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Sarah L. Stafford
William & Mary, slstaf@wm.edu

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This paper adds to the debate over whether self-policing can increase environmental protection by considering an issue that has been ignored in previous models—that self-policing may influence future enforcement. The model combines self-policing with targeted enforcement and allows for both deliberate and inadvertent violations. As expected, rewarding self-policers with more lenient future enforcement increases auditing, remediation, and disclosure of inadvertent violations. Self-policing can also serve as a complement to deliberate compliance and can thus further increase environmental performance. However, under reasonable conditions, self-policing can be a substitute for deliberate compliance and could therefore be detrimental to environmental protection.

JEL Classification: K32, K42, Q52, Q58

1. Introduction

There is an on-going debate in both the theoretical and empirical literature about the effectiveness of self-policing policies such as the Environmental Protection Agency's (EPA) Audit Policy. The EPA consistently publicizes the Audit Policy as a successful, innovative approach to compliance. For example, the introduction to EPA's 2002 Enforcement and Compliance Assurance Report, "Environmental Results through Smart Enforcement," includes the 26% increase in companies that self-disclose violations as one of the year's highlights (U.S. EPA 2003, p. 4). However, Pfaff and Sanchirico's (2004) finding that the typical self-disclosed violation is relatively insignificant leads them to question whether the Audit Policy is as effective as the EPA claims. Similarly, Stafford (2005) examines compliance with hazardous waste regulations before and after the establishment of the federal Audit Policy and does not find any significant evidence that the federal Audit Policy has affected overall compliance.[1]

The theoretical literature on self-policing is also mixed. While many theoretical models of self-policing show that it can increase environmental protection (e.g., Kaplow and Shavell 1994; Innes 1999a), other models demonstrate how self-policing can have significant negative effects (e.g., Heyes 1996; Friesen 2006). This paper adds to the debate over the ability of self-policing to increase environmental protection by considering one aspect of self-policing that has been ignored in previous models—that self-policing may influence future enforcement activity.

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* The College of William & Mary, Department of Economics, Williamsburg, VA 23187-8795, USA; E-mail slstaf@wm.edu.

[1] However the results suggest that state audit legislation and self-policing policies may decrease violations of hazardous waste regulations.

934

EPA's Audit Policy provides incentives for regulated facilities to conduct environmental audits and voluntarily self-police by offering significant penalty reductions for any disclosed violations that meet certain eligibility criteria. Additionally, the EPA's website for environmental auditing notes that when regulated facilities self-police, it can render "formal EPA investigations and enforcement actions unnecessary."[2] Although the EPA website implies that self-policing can affect future enforcement activity and Stafford (2007) finds that self-disclosures do decrease the probability of future inspections, to date all theoretical models of self-policing are essentially static models.

This paper adds to the existing theoretical literature on self-policing by incorporating self-policing into Harrington's (1988) dynamic targeted enforcement model. The paper then investigates the effect of self-policing on facility behavior and examines the circumstances under which self-policing can increase environmental protection and the circumstances under which it can be detrimental. The remainder of the paper is organized as follows: Section 2 provides a brief description of EPA's self-policing policy; section 3 reviews the theoretical literature on self-policing; section 4 presents a theoretical model of self-policing in a targeted enforcement regime; section 5 discusses the implications of self-policing for environmental performance under this model; and section 6 concludes.

2. EPA's Self-Policing Policy

In December of 1995 EPA issued "Incentives for Self-Policing: Discovery, Disclosure, Correction and Prevention of Violations," which encouraged facilities to voluntarily undertake environmental audits and provided incentives for facilities to voluntarily disclose and correct any violations of environmental regulations discovered by the audit.[3] Because this policy evolved from an EPA effort to encourage environmental auditing, the self-policing policy is more commonly referred to as the Audit Policy. Under the Audit Policy, any facility that voluntarily identifies, discloses, and corrects violations of environmental regulations is eligible for a reduction in the penalties associated with those violations. To be eligible for a complete waiver of punitive penalties, the self-disclosure must meet nine conditions:

i. Systematic discovery: Discovery must either take place during an environmental audit or during a self-evaluation that is part of a due diligence program.
ii. Voluntary discovery: The process through which the violation is discovered cannot be required by federal, state, or local authorities and cannot be required by statutes, regulations, permits, or consent agreements.
iii. Prompt disclosure: Violations must be disclosed within 21 days of discovery.
iv. Independent discovery and disclosure: The disclosure cannot be made after an inspection or investigation has been announced or notice of a suit has been given.
v. Correction and remediation: Any harm from the violation must be remediated and the violation must be corrected within 60 days of the date of discovery unless technological issues are a factor.
vi. No recurrence: The facility must identify why the violation occurred and take steps to ensure that it won't recur.

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[2] See http://www.epa.gov/compliance/incentives/index.html, last accessed January 11, 2007.
[3] 60 *Federal Register* 66705, December 22, 1995.

vii. No repeat violations: The same or a closely related violation cannot have occurred within the past three years at the facility or within the past five years at other facilities owned by the same parent organization.

viii. Not excluded: No serious harm or imminent endangerment to human health and the environment can have occurred as a result of the violation and the violation cannot have been a violation of an order, consent agreement, or plea agreement.

ix. Cooperation: The facility must cooperate with EPA, including providing all requested documents.

The Audit Policy does not apply to the portion of the penalty that is based on the economic benefit gained from noncompliance. For example, if a facility neglects to sample a particular waste stream for several months and discovers this violation through an environmental audit, assuming the violation meets all of the conditions above, the facility would receive a complete reduction in the punitive portion of the penalty but would continue to owe a penalty equal to the savings it received from not having conducted those samples. This requirement is necessary to ensure that regulated entities have no incentive to deliberately violate and then self-police. In the preceding example, there would be no benefit to deliberately not sampling and then self-policing if the regulated entity has to pay the cost of sampling after disclosure.

