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Monitoring, Enforcement, & Environmental Compliance: Understanding Specific & General Deterrence

State-of-Science White Paper

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This report reviews research on the current state of science in environmental deterrence measurement and develops findings and recommendations based upon technical feasibility, *without assessing implementation costs*. No work has been done to determine the costs or practicality of implementing the deterrence measures discussed in this report. In other words, this report does not determine the costs to the EPA of conducting any specific information gathering, deterrence measurement, or statistical analysis nor does this report assess the feasibility of doing so given the OECA's workload, workforce, and budget.

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Executive Summary

Regulatory punishment for pollution violations is a mainstay of nearly every industrialized nation's environmental policy, and a rich theoretical literature examines enforcement in general and environmental enforcement in particular. A smaller empirical literature studies the determinants of environmental compliance and behavior. Understanding real-world factors, however, is essential to the design and implementation of effective and efficient environmental regulation. This report reviews the policy-relevant environmental compliance literature, with emphasis on the growing empirical literature measuring the specific and general deterrence effects of environmental monitoring and enforcement.

Major findings strongly supported by the related literature include: (1) Regulation, monitoring, and enforcement have historically been, and remain, critical determinants of environmental behavior. (2) Environmental monitoring and enforcement activities generate substantial specific deterrence. (3) Environmental monitoring and enforcement activities generate substantial general deterrence. (4) Environmental monitoring and enforcement activities may generate significant emissions reductions, even for sector/contaminant combinations where compliance is typically high. (5) Enforcement and monitoring responses are heterogeneous across sources. (6) Quantitative databases and statistical methods exist for deterrence measurement. (7) Qualitative survey methods exist for deterrence measurement.

Major findings suggested, but not conclusively demonstrated, by the literature include: (1) The regulator reputation effect underlying general deterrence tends to decay. (2) There are limits to the "reach" of the reputation effect underlying general deterrence. (3) Deterrence varies across enforcement and monitoring instruments; inspections, intermediate enforcement actions, administrative fines, and criminal actions have different compliance impacts. (4) Sanctions should generally increase for repeat offenders, but important caveats to this rule exist.

Key recommendations, based on the author's subjective professional assessment of the related literature and the state of knowledge, include: (1) OECA should consider closely replicating statistical database analyses for measuring the specific and general deterrence effects of monitoring and enforcement. (2) OECA should consider closely replicating qualitative survey analyses for measuring the specific and general deterrence effects of monitoring and enforcement. (3) OECA should consider expanding existing qualitative survey analyses for measuring the specific and general deterrence effects of monitoring and enforcement. (4) For both quantitative and qualitative methods, studies based upon a universal metric are not advised. (5) Specific compliance rates and deterrence metrics should be statistically valid.

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1. Purpose & Scope

Regulatory punishment for pollution violations is a mainstay of nearly every industrialized nation's environmental policy, and a rich theoretical literature examines enforcement in general and environmental enforcement in particular. A smaller empirical literature studies the determinants of environmental compliance and behavior. Understanding real-world factors, however, is essential to the design and implementation of effective and efficient environmental regulation. This report reviews the policy-relevant environmental compliance literature, with emphasis on the growing empirical literature measuring the specific and general deterrence effects of environmental monitoring and enforcement.

The review highlights peer-reviewed research in domestic environmental settings. It focuses on peer-reviewed, published studies to ensure both quality and replicability. While many of the papers discussed were supported by the EPA's Office of Research and Development (ORD) Science to Achieve Results (STAR) program, this white paper typically considers the ensuing journal articles rather than the underlying STAR Grant final reports. Particularly important conference or policy papers that have received substantial professional or institutional vetting are also investigated. The report emphasizes the domestic environmental context to reference results most directly applicable to the Agency's mission. However, significant papers from other policy settings, like occupational safety, nuclear regulation, and tax compliance, are investigated when their methods or conclusions yield substantial insights for environmental deterrence. Similarly, the report discusses especially important results from other countries' environmental contexts.

This review stresses recent empirical research relevant to the measurement of general and specific deterrent impacts of compliance monitoring and enforcement. Seminal articles that strongly influenced the current state of science are referenced and explored, but less fundamental articles with publication dates prior to 1999 are generally not considered. This restriction avoids redundancies, generates a manageable final product, and emphasizes studies most relevant to today's policy context. The particularly interested reader should consult Cohen's [1999] excellent literature review or the EPA Compliance Information Project's [1999] Literature Summaries. Theoretical studies are typically referenced only to establish an appropriate conceptual framework, since effective and efficient policy implementation requires additional research that validates and assigns empirical magnitudes to important theoretical predictions. However, where vital insights can be gained from theory and experiential data are unavailable, more abstract details are provided.

This report reviews research on the current state of science in environmental deterrence measurement and develops findings and recommendations based upon technical feasibility, *without assessing implementation costs*. No work has been done to determine the costs or practicality of implementing the deterrence measures discussed in

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this report.[1] In other words, this report does not determine the costs to the EPA of conducting any specific information gathering, deterrence measurement, or statistical analysis nor does this report assess the feasibility of doing so given the EPA and OECA's workload, workforce, and budget.

This white paper proceeds as follows. Section 2 briefly reviews the literature on factors that influence environmental compliance. The discussion corresponds to Statement of Work sub-question 1C, "What confounding variables (variables other than monitoring and enforcement) impact environmental performance and responsiveness to regulatory actions?" The intent of this section is to place the literature examining the deterrence effects of monitoring and enforcement in context.

Sections 3 and 4 explore the deterrence impacts of compliance monitoring and enforcement in detail. Section 3 highlights the deterrence effects of regulator actions on the sanctioned or monitored firm, otherwise known as specific deterrence. Section 4 investigates the mechanisms and magnitudes of general deterrence, where regulatory actions directed towards one facility affect the behavior of other facilities. Sections 3 and 4 correspond to the Statement of Work's core question "How can OECA measure the general and specific deterrent impacts of compliance monitoring and enforcement?", sub-question 2 "What approaches to deterrence measurement are suggested by the relevant literature?", and sub-question 1 "What does the literature identify as the key factors motivating response to monitoring and enforcement actions?" Sections 3 and 4 dissect key studies to examine how the authors measured deterrence and consequently provide specific examples for OECA to follow.

Section 5 synthesizes research methodologies and presents frameworks for deterrence assessment. Additionally, Section 5 references a technical appendix that provides specific quantitative tools for database analyses of deterrence. This discussion corresponds to Statement of Work sub-question 2, and addresses "What approaches to deterrence measurement are suggested by the relevant literature?" and "What information currently collected by the EPA could OECA use to measure deterrence?"

Section 6 discusses major findings and recommendations. The section first presents conclusions that can be definitively supported by the literature, then reviews important findings suggested (but not definitely confirmed) by the literature, and finally offers ideas for further exploration. Subsequent recommendations follow Statement of Work sub-question 3 and suggest considerations for OECA actions and priorities.

2. Factors Influencing Environmental Performance

Numerous factors influence environmental compliance, and they can be loosely grouped into two categories. The first set of determinants is postulated by a standard economic model of the facility as a rational profit-maximizing decision-maker. Here,

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[1] Discussions with personnel at the Office of Enforcement and Compliance Assurance (OECA) suggest that estimating the costs and benefits of practical implementation from academic studies presents significant difficulties.

