects 4, 6, and 8 times a year.

[12] The value of $f(x)$ is derived from $\int_0^M f(x)\,dx = 1$.

Table 3. *Optimal numbers of violation days under static enforcement by mid-industries*

	Violation days								
	M = 78 days			*M = 52 days*			*M = 39 days*		
Mid-industry	*78*	*1–77*	*0*	*52*	*1–51*	*0*	*39*	*1–38*	*0*
Industrial chemicals	6		1	6		1	6		1
Other chemicals		3	2		2	3		2	3
Rubber and plastics	1		1	1		1		1	1
Primary metals	1			1			1		
Fabricated metal and machinery	9		1	9		1	9		1
Leather and fur	1	1	2		1	3		1	3
Food	6	1	4	5	2	4	4	3	4
Beverages	1	1	3	1	1	3		2	3
Textile		5	5		2	8		1	9
Paper and tobacco	1	2	3	1	1	4	1	1	4
Non-metallic minerals	2			2			2		
Livestock raising			2			2			2
Total	28	13	24	26	9	30	23	11	31

compliance, even for a single day. Fabricated metal and machinery and industrial chemicals also showed bad performances, with 90 per cent and 85 per cent of the total number of sub-industries exhibiting non-compliance, respectively. This finding may reflect that their abatement costs are large enough to exceed the expected non-compliance fines. Stricter enforcement for those industries will be necessary for an overall improvement in compliance performance. On the other hand, 24 out of 65 sub-industries would be fully compliant with no violation days during the 78 days. Every livestock producer would be compliant throughout the period under question.

As the number of monitoring days decreases, the standards tend to be observed more closely. Suppose that the regulatory agency reduces its monitoring days from 78 to 52. Two sub-industries that previously chose maximum violations choose now partial compliance and six sub-industries shift their optimal violation days to zero. When monitoring days are reduced to 39, five sub-industries reduce their optimal violation levels from the maximum allowed and seven sub-industries eliminate violation altogether. However, we observed that some industries such as industrial chemicals, primary metals, fabricated metal and machinery, and non-metallic minerals maintain the same number of violation days regardless of the length of monitoring.

Let us see how significant a role an imposition of higher non-compliance fines for repeated violations would play in reducing the number of violating days under a static enforcement system.[13] Suppose that the coefficient of imposition is 1.3 such that the non-compliance fines are increased by 1.3 times every time a firm's violation is detected. The optimal violation

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[13] The coefficient for repeated violation is used to compute the Korean effluent charge system equation.

Table 4. *Optimal numbers of violation days with coefficient of imposition of 1.3*

	Violation days								
	M = 78 days			*M = 52 days*			*M = 39 days*		
Mid-industry	*78*	*1–77*	*0*	*52*	*1–51*	*0*	*39*	*1–38*	*0*
Industrial chemicals	6		1	5	1	1	5	1	1
Other chemicals		2	3		2	3			5
Rubber and plastics	1		1		1	1		1	1
Primary metals	1			1			1		
Fabricated metal and machinery	9		1	9		1	9		1
Leather and fur		1	3		1	3			4
Food	5	2	4	3	4	4	2	4	5
Beverages		2	3		2	3		1	4
Textile		2	8			10			10
Paper and tobacco	1	1	4	1		5	1		5
Non-metallic minerals	2			2			1	1	
Livestock raising			2			2			2
Total	25	10	30	21	11	33	19	8	38

days by monitoring days are reported in table 4. Given monitoring days of 78 days, 25 sub-industries' violation days reach the maximum, ten choose partial compliance, and 30 fully comply. Given monitoring days of 52 days, 21 sub-industries' violation days reach the maximum, 11 choose partial compliance, and 33 fully comply. Given monitoring days of 39 days, 19 sub-industries' violation days reach the maximum, eight choose partial compliance, and 38 fully comply.

Comparing the simulation results in table 3 with those in table 4 enabled us to determine how much an imposition of higher non-compliance fines for repeated violations would improve the overall compliance performance. In the case of 78 monitoring days, three sub-industries shift their optimal violation days from non-compliance to partial compliance, and six sub-industries shift from partial compliance to full compliance. In the case of 52 days, five sub-industries shift from a maximum number of violations to partial compliance, and three sub-industries shift from partial compliance to full compliance. In the case of 39 days, four sub-industries shift from a maximum number of violations to partial compliance, and seven sub-industries shift from partial compliance to full compliance. Those industries where most sub-industries chose a maximum number of violation days under static enforcement remarked irresponsive to an imposition of higher non-compliance fines for repeated violations.

The optimal number of violation days for G1 and G2 under state-dependent enforcement are presented in table 5 and are obtained by minimizing equations (9) and (10).[14] Suppose that the regulatory agency

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[14] Simulating firms' behavior under state-dependent enforcement, we assume that all of 65 sub-industries belong to both G1 and G2 to begin with.