In 2005, approximately 1500 facilities self-disclosed a violation under the Audit Policy. To put this number in context, during this same time frame, 21,000 facilities were inspected or evaluated by EPA, and approximately 1.1 million facilities were subject to EPA regulation.[4] Facilities disclose violations of all of EPA's environmental statutes including the Clean Air Act, the Clean Water Act, and the Emergency Planning & Community Right-To-Know Act. An analysis of disclosures made in the early years of the Audit Policy (1994–1999) conducted by Pfaff and Sanchirico (2004) found that the majority of disclosed violations were reporting and recordkeeping violations. Since that early analysis, the number of disclosures has risen significantly and the distribution of disclosures across statutes has shifted somewhat. Unfortunately, EPA's database of disclosures does not contain enough information to conduct a similar analysis of more recent disclosures to determine whether the pattern of disclosures found by Pfaff and Sanchirico still holds. However, I can use more recent data to determine the typical penalty reduction. During the 2001–2005 period, data on penalty reduction is available for 70% of the disclosures received by EPA. Of these disclosures, 97% (or over two-thirds of all of the disclosures) resulted in a complete waiver of all penalties.[5]

3. Theoretical Literature on Self-Policing

The term "self-policing" is used in this paper and by EPA to denote a situation in which a facility voluntarily notifies authorities that it has violated a regulation.[6] In keeping with EPA's

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[4] Disclosure and inspection data from "Enforcement and Compliance Assistance Results: Numbers at a Glance Fiscal Year 2005," http://www.epa.gov/compliance/resources/reports/endofyear/eoy2005/2005numbers.html. Data on regulated facilities were taken from EPA's Envirofacts Database.

[5] These calculations are based on data from EPA's database of voluntary disclosures for fiscal years 2001–2005 obtained under the Freedom of Information Act.

[6] Other authors such as Kaplow and Shavell (1994) have termed this same activity "self-reporting." However, EPA uses the term self-reporting to denote a broader range of activities such as the requirement that facilities self-report emissions data to the Toxics Release Inventory.

use of the term, in this paper the act of self-policing does not require the remediation of environmental damages caused by the violation.[7] However, for facilities to fully benefit from EPA's Audit Policy, they must remediate any damages that result from the self-disclosed violation.

A number of theoretical papers have examined the concept of voluntary self-policing in a static setting. Kaplow and Shavell (1994) model a probabilistic enforcement regime in which facilities deliberately choose between compliance and noncompliance. The authors show that introducing self-policing will not affect deterrence as long as self-policers face a reduced fine equal to the certainty equivalent of the sanction they would face if they did not disclose but instead took their chances that the violation would be discovered. Additionally, self-policing will result in a welfare improvement because enforcement effort is reduced because self-policers need not be inspected. Moreover, if individuals are risk averse rather than risk neutral, Kaplow and Shavell show that self-policing can lead to welfare improvements through the reduction of risk.

Innes (1999a) extends this model by considering the potential benefits of remediation under a self-policing policy. Innes models the compliance decision as a continuous choice in the level of care that the facility expends, with the probability of environmental harm inversely related to the level of care. Facilities costlessly observe whether harm has occurred and can choose whether to remediate the harm immediately. Regulators engage in monitoring efforts and the probability that regulators detect environmental harm at a facility is increasing in monitoring effort. In this model, facilities will self-police and remediate as long as they pay a reduced fine equal to the expected penalty they would pay if they did not self-police. Under such a regime, the level of remediation will increase because self-policers remediate with certainty while nondisclosers only remediate when caught. Therefore self-policing can be welfare enhancing even if enforcement costs are not reduced. Moreover, the optimal penalty can be increased relative to a nonself-policing regime, resulting in a lower level of monitoring for a given level of deterrence, and thus lower enforcement costs. However, as shown in Innes (1999b), there may be a reduction of the initial level of care taken by regulated facilities because of the ability to self-police. Innes (2001) also shows that if violators can engage in avoidance activities, self-policing can increase efficiency by reducing such activities and, in turn, allowing the government to achieve the same level of deterrence with a reduced enforcement effort.[8]

Heyes (1996) incorporates self-policing into a model of environmental compliance; although, in this model, self-policing is not an independent choice because regulated facilities cannot remediate violations without disclosing such actions to regulators. As in Innes' models, facilities choose a level of preventative effort that inversely affects the probability that a facility will cause environmental harm. Facilities costlessly observe whether harm has occurred and can choose whether to remediate the harm immediately. Heyes assumes that remediation cannot be done covertly and thus remediation is, in effect, self-policing. If facilities do not self-police, the harm may be detected by the regulator with probability less than 1. Additionally, the cost of remediation increases if not done immediately. Heyes shows that decreasing the fine faced by self-policers relative to the fine for detected harm increases the level of self-policing. However,

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[7] In contrast, Innes (1999b) uses the term self-policing to denote a situation where facilities voluntarily clean up or remediate environmental damages prior to detection. In that paper, disclosure is not required as a part of self-policing.

[8] Because avoidance activities are reduced, the cost of increasing penalty levels is reduced and the government can substitute higher penalties for lower enforcement effort.

decreasing the fine faced by self-polluters can also decrease the initial level of care taken by regulated facilities.

Mishra, Newman, and Stinson (1997) construct a model of self-policing that is designed to capture specific aspects of EPA's Audit Policy. Because the focus of the model is on a facility's incentive to conduct a compliance audit and self-police, compliance is exogenous. More specifically, the model assumes that violations are probabilistic and do not depend on the facility's actions. Moreover, facilities can learn of their compliance status only through compliance audits, which are costly. Because remediation costs increase over time, facilities may audit to reduce expected costs given the likelihood of being caught later and forced to remediate at a higher cost. In this model, welfare improvements result only from increased remediation and decreased enforcement effort, not from increased deterrence.

Friesen (2006) also assumes that violations are probabilistic and do not depend on the facility's actions. Facilities learn of their compliance status through costly compliance audits and must decide first whether to audit and then whether to disclose any violations that are discovered. Regulators must decide whether to inspect a facility, but inspections are subject to error and violations are discovered with a probability less than 1. However, the probability of discovering a violation increases if the facility has conducted an environmental audit. Assuming that facilities must remediate any disclosed violations, Friesen shows that facilities will only audit if they intend to remediate the violation, although not all facilities will disclose their remediated violations. Friesen also shows that the regulator will not inspect a facility that has disclosed a violation. However, auditing will generally occur with probability less than 1 in equilibrium and thus self-policing does not preclude the need for regulator monitoring. Moreover, policies that encourage self-policing can lead to duplication of effort and thus be inefficient. Although Friesen's model does allow regulators to incorporate self-policing into their enforcement strategy, the model is not dynamic in the sense that regulated facilities and regulators repeatedly interact and optimal actions take future consequences of one's actions into account. To date, no model of self-policing incorporates such dynamic considerations.[9]

4. A Dynamic Model of Self-Policing in a Targeted Enforcement Regime

Harrington's (1988) model of targeted enforcement is the starting point for this dynamic model of self-policing.[10] Harrington's model was developed as a response to a widespread perception that facilities in the United States were "overcomplying" with environmental regulations given the low probability that a facility would be inspected and the relatively minor fines that a facility would receive if found to be in violation. Harrington demonstrates how a targeted enforcement regime can leverage enforcement resources and maintain a higher level of compliance than can be obtained through more traditional, nontargeted enforcement.