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compliance factors include traditional regulatory monitoring and enforcement, pollution abatement costs, the ability to influence future regulatory action, community characteristics and components of consumer demand, and investor pressure. The second set of determinants goes beyond traditional law and economic models, and includes management knowledge, managerial attitudes, and organizational structure.

The goal of this section is to *briefly* review the literature on non-regulatory compliance factors to put later discussions of the deterrence effects of monitoring and enforcement in context. There are two key messages. First, many factors influence environmental performance. Second, despite the diverse determinants of environmental behavior, the literature indicates that *regulation, monitoring, and enforcement have historically been, and remain, critical determinants of environmental outcomes.*

2.1 Factors Predicted by the Standard Economic Model

In the standard economic model, the facility chooses its environmental performance by balancing the expected costs of polluting with the expected benefits of doing so. This is consistent with the traditional law and economic framework that originated with Becker [1968] and Stigler [1970], and progressed as summarized in Polinsky and Shavell [2000]. Russell, Harrington, and Vaughn [1986] comprehensively applied this analytical framework to environmental behavior.

Perhaps the most natural explanation for environmental performance is marginal variable costs of abatement, as determined by technology, industrial characteristics, and other factors. If marginal abatement costs are small, facilities may maintain low emissions even in the absence of significant regulations. Unfortunately, published peer-reviewed studies examining abatement costs are limited. Relatively recent studies include McClelland and Horowitz [1999] for pulp and paper water pollution and Swinton [1998] and Rezek and Campbell [2006] for electricity air emissions. Results generally suggest significant marginal abatement costs, indicating that firms are unlikely to pollute at low levels in the absence of regulations or other pressures. Further, a key finding is that variable costs of contaminant reductions are extremely heterogeneous across both sources and industrial processes. Uniform regulatory policies and actions are therefore unlikely to achieve socially efficient outcomes.

Another important determinant of environmental behavior is firms' ability to influence future regulatory action. In a seminal paper, Maxwell, Lyon, and Hackett [2000] proposed a game theoretic framework where firms preempt future regulations by voluntarily reducing pollution emissions. The intuition is straightforward. Firms that expect consumers to lobby for stringent environmental regulation might voluntarily incur the necessary costs to reduce current emissions if this reduction prevents consumers from lobbying in the first place. In other words, facilities accept increased current abatement costs to prevent even larger regulatory costs in the future.

The published empirical evidence supporting the influence of preemptive behavior on environmental outcomes is suggestive, but not yet definitive. Maxwell,

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Lyon, and Hackett [2000] tested their theory by regressing state's releases of 17 TRI-reported toxic chemicals (per dollar value of shipments) on state-level demographics, political variables, and other controls. They concluded that the negative relationship between increases in a state's conservation group membership and that state's reported toxic releases was evidence for their regulatory threat theory. However, their sample size was small, it was difficult to disentangle the effects of regulatory threats from TRI reporting itself, and other mechanisms like consumer demand might well explain their empirical regularity.

Community characteristics may influence environmental behavior in several ways. For example, community pressure may influence the threat of future regulation as discussed above. Locational characteristics may also correlate with political action or bargaining power more broadly, and facilities in wealthier, better educated, and more socially-active neighborhoods may face greater incentives for pollution abatement. Site-specific factors may also relate to consumer purchasing power and preferences, and therefore community composition may influence environmental performance (Arora and Gangopadhyay [1995], Kirchoff [2000], and Cavaliere [2000]). Finally, it is possible that pure discrimination influences emissions, although the empirical evidence for this "environmental injustice" hypothesis is debatable (Hamilton [1995], Wolverton [2002], Becker [2004]). Of course, community characteristics may also influence the level of monitoring and enforcement directed at a specific facility. This indirect effect is subsumed in the specific and general regulatory deterrence discussed in Sections 3 and 4.

An empirical literature does indeed detect a significant influence of community characteristics on environmental behavior. Arora and Cason [1999] found that zip-code level TRI-reported toxic releases were correlated with numerous economic and demographic characteristics. Results varied significantly across regions, however. Earnhart [2004b] determined that a community's income, population density, unemployment rate, and average political affiliation influenced facility-level environmental performance at Kansas wastewater treatment plants. Becker [2004] found that some ideological and socio-economic factors influenced air pollution abatement expenditures at manufacturing plants. In contrast, however, several notable characteristics like voter turnout, education, and race/ethnicity did not yield consistent environmental implications. Most recently, Stafford [2007] analyzed the impacts of consumer preferences (as proxied by market size and the number of competitors) on hazardous waste violations reported by federally regulated facilities in the EPA's Biennual Reporting System. The author hypothesized that more competitive local markets would be associated with fewer violations because consumers favoring environmental performance have more consumption options. Indeed, results indicated that increased local market competition induced increased compliance with waste management statutes.

Locational composition results are not restricted to domestic institutions, and may matter more in settings with limited formal regulation. For example, Pargal and Wheeler [1996] found statistically and economically strong relationships between the BOD pollution intensity of Indonesian industrial sources and income, education, and population density. During the sample period, formal regulations in Indonesia were

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largely absent. In contrast, Dasgupta et al. [2000] established that the degree of direct influence by neighbors and community activism on Mexican firm's environmental practices was insignificant. Results suggested that local pressures operated primarily through regulation in the more formal Mexican legal setting. None-the-less, despite the mature regulatory regimes in the US, Canada, Australia, and New Zealand, Kagan et al. [2003] discovered that managers from pulp and paper mills located in these countries all reported significant effects of social pressures on water pollution and spill control.

Ownership structure and investor pressure may also affect environmental performance in the traditional economic model. For example, subsidiaries may be less inclined towards emissions reductions since liability rules protect their parent companies. Indeed, Grant and Jones [2001] studied TRI toxic releases by 2000 chemical facilities and found that subsidiaries had higher release rates than their non-subsidiary counterparts. In contrast, Grant and Jones [2004] found that foreign ownership had no detectable impact on chemical plant releases, presumably because other factors trumped any potential disregard for local communities by overseas parent companies.

In addition to ownership type, ownership concentration and influence may affect pollution outcomes. Suppose, for example, that fewer owners are more risk averse because risks are spread out over fewer individuals. Or, suppose fewer owners are better able to control costs due to more direct contact with facilities. In a study of Czech manufacturing firms, Earnhart and Lizal [2006] discovered that more concentrated ownership, including that of a single public owner, resulted in reduced air pollution emissions. Of course, regardless of their concentration, investor owners may express environmental preferences or concerns over future environmental regulation by decreasing demand for shares. Konar and Cohen [1997] and Konar and Cohen [2001] studied the relationship between stock prices and TRI-reported toxic emissions and environmental lawsuits. The authors determined that poor environmental performance resulted in lower asset values and negative stock price changes produced lower future toxic releases.