Table 5. *Optimal numbers of violation days under state-dependent enforcement by mid-industries*

	Violation days											
	M1 = 78 days			*M2 = 52 days*			*M1 = 52 days*			*M2 = 39 days*		
Mid-industry	*78*	*1–77*	*0*	*52*	*1–51*	*0*	*52*	*1–51*	*0*	*39*	*1–38*	*0*
Industrial chemicals	5	1	1	5	1	1	5	1	1	5	1	1
Other chemicals		3	2		1	4		2	3			5
Rubber and plastics		1	1		1	1		1	1		1	1
Primary metals	1			1			1			1		
Fabricated metal and machinery	8	1	1	8	1	1	8	1	1	8	1	1
Leather and fur		2	2		1	3		1	3			4
Food	1	6	4	1	6	4		7	4		5	6
Beverages		2	3		2	3		2	3		1	4
Textile		4	6			10		2	8			10
Paper and tobacco	1	1	4	1		5		2	4		1	5
Non-metallic minerals		2			2			2			2	
Livestock raising			2			2			2			2
Total	16	23	26	16	15	34	13	22	30	13	13	39

sets 78 days and 52 days for G1 and G2, respectively, 16 sub-industries would not be compliant with the standards, even for a single day, regardless of the group, while 23 sub-industries in G1 and 15 sub-industries in G2 would choose partial compliance, and 26 sub-industries in G1 and 34 sub-industries in G2 would be fully compliant. If the regulatory agency sets 52 days for G1 and 39 days for G2, 13 sub-industries would select maximum violation days regardless of the group, 22 sub-industries in G1 and 13 sub-industries in G2 would choose partial compliance, and 30 sub-industries in G1 and 39 sub-industries in G2 would be fully compliant. Overall, G2 tends to choose slightly less violation days than G1, as expected.

Comparing table 3 with table 5, we observe the effectiveness of state-dependent enforcement over static enforcement. Suppose that the regulatory agency shifts the regulatory system from static enforcement for 78 days to state-dependent enforcement for 78 days for G1 and 52 days for G2. Twelve sub-industries would shift from non-compliance to partial compliance, and two sub-industries would shift from partial compliance to full compliance. Among those industries where most sub-industries select a maximum number of violation days even under an imposition of higher non-compliance fines for repeated violations, all (two) sub-industries in non-metallic minerals, and not more than one sub-industry in fabricated metal and machinery and industrial chemicals would shift their optimal violation days from non-compliance to partial compliance. However, the primary metals industry would still violate the standards throughout the entire monitoring period.

If the regulatory agency shifts from static enforcement for 52 days to state-dependent enforcement for 52 days for G1 and 39 days for G2, 13 sub-industries shift the optimal violation days from non-compliance to partial compliance but there will be no change in the number of fully complying sub-industries.

We conclude that state-dependent enforcement will be more effective than an imposition of higher non-compliance fines for repeated violations in terms of the number of sub-industries exhibiting persistent non-compliance. However, interestingly enough, the number of fully complying sub-industries would be slightly larger under an imposition of higher non-compliance fines for repeated violations than under state-dependent enforcement. This finding empirically supports Viscusi and Zeckauser (1979) in that, as a regulatory system is made more strict, a portion of compliant industries choose not to comply. These industries include leather, fur, textiles, and other chemicals.

Most sub-industries in industries such as primary metals, fabricated metal and machinery, and industrial chemicals will continue to choose the maximum violation days despite a shift to the more effective enforcement system. For these industries, tougher regulatory systems are recommended. Therefore, in Korea, a uniform introduction of state-dependent enforcement would not necessarily produce the best outcomes in improving compliance performance. Rather, based on our simulation results, it would be desirable to discriminate against certain industries with enforcement systems of different intensity.

4. Concluding remarks

In this paper we empirically investigated the effectiveness of not only an imposition of higher fines for repeated violations, but also state-dependent enforcement in terms of a reduction in the number of violation days, by simulating emitting behavior for 65 sub-industries (12 mid-industries) in the Korean manufacturing industry.

In the case where non-compliance fines were increased by 1.3 times for repeated violations, three sub-industries shifted their optimal violation days from non-compliance to partial compliance, and six sub-industries shifted from partial compliance to full compliance, given 78 days of monitoring. Where the regulatory system was changed from static enforcement for 78 days to state-dependent enforcement for 78 days for group 1 and 52 days for group 2, 12 sub-industries shifted their optimal violation days from non-compliance to partial compliance, and two sub-industries, from partial compliance to full compliance.

We conclude that state-dependent enforcement will be more effective than an imposition of higher non-compliance fines for repeated violations in terms of the number of sub-industries persistently exhibiting non-compliance, but, the number of fully complying sub-industries will be slightly higher under an imposition of higher non-compliance fines for repeated violations than under state-dependent enforcement. These results suggest that Korea should discriminate against certain industries with enforcement systems of different intensity rather than uniformly introducing a state-dependent approach.

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