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[9] Livernois and McKenna (1999) present a dynamic model of self-reporting (as opposed to self-policing) in which firms choose whether to comply and whether to truthfully report their compliance status. Regulators use fines and inspection probabilities to both maximize initial compliance and induce truthful reporting (which ultimately leads to quicker remediation).

[10] While Harrington was not the first to introduce targeted or state-dependent enforcement (see, e.g., Landsberger and Meilijson 1982), he was the first to develop a model of targeted enforcement in an environmental context.

While Harrington's model has received some criticism in the theoretical literature, anecdotal and empirical evidence suggests that the targeted enforcement model is consistent with current EPA enforcement practices.[11] For example, the introduction to the Fiscal Year 2002 Enforcement and Compliance Assurance Report states that EPA's enforcement approach includes using "data analysis and other relevant information to marshal and leverage resources to target significant noncompliance" (EPA 2003, p. 3). Perhaps the most direct empirical test of the applicability of the targeted enforcement model to environmental regulation is that of Helland (1998), which examines enforcement of the Clean Water Act using data on the pulp and paper industry and finds that the results are generally consistent with targeted enforcement.

This model incorporates self-policing into Harrington's targeted enforcement model. As in the original model, regulated facilities are divided into two groups based on past compliance. Facilities with poor compliance records are placed in a target group and inspected with a higher probability than facilities in the nontarget group. Facilities found in violation of regulations are always moved into the target group while facilities found to be in compliance can transition to the nontarget group with some positive probability. Each period, facilities choose whether to comply. The regulator then inspects the facility with a probability based on the facility's group. Depending on the results of the inspection, facilities may be moved from one group to the other before the next period. Facilities that are not inspected stay in their group for the next period. As shown in Harrington (1988), this type of enforcement regime can lead to higher levels of compliance than would occur under a regime where all facilities face the same probability of inspection.[12]

Following the Harrington model, regulators classify all regulated facilities into one of two groups: G_1 is the "good" group and G_2 is the targeted or "bad" group. Inspection probabilities vary across the groups with the inspection probability for G_1 (π) less than the inspection probability for G_2 (ρ). However, unlike the Harrington model, there are two possible types of noncompliance, deliberate and inadvertent. Deliberate violations occur when a facility knowingly violates the regulations, for example, by sending hazardous waste to a nonhazardous waste landfill for disposal. An inadvertent violation occurs when a facility unknowingly violates the regulations (e.g., if one of its storage tanks is leaking) or violates without intending to (e.g., if hazardous materials are accidentally spilled on the ground).[13] The model includes two types of compliance because EPA's self-policing policy cannot be applied to all violations.[14] Given that Pfaff and Sanchirico (2004) speculate that some facilities may self-police to cover up other types of violations at a facility, including both types of violations in the model allows us to investigate the effect of self-policing on behavior that is not subject to self-policing. This compliance paradigm is similar to that of Livernois and McKenna (1999),

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[11] The criticism focuses on two main points: the "optimal" enforcement scheme does not minimize the costs of pollution control and the results may not hold under all information or cost structures. See, for example, Harford and Harrington (1991) and Raymond (1999).

[12] There have been a number of extensions to Harrington's basic model (for example, Harford and Harrington 1991 and Friesen 2003). However, none has incorporated self-policing.

[13] Although I refer to the two types of compliance as deliberate and inadvertent, the key distinction is that the deliberate violations are endogenous while inadvertent violations are exogenous. To simplify the model, I have made inadvertent violations completely endogenous, although in reality facilities have choices over types of equipment that can affect the probability that a violation will occur.

[14] As discussed in section 2, some violations are expressly omitted from the Audit Policy, such as repeated violations, violations of an order, consent agreement, or plea agreement, and violations that result in serious actual harm to human health and the environment.

Table 1. Notation Used in the Model

Symbol	Meaning
α	Expected present value of being in G_1 given the strategy under consideration
β	Expected present value of being in G_2 given the strategy under consideration
δ	Discount rate
π	Probability of inspection for facilities in G_1
ρ	Probability of inspection for facilities in G_2
a	Cost of auditing per period
c	Cost of abatement per period
F	Fine for an unremediated spill
g	Probability that facilities in G_2 that are found in compliance will transition to G_1
G_1	"Good" group: the group of facilities with relatively good compliance records
G_2	"Bad" or targeted group: the group of facilities with relatively bad compliance records
k	Cost of remediating a spill
p	Probability that a spill occurs
q	Probability that facilities in G_2 that disclose a spill will transition to G_1
R	Reduced fine for disclosed spill
Z	Fine for lack of abatement

although in that model there are two mechanisms by which a facility could violate the same regulation. In this model, the two types of violations are independent of each other.

For the deliberate violation I assume that regulations require a facility to abate pollution at a cost of c per period, with abatement costs differing across regulated facilities.[15] If a facility does not abate pollution and is inspected, this deliberate violation will be discovered and the facility will be fined Z.[16] Because lack of abatement can only be detected in the period in which it is committed, if the facility is not inspected, it cannot be fined for its current lack of abatement. Facilities are also subject to a probabilistic event (e.g., a spill) that occurs with probability p and will inadvertently render the facility noncompliant. To discover whether the event has occurred, facilities must conduct an audit at a cost of a.[17] Returning to compliance costs k, but once remediated the violation cannot be detected by regulators.[18] If the event occurs and a facility does not remediate but is inspected, it is assessed a fine F. For simplicity, let F include the cost of remediation (k) as well as a punitive fine. Alternatively, if the facility discovers the occurrence, remediates, and discloses it to regulators, the facility receives a fine R. Because R does not include the cost of remediation, $R + k$ must be less than F. To be consistent with EPA's Audit Policy, facilities must make the disclosure decision prior to an inspection occurring. Facilities cannot disclose deliberate violations to receive a reduced fine.

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[15] Because there are no interactions between facilities, facility subscripts are suppressed to simplify notation. Table 1 presents a list of the notation used in the model.

[16] This is a significant departure from Harrington's model where fines are dependent on a facility's group. In that model, maximum deterrence is achieved when the fine is set at 0 for facilities in G_1 and at the maximum possible level for facilities in G_2. However, Raymond (1999) shows that when facilities have heterogeneous costs (as is possible in this model), the optimal fine for G_1 depends on the distribution of costs. As discussed in section 4, given the complexity of this model, solving for the optimal fine level is beyond the scope of this paper. Because allowing fines to vary across the two groups will not qualitatively change the results of the analysis, I have chosen to simplify the model and keep the fines the same for each group.

[17] This assumption is consistent with Mishra, Newman, and Stinson (1997) and Freisen (2006).