2.2. Factors Not Predicted by the Standard Economic Model

Management knowledge, managerial attitudes, and organizational structure also determine compliance and performance. These corporate culture considerations do not fit neatly into the standard law and economic model of environmental behavior and compliance. Managers' understanding of complex legal requirements partially determines compliance. Dasgupta el al. [2000] conducted a survey of Mexican industrial facilities and found that environmental management strategies and training significantly improved compliance with pollution control laws, largely because managers were learning about the evolving regulatory structure. Winter and May's [2001] survey of Danish livestock operators determined that farmers with high levels of awareness of rules exhibited compliance levels 28 percent higher that farmers with low levels of awareness. While it may be that farmers most concerned with compliance expend the most effort to learn about regulations, Stafford's [2006] later study supports Winter and May's original

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interpretation. Facilities with more complex regulations (exogenously determined) are more likely to violate RCRA hazardous waste requirements, all else equal.

Manager attitudes also affect environmental behavior. Kagan et al. [2003] uncovered both qualitative and quantitative evidence that managerial outlooks significantly affected water pollution emissions of 13 pulp and paper mills in the US, Canada, Australia, and New Zealand. In particular, the authors found that firms with proactive environmental management styles invested in more advanced abatement equipment and more day-to-day environmental oversight. May [2005] surveyed 421 marinas and boatyards in the western US and determined that facility operators' attitudes towards government strongly influenced their deterrence perceptions. 'Conservative' boatyard operators were 13 percent more likely to have significant concerns about regulatory action and 16 percent less likely to feel obligated by a sense of duty to comply.

Recently, several authors have peered inside the "black box" of organizational structure to understand its role in environmental performance. Delmas and Toffel [2005] used survey and archival data to study institutional pressure and internal power distribution at US industrial sources. They found that facilities with strong market pressures and marketing departments adopted different environmental practices than facilities with influential non-market pressures and legal departments. For example, facilities that were more receptive to market constituents like customers, suppliers, the media, and community groups were more likely to adopt international environmental management systems. In contrast, facilities that were more receptive to non-market constituents like legislators and regulators were more likely to adopt government-sponsored voluntary pollution control programs. Howard-Greenville [2006] conducted a detailed ethnographic study of a large computer chip manufacturer, and results indicated that different sub-cultures framed environmental priorities, definitions, and solutions very differently. Therefore, firms with heterogeneous internal power dynamics are expected to have heterogeneous environmental outcomes, even in the presence of similar external pressures.

2.3 The Importance of Regulation

Despite the many factors influencing environmental performance reviewed in sub-sections 2.1 and 2.2, the literature strongly suggests one result central to this report. Regulation, monitoring, and enforcement have historically been, and remain, critical determinants of environmental behavior.

Table 1 summarizes key empirical studies that compare regulatory factors to other compliance determinants. Every reviewed study indicated that regulation/legislation is a more important determinant of environmental behavior than any other single factor. While Khanna and Anton's [2002] survey of S&P 500 firms indicated that second-order environmental practices like total quality management were largely attributable to market factors, first-order practices like environmental staffing, audits, and internal policies were attributable to legal and regulatory factors. Kagan et al. [2003] argued that regulation is principally responsible for large environmental gains for pulp and paper facilities in the

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US, Canada, Australia, and New Zealand. In a survey of Canadian pulp and paper facilities, Doonan et al. [2005] discovered that a full 70 percent of managers rated the government as the single most important source of environmental pressure. Similarly, Delmas and Toffel's [2005] survey of 493 US industrial sources indicated that the influence of regulators and legislators on environmental performance was considerably stronger than community organizations, activist groups, and the media. Finally, May [2005] showed that traditional regulation had a considerably stronger influence on marine industry managers' deterrence viewpoints than non-mandatory regulation.

3. Monitoring and Enforcement: Specific Deterrence

Given the critical importance of regulation, monitoring, and enforcement for environmental performance and compliance, it is important to assess empirical deterrence magnitudes. This section reviews the recent literature on the specific deterrence effects of monitoring and enforcement. In this context, specific deterrence refers to the effects of regulatory actions on the evaluated or sanctioned firm itself. General deterrence effects, in which regulatory actions aimed at one facility impact the environmental performance at other facilities, are considered in the next section.[2]

The key goal of this section is to dissect important studies. The examination of each paper's approach to measuring specific deterrence should provide concrete examples for possible replication. Collectively, the results of the specific deterrence literature indicate that both qualitative and quantitative methods exist to measure specific deterrence. Further, joint results show that significant reductions in non-compliance and emissions are obtainable with traditional monitoring and enforcement. *Inspections and enforcement actions consistently produce improved future environmental performance at the evaluated or sanctioned facility*. Results hold both historically and currently.

3.1 The Specific Deterrence Literature

Table 2 summarizes key empirical studies that measure the specific deterrence effects of domestic environmental monitoring and enforcement. The seminal paper empirically assessing specific deterrence is Magat and Viscusi [1990]. Magat and Viscusi [1990] explored the relationship between EPA inspections and self-reported biochemical oxygen demand (BOD) discharges at 77 major US pulp and paper mills for the period 1982-1985. The authors found that lagged inspections had statistically significant negative impacts on both BOD compliance status and continuous BOD discharges. The results were also economically significant. Lagged inspections induced as much as a 20 percent reduction in mean BOD discharges in the quarter following an inspection.

[2] Although rare, some authors (see, for example, Earnhart [2004a], Earnhart [2004b], and Glicksman and Earnhart [2007]) use the phrase 'general deterrence' to describe facility-specific deterrence associated with the predicted threat of an inspection or enforcement action. For the purposes of this report, all facility-specific responses to monitoring and enforcement are considered specific deterrence. Only impacts on facilities other than the sanctioned facility are considered general deterrence here.

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Other notable early papers included Deily and Gray [1991], Gray and Deily [1996], and Nadeau [1997]. Deily and Gray [1991] studied 49 steel plants between 1976 and 1986, a period of rapid decline in the steel industry. They studied the response of plant-closing probabilities to all EPA/state enforcement actions in the industry. The authors found that a 12 percent increase in the predicted probability of EPA and state enforcement activity over the entire sample period increased the likelihood that a plant would close by 1 percentage point. In a related study, Gray and Deily [1996] analyzed the impact of non-monetary enforcement actions on the self-reported annual particulate, sulfur dioxide, and nitrogen oxide compliance of 41 US steel manufacturers for the period 1980-1989. Here, the authors detected a substantial impact of *actual* lagged inspections and non-monetary enforcement actions on air pollution compliance, but they found limited evidence that the predicted threat of these actions directly influenced environmental behavior.[3] Actual enforcement actions seem to have spurred changes in environmental behavior.

In a study of self-reported air pollution compliance rates for 175 US pulp and paper plants from 1979-1989, Nadeau [1997] showed that EPA regulatory activity can significantly affect plants' duration of non-compliance. In particular, Nadeau [1997] studied the response of time spent in violation of air pollution statutes to EPA/state inspections and enforcement actions. Results indicated that a 10 percent increase in a plant's predicted threat of enforcement actions, including monetary penalties, resulted in a 4 to 5 percent reduction in the violation length. Results for predicted inspection activity, however, were largely indeterminate. A 10 percent increase in a plant's predicted threat of inspection resulted in a 0 to 4 percent reduction in the length of non-compliance.