[18] If a probabilistic violation could be detected after remediation, facilities would not audit unless they planned to disclose any discovered violations.

Table 2. Transition Matrix for Each Target Group

Regulator's Information for Period t	Starting in G_1		Starting in G_2	
	Stay in G_1	Move to G_2	Move to G_1	Stay in G_2
i. Compliance	1	0	g	$1 - g$
ii. Violation	0	1	0	1
iii. Disclosure	1	0	q	$1 - q$
iv. No information	1	0	0	1

Each period, regulators receive one of four possible signals about the facility's compliance status:

   i. Compliance: The facility is inspected and there are no detected violations.
   ii. Violation: The facility is inspected and a violation (deliberate and/or inadvertent) is detected.
   iii. Disclosure: The facility discloses an inadvertent violation and there is no deliberate violation (either because the facility abated or because there is no inspection).
   iv. No information: The facility does not disclose and there is no inspection.

Note that this information structure assumes that regulators do not distinguish between types of violations for targeting purposes. The transition matrix presented in Table 2 shows the probability that a facility in Group i moves to Group j for the next period given the regulator's signal.

   With no information, the facility's group does not change. Facilities in G_2 that are found in compliance will move to G_1 with probability g. Facilities found to be in violation will be in G_2 next period, regardless of their starting point. Finally, facilities that disclose but have not been found to be in violation through an inspection will stay in G_1 if they begin in G_1 and will move to G_1 with probability q if they begin in G_2.[19] Assuming that inspection probabilities and fines are constant, as long as future payoffs are discounted by δ where $0 \leq \delta < 1$, Harrington (1988) shows that the optimal facility policy is a stationary policy and is independent of the initial state of the system.

   With respect to deliberate violations, the facility has two possible choices, to abate or to pollute. With respect to the probabilistic violations, the facility must make three decisions: (i) whether to audit; (ii) whether to remediate a violation is one if discovered; and (iii) whether to disclose a violation.[20] If a facility decides not to audit, it has no more decisions to make. If it does audit, it can choose to remediate but conceal the violation, remediate and disclose the violation, or to not remediate and not disclose. This is consistent with EPA's Audit Policy, as remediation is required as a part of disclosure. However, auditing without remediation or disclosure is dominated by not auditing because the facility saves the cost of auditing with no change in the probability of detection. Thus, there are three viable actions with respect to probabilistic violations: no audit; audit–remediate–conceal; or audit–remediate–disclose.[21]

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[19] Allowing regulators to move facilities that disclose in G_1 to G_2 with some positive probability does not qualitatively change the results although it does slightly complicate the model. Therefore, I assume that this does not occur.

[20] For some violations, such as recordkeeping violations, it may not be possible to "remediate" without disclosure.

[21] Because facilities that disclose in G_2 increase the likelihood that they will transition back to G_1, a facility might want to fake a probabilistic violation, that is disclose when a violation has not occurred. To ensure that this does not occur, the regulator could set q and R so that fraudulent reporting is never optimal. Alternatively, the regulator could verify that disclosures are valid and impose further fines on any facility that fraudulently reports a violation. Rather than add additional complexity to the model, I assume that the penalty for fraudulent reporting is high enough to ensure that facilities do not fraudulently report.

Table 3. Expected Costs for Each Strategy

Strategy	Cost Starting in G_1	Cost Starting in G_2
(i) Abate/no audit	$c + p\pi F + p\pi\delta\beta + (1 - p\pi)\delta\alpha$	$c + p\rho F + p\delta\beta + (1 - p)(1 - \rho)\delta\beta +$ $(1 - p)\rho(1 - g)\,\delta\beta +$ $(1 - p)\rho g\delta\alpha$
(ii) Pollute/no audit	$\pi Z + p\pi F + \pi\delta\beta + (1 - \pi)\delta\alpha$	$\rho Z + p\rho F + \delta\beta$
(iii) Abate/conceal	$c + a + pk + \delta\alpha$	$c + a + pk + \rho g\delta\alpha + (1 - \rho g)\delta\beta$
(iv) Pollute/conceal	$a + pk + \pi Z + \pi\delta\beta + (1 - \pi)\delta\alpha$	$a + pk + \rho Z + \delta\beta$
(v) Abate/disclose	$c + a + p(k + R) + \delta\alpha$	$c + a + p(k + R) + p(1 - q)\,\delta\beta + (1 - p)(1 - \rho)\delta\beta + (1 - p)\rho(1 - g)\delta\beta + pq\delta\alpha + (1 - p)\rho g\delta\alpha$
(vi) Pollute/disclose	$a + p(k + R) + \pi Z + \pi\delta\beta + (1 - \pi)\delta\alpha$	$a + p(k + R) + \rho Z + \rho\delta\beta + (1 - p)(1 - \rho)\delta\beta + p(1 - \rho)(1 - q)\delta\beta + (1 - \rho)q\delta\alpha$

Combining these actions with the actions for deliberate violations yields six possible strategy combinations:

- i. Abate/no audit
- ii. Pollute/no audit
- iii. Abate/conceal
- iv. Pollute/conceal
- v. Abate/disclose
- vi. Pollute/disclose

Given these strategies, one can write down the expected cost of each strategy based on whether the facility is in G_1 or G_2. For example, a facility that undertakes a strategy of abating but not auditing (strategy 1) if it is in G_1 will have the following expected cost:

$$c + p[\pi(F + \delta\beta) + (1 - \pi)\delta\alpha] + (1 - p)\delta\alpha = c + p\pi F + p\pi\delta\beta + (1 - p\pi)\delta\alpha,$$

where α is the expected present value of being in G_1 given the strategy being considered and β is the expected present value of being in G_2 given the strategy being considered. Under this strategy, the facility pays c to abate. Additionally, because it does not audit, with probability $p\pi$ the facility is inspected and found to be in violation, fined F, and put into G_2 for the following period; with probability $p(1 - \pi)$ it is in violation but not inspected and thus stays in G_1; and with probability $(1 - p)$, there is no violation, so it also stays in G_1 regardless of whether it is inspected. Using the same logic, one can develop the expected cost of each strategy for each initial starting point as shown in Table 3. The facility then has 36 possible policies denoted by f_{ij}, where i describes the strategy taken in G_1 and j describes the strategy taken in G_2. To evaluate the expected cost of each policy, one solves the system of equations formed by taking the expected cost of strategy i using G_1 as a starting point and the expected cost of strategy j using G_2 as a starting point.[22]

Some of the expected cost functions are very straightforward. For example, a facility that chooses a policy of abatement and disclosure in both groups (f_{55}) is always in full compliance

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[22] The expected costs of the 36 facility policies are available from the author on request.

Table 4. Optimal Facility Policies as a Function of Audit and Abatement Costs

Audit Costs	Abatement Costs		
	Low: $\pi Z > c$	Moderate: $\rho Z > c > \pi Z$	High: $c > \rho Z$
Low: $\pi p F > a + pk$	f_{33}	f_{43}, f_{45}	$f_{43}, f_{44}, f_{45}, f_{46}$
Moderate: $\rho p F > a + pk > \pi p F$	f_{13}, f_{15}	$f_{13}, f_{15}, f_{23}, f_{25}$	$f_{13}, f_{14},^{a} f_{15}, f_{16},^{a} f_{23}, f_{24}, f_{25}, f_{26}$
High: $a + pk > \rho p F$	f_{11}, f_{13}, f_{15}	$f_{11}, f_{13}, f_{15}, f_{21}, f_{23}, f_{25}$	$f_{11}, f_{12},^{a} f_{13}, f_{15}, f_{16},^{a} f_{21}, f_{22}, f_{23}, f_{25}, f_{26}$

1 = abate/no audit, 2 = pollute/no audit, 3 = abate/conceal, 4 = pollute/conceal, 5 = abate/disclose, 6 = pollute/disclose.
[a] Will only occur under very restrictive conditions. Details are available from the author on request.

and has an expected present value cost of

$$\frac{c + a + p(k + R)}{1 - \delta}.$$

However, other policies have much more complicated expected costs because the regulated facility will move in and out of the two groups based on inspections and disclosures. For example, the expected cost of policy f_{23}, where a facility neither abates nor audits in G_1 but abates and discloses in G_2 is

$$\frac{(\pi Z + \pi p F)(1 - \delta + p \delta q + (1 - p)\delta \rho g) + (c + a + pk + pR)\delta \pi}{(1 - \delta)(1 - \delta + \delta \pi + p \delta q + (1 - p)\delta \rho g)}$$

if the facility begins in G_1 and

$$\frac{(\pi Z + \pi p F)(p \delta q + (1 - p)\delta rg) + (c + a + pk + pR)(1 - \delta + \delta \pi)}{(1 - \delta)(1 - \delta + \delta \pi + p \delta q + (1 - p)\delta \rho g)}$$

if the facility begins in G_2. Each of these expressions contains $(\pi Z + \pi p F)$, the expected cost of carrying out the policy in G_1, and $(c + a + pk + pR)$, the expected cost of carrying out the policy in G_2. Note that the fraction of the time the facility spends in each group depends on the group in which the facility starts, the probability of inspection in each group, and the transition probabilities.

Given the regulator's targeting plan and the facility's costs, the goal of the facility is to choose the policy that minimizes the present value of expected costs. One policy can be immediately ruled out as nonoptimal. Abatement and disclosure regardless of group (f_{55}) is strictly dominated by abatement and auditing–remediation–concealment in both groups (f_{33}) because the only advantage to disclosure in this model is that one may receive some benefit in terms of moving out of G_2 to G_1.[23] However, because the facility is always in compliance, it receives no benefit from being in the nontarget group.

Which facility policy will ultimately be most profitable depends on the relative costs of abatement and auditing as shown in Table 4. Because auditing without remediation is never optimal, in the following discussion the cost of remediation is subsumed in the cost of auditing. As long as audit costs are low, facilities will always audit. However, whether they will abate or

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[23] Given the assumption that after remediation a probabilistic violation cannot be detected, there are no other benefits to disclosure. If corrected violations can be detected and fined, disclosure would provide additional benefits.
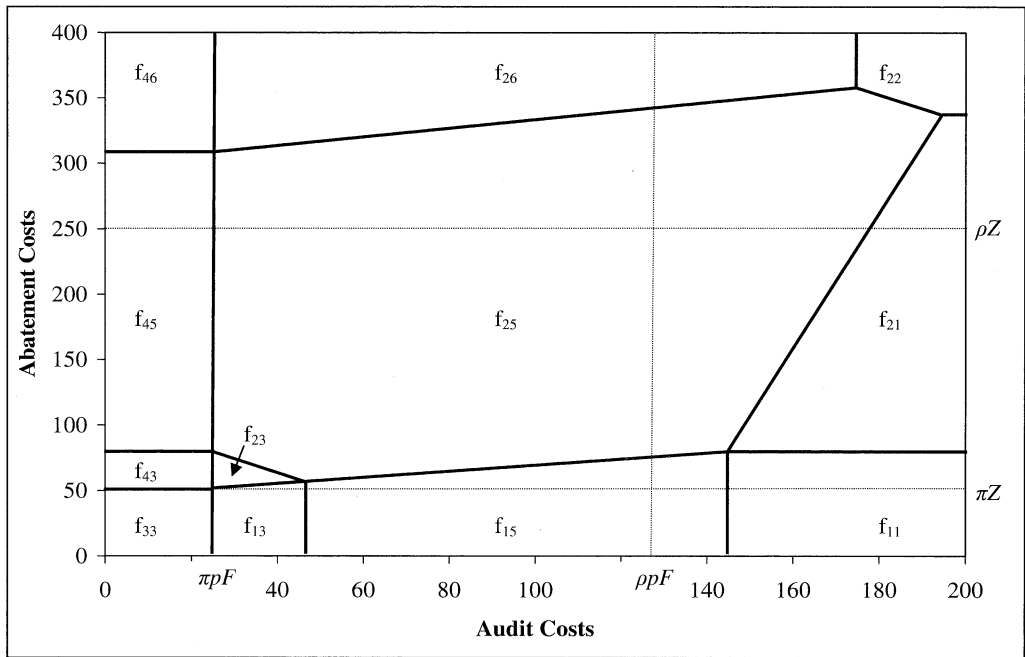
Figure 1. Optimal facility behavior under selected regulatory parameters. $Z = 1000$; $p = 0.05$; $F = 10,000$; $\delta = 0.9$; $\pi = 0.05$; $\rho = 0.25$; $g = 0.2$; $R = 100$; $q = 0.8$.

disclose depends on abatement costs and fines for disclosed violations. As long as abatement costs are low, facilities will always abate but whether they will audit and disclose depends on the relative costs of auditing and the fines for disclosed violations. When both audit and abatement costs are low, facilities will always audit and abate, but will not disclose because facilities do not care about the probability of inspection. When neither audit or abatement costs are low, the optimal strategy is more difficult to determine and depends not only on the relative costs of auditing and abatement, but also on the rates at which facilities are moved between the two groups and the fines imposed for disclosed violations.