More recently, Earnhart [2004a] and Earnhart [2004c] investigated the relationship between regulator activity and self-reported BOD discharges from 40 Kansas wastewater treatment facilities for the period 1990-1998. The key metric in both studies was the response of BOD discharges to EPA/state enforcement and monitoring actions. The most consistent result across the analyses was that lagged actual inspections and lagged actual enforcement actions caused reductions in BOD discharges (as a percentage of permitted levels). Interestingly, the author detected no deterrence difference between actual EPA inspections and actual local authority inspections. Other findings, including deterrence effects of the threat of inspection and the threat of enforcement were inconsistent across papers and statistical specifications. As Earnhart [2004c] highlights, these papers also suggest that empirical tests of specific deterrence may be sensitive to statistical specification. In other words, the same data can sometimes yield different conclusions when assessed via alternative statistical methods.

May [2005] analyzed survey results from approximately 200 marine facilities (marinas and boatyards) in Washington and California. In a study of how managers' reported deterrence fears responded to regulator inspections and sanctions, the author

[3] Many studies reviewed in this document contributed significantly to the literature in ways not discussed. For example, Gray and Deily [1996] also analyzed the impact of firm compliance on regulator behavior. However, this review only focuses on determinants of compliance, specific deterrence, and general deterrence.

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found that inspections significantly contributed to managers' deterrence viewpoints. Facilities inspected in the last 5 years had higher deterrent fears than those not inspected. In contrast, past sanctions for water quality violations were not associated with higher deterrence fears. Keohane, Mansur, and Voynov [2006] studied the impact of new source review (NSR) enforcement lawsuits on the sulfur dioxide and utilization rates of 249 electric power plants for the period 1996-2000. The authors determined that the threat of a NSR lawsuit, as primarily predicted by lagged emissions rate increases, lagged large capital investments, and parent company characteristics, significantly decreased emissions by these plants. Actually implemented lawsuits, however, had little impact on facilities' air contaminant emissions. The authors interpreted their results to indicate that firms strongly sought to avert enforcement ahead of time, but imposed enforcement actions did not contribute to any further improvements above and beyond changes already made.

Most recently, Glicksman and Earnhart [2007] analyzed both qualitative and quantitative evidence of specific deterrence for water discharges in the chemical industry. The statistical database analysis examined how plants' composite BOD and TSS discharges responded to EPA/state enforcement actions. The survey component covered 267 of the 1003 originally solicited chemical facilities (a 26.6 percent response rate). Glicksman and Earnhart [2007] established that inspections and fines both produced significant deterrence effects. Nearly 75 percent of survey respondents reported that fines were an effective deterrent and approximately 87 percent reported that inspections definitely or probably effectively induced water pollution compliance. Similarly, the statistical results indicated that both inspections and enforcement actions resulted in decreased aggregate conventional water pollution emissions. The authors further explored the relative contribution of state actions vs. federal actions as well as administrative actions vs. judicial actions, but results interpreted broadly failed to reveal consistent patterns.

A particularly notable recent paper is Gray and Shadbegian [2005]. In addition to measuring specific deterrence in a framework consistent with earlier studies, the authors also considered factors that influenced the *responsiveness* to monitoring and enforcement actions. They examined 116 pulp and paper mills for the period 1979-1990, and their key metric was the response of air pollution compliance to EPA/state inspections and enforcement actions. Results indicated that plants increased their CDS-reported air pollution compliance rates by approximately 10 percent in response to a marginal regulator action. This result held roughly equally for inspections and enforcement instruments. Additionally, the authors found heterogeneous enforcement responses across plants. For example, pulp mills were less sensitive to inspections than paper mills and plants owned by larger parent companies were less sensitive to inspections, but more sensitive to enforcement actions, than plants owned by smaller parent firms.

Specific deterrence effects are not restricted to domestic environmental institutions. For example, Laplante and Rilstone [1996] explored the impact of inspections and the predicted threat of inspection on the biochemical oxygen demand (BOD) and total suspended solid (TSS) discharges of 47 Canadian pulp and paper mills.

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The authors found inspections and their associated threat reduced mills' absolute BOD discharges by approximately 28 percent. Similarly, Dasgupta et al. [2001] demonstrated that inspections on manufacturing facilities in Zenjiang, China reduced common water pollutants by between 0.4 and 1.2 percent and reduced air particulates by approximately 0.3 percent. Outside of the environmental arena, Gray and Mendeloff [2005] found that OSHA inspections reduced workplace injuries by approximately 19% in 1979-1985, 11% in 1987-1991, and 1% in 1992-1998. Further, they showed that inspections with penalties had a significantly stronger effect than inspections without penalties.

3.2 Specific Deterrence: Repeat Offenders

The empirical literature on repeat offenders is very limited. Miller [2005] explored the effect of administrative, civil, and criminal enforcement activities on US companies' recidivism for the period 1970 to 1997. The key metric was the response of recidivism to various regulatory actions. The analysis revealed that both civil and administrative penalties reduced repeat offenses. However, both did so about equally, despite the fact that administrative penalties are constrained to be lower on average. Criminal enforcement appeared to dominate other enforcement actions, and results suggested that criminal sanctions significantly reduced repeat offenses. Also, there was some suggestive evidence that criminal fines that increased in the number of offenses were particularly effective for reducing recidivism. All of these results, however, were extremely preliminary. Clearly, recidivism represents a promising area of future empirical research.

Given the lack of observational studies, it is perhaps informative to consider the theoretical literature. Law and economic models indicated that it is frequently optimal to sanction repeat violators more severely than first time violators. See, for example, Polinsky and Shavell [1998]. This view is consistent with numerous environmental penalty structures, including Clean Water Act fines. The basic intuition is simple. When a potential violator considers violating for the first time, the specific deterrence effect will potentially be enhanced by knowing that a violation now may not only trigger a penalty but may also enhance penalties in the future. Guttel and Harel [2005] extended the traditional model to incorporate behavioral economic considerations. They also concluded that penalties should be increasing in the number of violations.[4]

However, *economic* support for increased penalties for repeat environmental offenders rests on one key assumption. The assumption is that it must be socially optimal to deter violations from the recidivating facility. It is possible that large numbers of repeat violations may signal extremely high costs of compliance (due, for example, to plant vintage or industrial subcategory) at the relapsing facility. In some cases, this facility may actually be expending greater costs to reduce marginal units of pollution than

[4] There is also a theoretical literature that suggests that penalties should be decreasing in the number of violations. See, for example, Emons [2003]. However, the assumptions in this strand of the literature generally don't seem appropriate for the majority of environmental regulations. In particular, this area of the literature assumes that imposed fines are extremely large relative to the sanctioned firm's wealth and that increasing penalties in some period inherently implies lower penalties in another period.

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society is receiving in benefits from these marginal reductions. Further, given limited agency enforcement budgets, significantly greater abatement and environmental benefits may be achieved by targeting resources towards violators with smaller marginal abatement costs and greater ability to comply. In short, while it is likely that increasing sanctions for repeat offenders is an optimal policy for many recidivists, this strategy may not achieve the greatest social and environmental benefits when applied to facilities with numerous repeat offenses driven by extreme abatement costs.