Figure 1 shows the optimal facility behavior for a given set of regulatory parameters.[24] In this example, behaviors range from complete compliance (f_{33}) to complete noncompliance (f_{22}), with a wide range of policies in between. However, not all of the policies listed in Table 4 occur under this particular regulatory regime. Because self-policing is inexpensive (R is small) and provides significant benefits (q is large), the policies f_{24} and f_{44} that do not include disclosure in the target group are dominated by analogous policies that do, f_{26} and f_{46}. If R were larger and q smaller, f_{24} and f_{44} would replace f_{26} and f_{46}, although the boundaries between the other policies would change as well. There are three other policies listed in Table 4 that do not occur in Figure 1—f_{12}, f_{14}, and f_{16}. These policies all call for abatement in the nontarget group but deliberate violation in the nontarget group. These strategies are optimal only under very restrictive conditions on the parameters, and thus, while they are theoretically possible, they are unlikely to occur.[25]

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[24] The selection of parameter values was made to demonstrate the wide range of policies that could be optimal for a given regulatory regime.

[25] Details are available from the author on request.

Table 5. Possible Changes in Facility Behavior When Self-Policing Is Rewarded

Audit Costs	Abatement Costs		
	Low $\pi Z > c$	Moderate $\rho Z > c > \pi Z$	High $c > \rho Z$
Low: $\quad \pi p F > a + pk$	No change	Increased disclosures in G_2	Increased disclosures in G_2; increased or decreased abatement in G_2
Moderate: $\quad \rho p F > a + pk$ $\quad\quad > \pi p F$	Increased disclosures in G_2	Increased disclosures in G_2; decreased abatement in G_1	Increased disclosures in G_2; decreased abatement in G_1^{a}; increased or decreased abatement in G_2
High: $\quad a + pk > \rho p F$	Increased audits and disclosures in G_2	Increased audits and disclosures in G_2; decreased abatement in G_1	Increased audits and disclosures in G_2; decreased abatement in G_1^{a}; increased or decreased abatement in G_2

[a] Theoretically abatement can increase in G_1, but this will only occur under very restrictive conditions. Details are available from the author on request.

5. Implications of Self-Policing for Environmental Performance

As shown in Table 4, a targeted enforcement regime with self-policing can elicit a wide range of behavior. To evaluate the implications of self-policing for environmental performance, we thus need to consider how introducing self-policing changes facility behavior. To determine what facilities will do in the absence of self-policing, I set the penalty for disclosed violations equal to the penalty for detected violations ($k + R = F$) and keep all facilities that disclose in the target group in the target group for the next period ($q = 0$). We can then compare the optimal facility policy with and without self-policing to determine the effect that self-policing has on compliance behavior. Table 5 summarizes the changes in optimal facility behavior that can occur when self-policing is introduced.

When there is no self-policing, all policies that involve disclosure are dominated by analogous policies that involve concealment. Obviously the introduction of self-policing will increase the number of disclosures; although, some facilities will continue to not disclose either because of the relative cost of auditing and disclosing or because they have nothing to gain from disclosure. While regulators are likely to value the disclosures themselves as a valuable source of information, introducing self-policing will also increase the number of facilities that audit, which in turn will increase the number of facilities that promptly remediate probabilistic violations. As shown in Table 5, this increase in auditing will occur at some facilities with high audit costs; although, it will only occur when the facilities are in the target group because the self-policing policy modeled in this paper does not benefit facilities in the nontarget group.

Introducing self-policing can also change the incentives for a facility to deliberately violate regulations. Interestingly, depending on a facility's costs and the reward to self-policing, self-policing can serve as both a substitute for and a complement to abatement. To illustrate this point, consider Figure 2, which shows how the introduction of self-policing affects optimal facility behavior for the same set of regulatory parameters used in Figure 1. The solid lines show how the space is partitioned prior to the implementation of self-policing, and the dashed lines show how the space is partitioned after self-policing is introduced. For each region, the first policy listed is the optimal policy without self-policing, and the second is the optimal policy with self-policing.
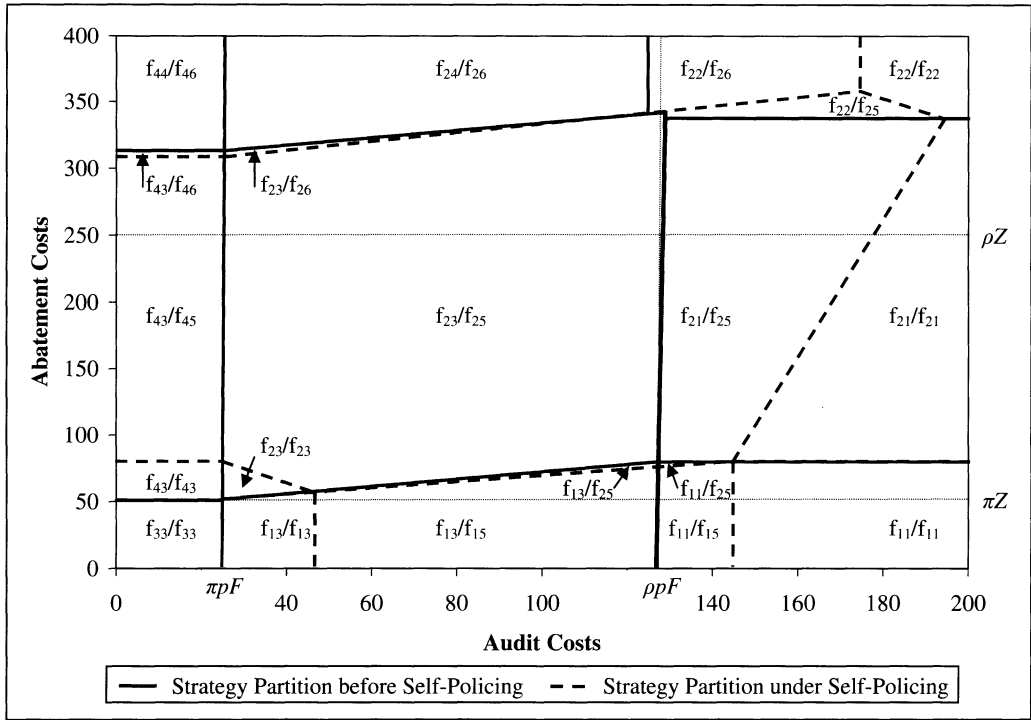
Figure 2. Effect of self-policing under selected regulatory parameters. In each region, the first policy listed is the optimal policy before self-policing and the second is the optimal policy under self-policing. Parameters before self-policing: $Z = 1000$; $p = 0.05$; $F = 10,000$; $\delta = 0.9$; $\pi = 0.05$; $\rho = 0.25$; $g = 0.2$; $R = 10,000$; $q = 0$. Parameters under self-policing: $Z = 1000$; $p = 0.05$; $F = 10,000$; $\delta = 0.9$; $\pi = 0.05$; $\rho = 0.25$; $g = 0.2$; $R = 100$; $q = 0.8$.