4. Monitoring and Enforcement: General Deterrence

Law enforcement agencies and legal scholars have long postulated that monitoring and enforcement spills over to deter violations at facilities beyond the sanctioned entity. If this is true, this regulator reputation-building 'general deterrence' effect has critical implications. Notably, focusing on deterrence effects at the sanctioned facility alone may seriously underestimate the efficacy of fines and other sanctions.

This section reviews the literature on the general deterrence effects of monitoring and enforcement. A key goal is to dissect important studies. The examination of each paper's approach to measuring general deterrence should provide specific examples for possible replication. Collectively, the results of the general deterrence literature indicate that both qualitative and quantitative methods exist to measure general deterrence. Further, joint results show that environmental facilities learn from the experiences of their neighbors, and this learning impacts compliance behavior. *Inspections and enforcement actions consistently produce significant spillover effects on non-sanctioned facilities. Consequently, a substantial improvement in environmental quality might be achieved from a relatively small additional investment in traditional monitoring and enforcement.*

4.1 The General Deterrence Literature

Despite regulators' mature beliefs in general deterrence, an empirical literature investigating spillover effects of monitoring and enforcement has only recently emerged. Early studies included Stafford [2002] and Stafford [2003]. Stafford [2002] studied the response of 8411 hazardous waste-generating facilities to a rule change that significantly increased financial penalties for violation. The 10 to 20 fold increase in potential fine magnitudes generated an approximately 15 percent reduction in regulated plants' violation probabilities. In contrast, Stafford's complementary 2003 study found no consistent effect of state-level strict liability rules on hazardous waste violations. This more recent study, however, did find that increased state-level environmental spending decreased Class I pollution violations. While these findings may indicate improved environmental performance, results may also suggest the presence of firm-level strategic reporting behavior since Class II record-keeping violations increased at the same time. In other words, while it is possible that increased spending reduced violations, it is also possible that increased spending increased instances where firms cheat by no longer self-reporting violations. Collectively, Stafford [2002] and Stafford [2003] considered the impact of rule and budget changes that may have enhanced the regulator's reputation for

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toughness. Therefore, these papers importantly informed the deterrence spillovers literature. They did not, however, directly differentiate between specific and general deterrence.

Table 3 summarizes important recent empirical studies that directly measure the general deterrence effects of domestic environmental monitoring and enforcement. In companion studies, Thorton, Gunningham, and Kagan [2005] and Gunningham, Thorton, and Kagan [2005] used survey and interview evidence from chemical and electroplating facilities to directly take up the issue. Using a survey of 233 firms across 8 industries, Thorton et al. [2005] examined managers' knowledge of important 'signal enforcement case' and firms' self-reported environmental responses to knowledge of enforcement actions levied against other facilities. Gunningham et al. [2005] used interview evidence from 35 chemical and electro-plating facilities to explore managers' reasons for environmental performance and their stated responses to enforcement actions levied against other facilities in their industry. The authors found that 89 percent of survey respondents could recall some enforcement actions imposed on other firms, 63 percent of survey respondents took an environmental action in response to learning about a sanction at another facility, and a large majority of interview respondents reported that other firm's regulatory activity impacted their own attention to environmental issues. Results indicated that general deterrence, interpreted broadly, is a significant factor for environmental behavior.

Thorton, Gunningham, and Kagan [2005] and Gunningham, Thorton, and Kagan [2005] also explored the specific mechanisms that might drive general deterrence. The authors detected that respondents were frequently aware of *infractions* at other facilities that triggered sanctions but not could recall other details like the penalty amount. The authors further found that only a small number of interview respondents reacted to knowledge of penalties at other facilities by performing a specific environmental action to immediately avoid a similar infraction. Yet, many officials indicated that learning about someone else's fine focused their attention on environmental issues or altered their long-term compliance motivations. Collectively, the companion studies concluded that general deterrence may operate more as focusing, reminder, or reassurance mechanism than a short-run fear-generating mechanism. The authors also note that fines may serve as a trigger mechanism for social stigma effects, which may be particularly strong for larger firms.

Shimshack and Ward [2005] used data on BOD and TSS discharges from 217 pulp and paper mills to explore the regulator reputation-building effect of general deterrence. In particular, the authors statistically analyzed the response of plants' BOD and TSS discharges to lagged enforcement and monitoring activity at both the sanctioned plant and other plants in the same regulatory jurisdiction. Shimshack and Ward [2005] found that an additional fine induced about a two-thirds reduction in the statewide water pollution violation rate in the year following that fine. Nearly all of this large result was attributable to spillover effects, as the average deterrence impact on each of the other plants in a state was almost as strong as the impact on the sanctioned facility. The authors also showed that general deterrence was increasing in the amount of the penalty. In other

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words, larger fines induced fewer subsequent violations by other plants in the state. Other results included the finding that non-monetary enforcement responses like notices of violation alone had little influence on plant-level compliance.

For both the existence of fines and fine magnitude specifications, Shimshack and Ward [2005] detected that the regulator reputation deterrence effect decayed significantly after one year. This portion of the analysis was based on the response of BOD and TSS violations to separate one year and two year lagged fine variables. While the marginal penalty induced an approximately 67 percent reduction in statewide violation rates in the subsequent year, this regulator-reputation effect declined to about 27 percent in the second year following the fine. Results suggested that pulp and paper plants regularly updated their beliefs regarding regulatory stringency.

State of Oregon Department of Environmental Quality [2004] conducted an extensive survey of 450 regulated companies in Oregon for one month in 2002. The sample was selected primarily from high priority industries, and thus results are not representative for less visible industrial sectors. Key metrics included the response of managers' self-reported environmental behavior to hearing about inspections and sanctions at other facilities. Respondents frequently reported significant general deterrence effects. For example, 38 percent of surveyed companies made changes in response to hearing about inspections at another facility and 14 percent reportedly made changes in response to hearing about sanctions at other facilities. Such changes included improved water treatment, investment in new equipment, environmental personnel additions, and employee training. Oregon DEQ estimated that inspections and penalties directly generated an average of 1.6 environmental changes per company. 2.6 additional environmental actions per company occurred when other facilities later heard about the enforcement response.

In Oregon DEQ [2004], inspections seemed to have stronger specific and general deterrence effects than penalty actions, largely because inspections appeared to be better publicized. Additionally, concerns about penalty actions depended critically on the size of the penalty and the number of facilities penalized in a given period. Notably, the study also found heterogeneous responses to enforcement. In particular, small companies were significantly less likely to respond to general deterrence, in part because these organizations were considerably less likely to be aware of regulatory activities devoted towards other facilities. Further, a substantial portion of company officials reported that enforcement actions sent strong signals to non-regulatory constituents and therefore regulatory actions significantly, yet indirectly, contributed to compliance.

In a study of particulate, sulfur dioxide, and toxics emissions from 521 US manufacturing plants located within 50 miles of three major cities, Gray and Shadbegian [2007] analyzed the response of toxic and conventional air pollution violations and emissions to EPA/state inspections and enforcement actions. The authors found evidence for both specific and general deterrence. Inspections increased compliance with regulations for both the inspected facility and for nearby plants. The specific and general deterrence effects of inspections were found to be approximately the same magnitude.

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Interestingly, the authors also determined that general deterrence was restricted to states, suggesting that regulatory jurisdictions may be important determinants of the "reach" of the regulator reputation effect underlying general deterrence.