Recall that facilities in the target group can transition to the nontarget group either through a clean inspection report or through a voluntary disclosure. For some facilities, disclosing a violation may be a more cost-effective pathway back to the nontarget group than abatement, and thus they may substitute disclosure for abatement in the target group. In Figure 2, this type of substitution is shown by the two small regions near the top-left side of the figure. Some facilities with low audit costs and high abatement costs switch from f_{43} to f_{46} when self-policing is introduced, and some facilities with moderate audit costs and high abatement costs switch from f_{23} to f_{26}. While the exact size of the region in which this type of substitution can occur will depend on the parameters of the model, the range over which it occurs is always relatively small. However, it is important to remember we do not know the underlying distribution of facility audit and abatement costs. Therefore, even though the range of costs over which a particular policy is optimal may be limited, there could be a significant number of facilities in any given region of the figure.

Self-policing in the target group can also serve as a substitute for abatement in the nontarget group. In Figure 2 there are two regions where this occurs: The two areas on either side of the ρpF line near the bottom of the figure. In the area to the left of the ρpF line, facilities switch from f_{13} to f_{25} when self-policing is introduced, and in the area to the right, facilities switch from f_{11} to f_{25}. Without self-policing, these facilities abate in the nontarget group to avoid being moved to the target group. However, because in this example self-policing offers a relatively reliable pathway back to the nontarget group, when self-policing is introduced these facilities no longer find it necessary to abate when they are in the nontarget group. The range of

costs for which this type of substitution will occur is generally small; although, it does vary depending on the parameters of the model.

To demonstrate how self-policing can complement abatement, consider the triangular area near the upper-right side of Figure 2. Facilities in this area use f_{22} when self-policing is not possible but f_{25} when self-policing is possible. Thus, when self-policing is not rewarded, neither auditing nor abating in the target group is cost-effective. When self-policing is rewarded, these facilities find it optimal to do both. The intuition behind this result is that for a disclosure to benefit a facility, the facility cannot be found to be in deliberate violation during an inspection. Thus, for some facilities, the combination of disclosing and abating maximizes their net benefit.[26] Once again, the range over which disclosure and abatement are complements is generally small, although it varies based on the parameters of the model.

In summary, the introduction of self-policing can change facility behavior in a number of different ways. On the positive side, it can increase the level of auditing, disclosures, and abatement. On the negative side, it may result in a decrease in abatement. The extent to which each of these effects will occur will depend on the design of the self-policing policy (i.e., the setting of R and q), other enforcement parameters (g, π, ρ, F, and Z), and most importantly, the underlying distribution of audit and abatement costs. Moreover, whether a self-policing policy will provide increased environmental protection will depend not only on those factors, but also the benefit to the environment from increased auditing, disclosure, and abatement.

Because data on the joint distribution of abatement and audit costs, as well as the relative benefit from auditing (i.e., remediation of probabilistic violations), disclosure, and abatement are not readily available, it is not possible to theoretically estimate the overall effect of EPA's current audit policy on environmental performance. However, we can examine the potential effect that various enforcement policy changes would have on the level of auditing, disclosure, and abatement. Table 6 summarizes these effects.[27] First consider those parameters specific to the audit policy: R and q. Decreasing R, the fine associated with a disclosed violation, will obviously lead to more disclosures in the target group.[28] Additionally, decreasing R can lead to more audits (and thus higher levels of remediation) at facilities in the target group. However, a decrease in R also can lead to a decrease in abatement in the nontarget group because a lower R provides a cheaper pathway back into G_1 for facilities that are moved to G_2 because of noncompliance or lower levels of abatement in G_2 as disclosure becomes a more cost-effective substitute for abatement in the target group. Finally, it is possible that a decrease in R could lead to an increase in abatement in G_2 because auditing and abatement can be complements. Increasing q, the probability that a facility that discloses in G_2 will be moved to G_1, has the same qualitative effect as a decrease in R: It will increase audits and disclosures in G_2, decrease abatement in the nontarget group, and either increase or decrease abatement in G_2.

Next consider those parameters that are not specific to self-policing. As in a targeted enforcement model without self-policing, increasing g (the probability that a facility in G_2 with a clean inspection report will be moved into G_1) increases abatement at facilities in G_2 but can lead to less abatement in G_1 because it provides an easier path back to G_1 for facilities that are moved to G_2 because of noncompliance. Moreover, increasing g when self-policing is possible can lead to

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[26] Although theoretically the introduction of self-policing could result in an increase in abatement from the nontarget group when abatement costs are high, this can only occur under very restrictive and arguably unreasonable parameter conditions.

[27] Formal proof is available from the author on request.

[28] Facilities in the nontarget group will never disclose as long as R is greater than 0.

Table 6. Effect of Policy Parameters on Audits, Disclosures, and Abatement

Parameter Change	Possible Effect of Parameter Change on		
	Audits	Disclosures	Abatement
Decrease R, fine for disclosed violations	G_1: no change G_2: increase	G_1: no change G_2: increase	G_1: decrease G_2: increase/decrease
Increase q, probability facility disclosing in G_2 moves to G_1	G_1: no change G_2: increase	G_1: no change G_2: increase	G_1: decrease G_2: increase/decrease
Increase g, probability facility with clean inspection in G_2 moves to G_1	G_1: no change G_2: increase/decrease	G_1: no change G_2: increase/decrease	G_1: decrease G_2: increase
Increase π, probability of inspection in G_1	G_1: increase G_2: decrease	G_1: no change G_2: decrease	G_1: increase/decrease G_2: decrease[a]
Increase ρ, probability of inspection in G_2	G_1: no change G_2: increase/decrease	G_1: no change G_2: increase/decrease	G_1: increase/decrease G_2: increase[a]
Increase F, fine for detected probabilistic violations	G_1: increase G_2: increase	G_1: no change G_2: increase/decrease	G_1: increase/decrease G_2: increase/decrease
Increase Z, fine for lack of abatement	G_1: no change G_2: increase/decrease	G_1: no change G_2: increase/decrease	G_1: increase G_2: increase

[a] Under very restrictive conditions, the opposite effect could occur. Details are available from the author on request.

fewer disclosures and audits in G_2 if it is cheaper to return to G_1 via a clean inspection rather than through a disclosure. However, because abatement and audits can be complements, increasing g could lead to increased audits and disclosures in G_2 under the right parameter conditions.