Spillover effects of environmental enforcement not only affect compliance, but beyond compliance behavior as well. For example, Shimshack and Ward [2007] examined the impact of enforcement-induced regulator reputation on the beyond-compliance water pollution discharges of 251 major pulp and paper mills for the period 1990-2004. In particular, the authors examined the response of BOD and TSS discharges to lagged enforcement activities at other facilities in the same state. Shimshack and Ward [2007] found that, even in an industry where compliance was generally high, an increase in enforcement through fines can cause a significant reduction in discharges. General deterrence induced plants with discharges typically below legally permitted levels to go further beyond compliance when regulators issued fines. Also, likely non-compliant plants often responded to sanctions on other facilities by reducing discharges well below levels simply required for compliance. In aggregate, BOD and TSS discharges within a state fell by approximately 7 percent in the year following a sanction in that state. Most of the reduction was due to plants going beyond compliance, rather than simply a reduction in violations.

Shimshack and Ward [2007] also demonstrated how these empirical regularities can be rationalized by economic theories of discharge randomness and discharge jointness. Plants with partially random discharges may have some possibility of a fine from accidental releases over the permitted amount (Brannlund and Lofgren [1996], Bandyopadhyay and Horowitz [2006]) and therefore may reduce discharges even further beyond compliance when they perceive a more stringent enforcement environment. Similarly, a plant compliant in one pollutant may face some possibility of a fine for violations on a different, but jointly-produced, pollutant. If such a plant perceives an increased regulatory threat by observing fines on other facilities, it may reduce the pollutant with the binding limit and correspondingly push the jointly-determined pollutant even further beyond compliance.

Finally, evidence for general deterrence effects is not restricted to domestic environmental policies. Dubin et al. [1990] and Dubin [2007] found significant impacts of tax audits on compliance. For example, Dubin [2007] showed that a doubling of criminal investigation cases would yield nearly $17 billion in increased tax revenues. Nearly all of these increased collections stemmed from general deterrence, as 94 percent of new inflows came from people not actually investigated. These large spillover effects strongly suggest that is cost effective to increase IRS sanctions. In fact, the author estimated that a $25 million dollar investment in additional investigations, prosecutions, and sanctions would yield nearly $1.7 billion in additional revenues. Despite the strength of the regulator reputation effect, the impact decayed over time. Taxpayers adjusted their behavior to correspond to updated audit perceptions every two to three years. Finally, the author found suggestive evidence that media information dissemination enhanced deterrence spillovers.

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General deterrence effects beyond tax and the environmental settings are more uncertain. Feinstein (1989) found no evidence for either specific or general deterrence effects from safety sanctions on 17 nuclear power generators. However, this institutional context was quite unique, as each facility had a resident inspector who has primary responsibility for plant safety. Additional inspectors also conducted an average of more than one evaluation per month.

5. Replication considerations

A key goal of Sections 2 and 3 was the examination of diverse approaches to measuring specific and general deterrence. Reviewed papers provide an excellent foundation for possible replication. While several definitive findings arise from the existing literature, care should be exercised before extrapolating more nuanced results beyond the relevant institutional settings. Consequently, replication for new sectors, contaminants, and time periods could importantly contribute to the state of knowledge on deterrence. This section discusses replication considerations, examines studies particularly promising for replication, and reviews the strengths and weaknesses of the diverse approaches to compliance and deterrence measurement. All discussions are based upon the author's subjective assessment of the related literature and the state of knowledge.

Quantitative Database Analyses

Theoretically, the quantitative database analysis approach could be replicated for other sectors by OECA. This approach is most directly applicable to regulations and sub-samples with continuous self-reported emissions data over many facilities and several time periods. Such comprehensive data allow for month-by-month, quarter-by-quarter, or year-by-year compliance determination and emissions assessment for all analyzed facilities. For example, major facilities' water pollution data from the Permit Compliance, air pollution data from the Continuous Emissions Monitoring System, and toxics data from the Toxic Releases Inventory fit this framework. The approach is also applicable to regulations and sub-samples with comprehensive compliance indicators over several periods. Major facilities' water pollution violation data from the Permit Compliance System, air pollution violation data from the Continuous Emissions Monitoring System, hazardous waste violation data from the RCRA Biennial Reporting System, and air pollution violation data from the Compliance Data System fit this framework.

Quantitative database analyses are particularly powerful for individual sectors with census or near census monitoring coverage. Sector-specific analyses of common discharges or violations from CWA major sources are a notable example. The technical appendix summarizes rigorous statistical procedures for implementation in such contexts. Strengths of the quantitative approach include the identification of actual empirical deterrence magnitudes. It is difficult to assess the extent to which enforcement and monitoring affect compliance in qualitative frameworks. Well-designed quantitative analyses also provide the opportunity to control for confounding factors. Further, database analysis reveals how regulated facilities actually responded to monitoring and

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enforcement, rather than how these facilities say they responded to monitoring and enforcement. In other words, quantitative analyses avoid survey response bias, recall bias, and strategic reporting bias. This latter concern, where respondents may have incentives not to reveal certain information truthfully in a survey, may be particularly crucial for surveys conducted by the regulatory agency itself. Quantitative database analyses tie monitoring and enforcement actions to actual measures of compliance and emissions, which are better connected to environmental quality than the intermediate factors like process and management modifications that are typically measured by qualitative methods. Finally, quantitative analyses do not require approval from OMB, via an Information Collection Request (ICR).

The basic analyses in Shimshack and Ward [2007] and Gray and Shadbegian [2005] provide particularly promising foundations for replication to other sectors, other contaminants, and other time periods. In Shimshack and Ward [2007], the key question is 'What is the empirical relationship between pollution discharges and lagged enforcement actions on other facilities?' Answers directly measure general deterrence. The study's key metric is the response of plants' BOD and TSS discharges to inspections and EPA/state fines. Monthly BOD and TSS discharge data, expressed as a percent of permitted levels, are the dependent variables. The key explanatory variable is a 0-1 indicator that reveals the existence of a fine on another plant in a given plant's state in any of the 12 months preceding the evaluated period. The log of total fine magnitudes on other plants in a given plant's state in any of the 12 months preceding the evaluated period is another possible independent variable. Other explanatory variables include year indicators to control for general time trends, seasonality indicators to control for seasonal variation, and plant-specific indicators to control for time invariant confounding factors like community characteristics, industrial sub-sector, and basic control technology. Techical appendix A.1 discusses statistical methods for Shimshack and Ward [2007] type analyses.

In Gray and Shadbegian [2005], the key question is 'What is the empirical relationship between a plant's pollution discharges and lagged enforcement and monitoring actions directed at that facility?' An important supplemental question is 'What factors determine a plant's sensitivity to monitoring and enforcement activities?' Answers directly measure specific deterrence and its sensitivity to important confounding factors. The study's key metric is the response of plants' air pollution compliance status to EPA/state inspections and enforcement actions. The dependent variable is a 0-1 indicator reflecting whether the specific plant was in compliance with air pollution regulations throughout the year. The key explanatory variables are predictions of total enforcement actions and total inspections directed towards a plant in the given year. To measure the sensitivity of deterrence to other factors, the key explanatory variables are the predictions interacted with plant-specific characteristics like industrial sub-sector (pulp/paper in their analysis), plant age, and plant size. Since Gray and Shadbegian [2005] do not use plant-specific indicator variables to control for time invariant confounding factors, the study also includes detailed plant and firm characteristics. Technical appendix A.3 discusses statistical methods for Gray and Shadbegian [2005] type analyses. Confounding variable data is typically not collected by the EPA itself and

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must be obtained externally. This may be a disadvantage of this specific quantitative analysis approach for OECA.