Increasing the inspection rate in the nontarget group, π, decreases the relative costs of both audits and abatement in the nontarget group and thus can lead to an increase in audits and/or abatement in G_1. However, because audits and abatement can be substitutes for each other, as auditing in G_1 becomes cheaper, abatement in G_1 could decrease. Moreover, some facilities may substitute audits in G_1 for abatement or disclosures in G_2. Similarly, as abatement in G_1 becomes cheaper, facilities may substitute abatement in G_1 for audits and disclosures in G_2. Finally, as the benefit of being in the nontarget group decreases (i.e., as π approaches ρ), facilities in the target group will be less willing to invest in abatement or disclosures in the hopes of being moved back to the nontarget group. Thus, even if auditing and abatement do not change in G_1, we could see a further decrease in audits, disclosures, and abatement in G_2 because increasing π without increasing ρ decreases the leverage of a targeted enforcement regime.[29] Increasing ρ, the inspection rate in the target group, decreases the relative costs of both audits and abatement in the target group and thus can lead to an increase in audits, disclosures, or abatement in G_2. Additionally, increasing ρ increases the leverage of the target enforcement regime because it increases the costs of being in the target group relative to the nontarget group. Therefore, we may also see an increase in abatement in the nontarget group. However, as abatement in G_2 becomes cheaper, facilities may substitute abatement in G_2 for audits and disclosures in G_2 or for abatement in G_1.[30]

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[29] It is possible that facilities might choose to switch from disclosing in the target group to abating in the target group as π increases. However, this could only occur for a very small set of parameters and abatement costs.

[30] Although it is also possible that as auditing in G_2 becomes cheaper, abatement in G_2 could decrease; the conditions for this to occur are quite restrictive.

Increasing F, the fine for detected (as opposed to disclosed) probabilistic violations, decreases the relative cost of audits and thus can lead to an increase in audits in both groups and an increase in disclosures in the target group. Additionally, because increasing F increases the cost of the target group for facilities that do not audit in that group, some facilities begin to abate in the nontarget group. On the other hand, for facilities that do not audit in the nontarget group, increasing F increases the cost of the nontarget group, which will decrease the incentives for firms to disclose or abate in the target group. Moreover, if audits and abatement are substitutes, an increase in F can lead to a decrease in abatement in both groups. On the other hand, for some facilities in the target group, audits and abatement may be complements, so increasing F could lead to an increase in abatement in the target group.

Increasing Z, the fine for lack of abatement, decreases the relative cost of abatement and thus can lead to an increase in abatement in both groups. Additionally, because increasing Z increases the cost of the target group for facilities that do not abate in that group, some facilities will begin to audit and possibly disclose in the target group. However, if audits and abatement are substitutes, increasing Z can lead to a decrease in audits and disclosures in the target group. On the other hand, for some facilities in the target group, audits and abatement can be complements so increasing Z could lead to an increase in audits and disclosures in the target group.

As shown in Table 6, none of the possible parameter changes will have a purely positive effect on environmental performance. Thus, in designing a self-policing policy, the regulator must recognize the trade-offs between increasing auditing, disclosures, and abatement. In particular, many of the policy changes that increase auditing and disclosures will decrease abatement and vice versa. If the goal of the regulator is to increase the remediation of probabilistic violations by increasing the number of facilities that audit, increasing F, the fine for probabilistic violations, can increase audits in both the target and nontarget groups. Although this will not necessarily result in an increase in disclosures, it would increase the remediation of probabilistic violations and thus could result in a significant increase in environmental protection if such violations are likely to cause serious harm to the environment. Additionally, such a change would not necessarily cause a decrease in abatement because auditing and abatement can be complements to each other. Of course, there are limits to a regulator's ability to raise penalties that are not represented in this model but are well-discussed within the literature.[31]

Alternatively, decreasing the fine for disclosed violations R and increasing the probability that a facility that discloses in the target group q will increase both audits and disclosures at facilities in the target group but will not affect auditing in the nontarget group. However, such actions are likely to result in decreased abatement because facilities can use disclosures to decrease the probability of future enforcement actions.[32] This effect is consistent with Pfaff and Sanchirico's (2004) proposition that facilities might use the disclosure of minor violations as "red herrings" to discourage inspections or distract regulators from other problems.

Table 6 also highlights the fact that increases in auditing will not necessarily be accompanied by increases in disclosures. For example, increasing F could result in more audits but fewer disclosures. Thus, any analysis of the effectiveness of a self-policing policy should not

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[31] In fact, Harrington's (1988) original model was developed in part to examine how to leverage enforcement resources when penalties are restricted.

[32] Additionally, such changes could increase the incentive for a facility to fraudulently disclose a violation.

use disclosures as a sole measure of the policy's effectiveness. While the introduction of a self-policing policy will result in an initial increase in disclosures, changes in an enforcement regime over time could result in fewer disclosures but a higher level of environmental protection. Finally, note that changes to policy parameters that are external to the self-policing policy will have an ambiguous effect on auditing and disclosure. Thus, any proposed changes to the overall enforcement regime should be examined carefully for their possible impact on auditing and disclosure.

6. Conclusions

This paper presents a theoretical model of self-policing in a targeted enforcement regime. The model was designed to closely follow the design of EPA's audit policy, particularly the idea that self-policing may affect future enforcement. As expected, rewarding facilities that disclose with lower penalties and more lenient future enforcement increases the incentives to both audit and disclose. Because increased audits lead to increased remediation, self-policing can increase environmental protection. Additionally, disclosures themselves may be valuable to regulators as a source of information or if remediation requires disclosure (as would be the case with reporting violations). These results are consistent with many other theoretical models of self-policing. However, adding a dynamic aspect to self-policing and including both deliberate and inadvertent violations reveals new ways in which self-policing can affect facility behavior. On the positive side, self-policing can be complementary to other types of compliance and could increase environmental performance in areas that are not subject to self-policing. On the negative side, self-policing can be a substitute for other types of compliance and could therefore be detrimental to environmental protection. The model also demonstrates that changes to enforcement policies can have spillover effects, and thus proposed changes to enforcement policies should consider the effect on facilities' incentives to audit and self-police.

Finally, in this model, designing the optimal enforcement regimes and self-policing policy requires information about the joint distribution of different types of compliance costs. This suggests that more focused self-policing policies—either for specific industries or specific media—might be better able to increase environmental protection than a policy that applies equally to all facilities and all media. In the United States, many media programs do have self-policing policies in addition to the Audit Policy. However, because environmental audits are generally conducted for all environmental processes at a facility, too much differentiation across media programs could affect a facility's overall incentives to audit.

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