Note that the metrics in both Shimshack and Ward [2007] and Gray and Shadbegian [2005] are sector-specific (both pulp and paper) and regulation-specific (the former analyzes conventional water pollutants regulated under the Clean Water Act and the latter analyzes criteria air pollutants regulated under the Clear Air Act). These metrics are similar to those used in other quantitative database analysis studies, including Earnhart [2004a], Earnhart [2004c], Shimshack and Ward [2005], and Keohane et al. [2006].[5] While these metrics are narrowly defined, they are of significant supplemental value to OECA's mission since they directly measure the general and specific deterrence *for pollution*. This stands in contrast to the agency's commonly utilized output-oriented metrics (number of inspections, total penalty amounts, etc.) or intermediate process-oriented metrics (value of injunctive relief). More specific compliance and deterrence metrics are also more statistically rigorous, as it is difficult to credibly create statistically valid indices across pollutants or sectors. Finally, more universal or output-oriented metrics mask important heterogeneity across sectors and are therefore more likely to obscure, rather than illuminate, our understanding of specific and general deterrence.

Another notable feature of most quantitative database analyses, including Earnhart [2004a], Earnhart [2004c], Gray and Shadbegian [2005], and Shimshack and Ward [2007], is lagged monitoring and enforcement variables. Lags serve two important purposes. First, lags reduce statistical simultaneity (endogeneity) and help isolate the direction of causality. If contemporaneous monitoring and enforcement variables are included in the analysis, any statistically detected correlations between these factors and compliance or emissions may reflect the causal effect of compliance and emissions on monitoring and enforcement actions due to regulator targeting. This reverse causation influence is likely to understate true deterrence effects. Second, lags allow time for firms to alter their environmental behavior in response to monitoring and enforcement actions.

Qualitative Survey Analysis

Qualitative deterrence assessments have significantly contributed to the state of science. Key advantages of the survey approach include the ability to examine organizational culture issues, knowledge of enforcement and monitoring activity across facilities, and the interactions between policies in greater depth. An additional advantage is that deterrence and compliance metrics from survey methods can be defined more broadly than metrics for quantitative analysis. For example, May [2005], Oregon DEQ [2004], Thorton et al. [2005], and Gunningham et al. [2005] all simultaneously explore multiple regulations across multiple sectors. Finally, while effective surveys require considerable care, less statistical expertise is needed for implementing qualitative approaches.

The basic methods and questions in Oregon DEQ's [2004] company survey provide particularly promising foundations for replication to other regions, other sectors,

[5] See Tables 2 and 3 for more detail on the metrics used in these studies.

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and other time periods. Oregon DEQ [2004] surveyed 450 regulated facilities by telephone over a one month period in 2002. Most facilities were randomly selected from high priority sectors. The response rate was 68 percent.[6] Key questions assessed company attitudes about environmental compliance, frequency and kinds of process modifications made because of environmental issues, most important factors stimulating compliance, and stated perceptions of regulatory risk. Questions specifically targeting general deterrence examined awareness of inspections and enforcement actions at other facilities and company response to awareness of inspections and enforcement actions at other facilities. The actual survey is attached as an appendix to Oregon DEQ [2004].

Theoretically, many features of Thorton et. al. [2005] could also be replicated to other sectors, other time periods, and other geographic areas. Results would provide meaningful insights into specific and general deterrence. Thorton et. al. [2005] surveyed 233 facilities in 8 industries by telephone sometime after December of 2000. A random sample of approximately 290 facilities in 8 pre-selected industries was determined, and calls yielded a response rate of 80 percent. Key questions assessed awareness of important regulatory signal cases in the industry, awareness of inspections and enforcement actions at other facilities, stated response of regulatory risk perceptions to such awareness, and stated compliance action response to such awareness. In particular, respondents were asked if hearing about a fine or prison sentence at another company in their industry induced them to (1) review their environmental programs, (2) change their management plans, (3) change their environmental record-keeping, (4) change employee training, (5) change equipment, and (6) change their physical plant. The actual survey is not publicly available, but should be available directly from Neil Gunnigham at the Australian National University.

How often should replication occur?

Given resource constraints, it is not practical to *frequently* repeat either qualitative or quantitative analyses for the same regulated facilities and same regulations. Implementation of any technique is costly. Unfortunately, the literature does not examine how frequently replication should occur. The key consideration is likely the internal benefits and costs of assessment, although this white paper does not attempt to determine the costs or practicality of implementing any specific information gathering, deterrence measurement, or statistical analysis. My subjective assessment is that broad conclusions are likely applicable for 10-20 years for sectors/regulations in which technical change is modest, regulations are fairly static, and managerial attitudes are not evolving rapidly. More detailed results, including the specific magnitudes of deterrence effects, probably have a lifespan of less than 10 years for most industry/regulation combinations.

It is not the case, however, that rapidly decaying deterrence effects over time render any given study obsolete. The key consideration is whether the underlying decision-making process has importantly changed, on average, for the regulated facilities. For most regulated industries, average deviations from organizational structure and managerial attitude trends remain relatively small over multiple year periods. Suppose,

[6] May's [2005] 49 percent response rate is more typical of the broader literature.

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for example, a quantitative database study finds that an additional fine reduces aggregate discharges in a state by 8 percent but that this effect is no longer significant after one year. These findings suggest that, X years from now, firms in the studied industry are expected to pollute baseline levels (after controlling for trends) if they observe no fines in the preceding year (X-1 years from now). If they do observe a fine in the preceding year (X-1 years from now), however, they are still expected to reduce pollution by 8 percent below baseline levels (X years from now) unless dramatic organizational, managerial, or technical changes have occurred in the industry.

How should samples be collected?

Sample selection is an important component of both quantitative and qualitative methods. No comprehensive assessment of an entire regulated community is recommended, as implementation costs would be prohibitive. Further, since the regulated universe changes over time, a universal study yields no additional information for future policy making than a statistically valid sample. Every study reviewed in Sections 3 and 4 examines specific regulations for a limited number of sectors, and most study few regulations for few industries (see, for example, Earnhart [2004a], Gray and Shadbegian [2005], Shimshack and Ward [2005], Thorton et al. [2005], Gunningham et al. [2005], and Gray and Shadbegian [2007]). Further, results from such a broad analysis would likely obscure, rather than illuminate, important heterogeneity in deterrence assessment.

Sample selection should first identify sectors, contaminants, and even characteristics ('majors') based upon agency priorities. Such priorities may include environmental impacts, traditional compliance rates, or assessment costs. For quantitative analyses of specific deterrence, a random sample may then be obtained. For quantitative analyses of general deterrence, a near-census for the sector(s)/contaminant/characteristic is most desirable. This is possible for major facilities in much of the PCS, CEMS, CDS, TRI, and the RCRA Biennial Reporting Systems. For qualitative survey approaches, random samples should be obtained. Note that the originally selected survey sample should be considerably larger than necessary for statistical validity, as response rates will be significantly less than 100 percent. In all cases, replications should explain their sampling procedure in detail and should acknowledge that individual generated results are most useful for assessing compliance and deterrence effects in the context of this sector/contaminant/characteristic combination. More general statements can be made in conjunction with the larger literature, much of which is reviewed in this document.

6. Major Findings & Recommendations

Regulatory punishment for pollution violations is a mainstay of nearly every industrialized nation's environmental policy. This report reviews the relevant environmental compliance literature, with emphasis on measuring the specific and general deterrence effects of environmental regulatory activity. This section first presents conclusions that can be conclusively supported by the literature. The major criterion for this categorization is broad-based support across several studies in several sectors. The section then reviews important findings suggested (but not definitely confirmed) by the

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literature. The major criterion for this categorization is support by three or fewer notable studies and the absence of strong contradictory evidence. This section concludes with recommendations for OECA consideration. All findings and recommendations are based upon the author's subjective assessment of the related literature and the state of knowledge.

Major Findings Strongly Supported by the Related Literature

- Regulation, monitoring, and enforcement have historically been, and remain, critical determinants of environmental behavior.

  As demonstrated in Section 2 of this paper, many factors influence environmental compliance. However, every reviewed study that compared traditional regulation to other compliance determinants indicated that regulation/legislation is a more important determinant of environmental behavior than any other single factor. This includes Khanna and Anton [2002], Kagan et al. [2003], Doonan et al. [2005], Delmas and Toeffel [2005], and May [2005]. In many cases, regulators and legislators were extremely influential. For example, Doonan et al. [2005] found that a full 70 percent of pulp and paper managers rated the government as the single most important source of deterrence pressure.

- Environmental monitoring and enforcement activities generate substantial specific deterrence.

  Every reviewed study that examined the impacts of domestic environmental monitoring and enforcement actions on the inspected or sanctioned facility found at least some evidence for specific deterrence. This includes Magat and Viscusi [1990], Deily and Gray [1991], Gray and Deily [1996], Nadeau [1997], Earnhart [2004a], Earnhart [2004c], May [2005], Gray and Shadbegian [2005], Keohane et al. [2006], and Glicksman and Earnhart [2007]. In many cases, the specific deterrence effects were large. For example, Gray and Shadbegian (2005) found that the threat of an additional enforcement action or inspection increased future compliance with air pollution regulations in the pulp and paper sector by 10 percent.

  Inspections and enforcement activities directly affect future compliance and environmental performance. Further, many other important compliance factors relied on the enforcement and monitoring process for information. For example, Kagan et al. [2003] found that facilities frequently reported that enforcement activities significantly impacted consumer and community perceptions of their environmental performance.

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- Environmental monitoring and enforcement activities generate substantial general deterrence.

  Every reviewed study that examined the spillover effects of environmental monitoring and enforcement on other facilities uncovered support for the existence of general deterrence. This includes Thorton et al. [2005], Gunningham et al. [2005], Shimshack and Ward [2005], Oregon DEQ [2004], Gray and Shadbegian [2007], and Shimshack and Ward [2007]. In many cases, general deterrence effects are practically important. For example, Shimshack and Ward [2005] found a nearly 2/3 reduction in the statewide probability of a conventional water pollution violation in the year following a fine. Failure to account for such general deterrence may significantly underestimate the efficacy of fines, inspections, and other regulatory actions.

- Environmental monitoring and enforcement activities may generate significant emissions reductions, even for sector/contaminant combinations where compliance is typically high.

  Reviewed studies consistently find specific and general deterrence effects of environmental monitoring and enforcement, even in industries with relatively high compliance rates. Earnhart [2004a] and Earnhart [2004c] find substantial specific deterrence from monitoring and enforcement actions in the Kansas wastewater industry where average conventional water pollution discharges are 45 percent of permitted levels. Shimshack and Ward [2005] find significant general deterrence for conventional water pollutant fines in a sector with 98 percent average compliance rates. Gray and Shadbegian [2005] find significant specific and general deterrence for 521 US manufacturing plants that exhibit an 89 percent average compliance rate with air regulations.

  Further, Shimshack and Ward [2007] find that plants with discharges typically below legally permitted levels reduce discharges further when regulators issue fines, even on other plants. Likely non-compliant plants often respond to sanctions by reducing discharges well beyond reductions required to meet statutory requirements. Failure to account for this often overlooked aspect of deterrence may understate the efficacy of enforcement activities. Because this enforcement-induced beyond compliance effect magnifies the impact of regulatory activity, results again suggest that a substantial improvement in environmental quality may be achieved with a relatively modest additional investment in traditional monitoring and enforcement.

- Enforcement and monitoring responses are heterogeneous.

  The literature on both specific and general deterrence effects indicates heterogeneous responses to enforcement and monitoring. For example, the quantitative database analysis literature (see, for example, Earnhart [2004a], Gray and Shadbegian [2005], Shimshack and Ward [2005], and Gray and Shadbegian

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[2007]) finds significantly different deterrence magnitudes for different sectors, different time periods, different enforcement actions, and different monitoring instruments. Factors like facility-specific abatement costs, industrial sub-sector, and facility size determine responses to regulatory activity. A few studies examine heterogeneity in more detail. For example, Gray and Shadbegian [2005] found that pulp mills were less sensitive to inspections than paper mills and plants owned by larger parent companies were less sensitive to inspections but more sensitive to enforcement actions than plants owned by smaller parent firms. Gunningham et al. [2005] also found that deterrence was a smaller overall concern to larger facilities.

- Quantitative databases and statistical methods exist for deterrence measurement.

  Sections 3 and 4 of this white paper discuss more than 15 recent papers that quantitatively measure the specific and/or general deterrence effects of monitoring and enforcement actions. Quantitative databases and statistical methods exist for deterrence measurement. Tables 2 and 3 list the critical metric for the studies most directly relevant to OECA's own assessment and priorities. A notable feature of the quantitative database analyses (see, for example, Earnhart [2004a], Gray and Shadbegian [2005], Shimshack and Ward [2005], and Gray and Shadbegian [2007]) is that the key metrics are restricted to specific regulations and specific populations.[7]

- Qualitative survey methods exist for deterrence measurement.

  Sections 3 and 4 of this white paper discuss more than 5 important recent studies that qualitatively measure the specific and/or general deterrence effects of monitoring and enforcement actions. Qualitative survey methods exist for deterrence measurement. Tables 2 and 3 list the critical metric for the studies most directly relevant to OECA's own assessment and priorities. A notable feature of the qualitative survey analyses (see, for example, May [2005], Thorton et al. [2005], and Gunnigham et al. [2005]) is that key metrics are typically restricted to specific populations (or a small number of specific populations), but not specific regulations. State of Oregon DEQ [2004] represents a notable exception, where metrics are defined for several regulations in eight industries.

Major Findings Suggested, but Not Conclusively Demonstrated, by the Literature

- The regulator reputation effect underlying general deterrence tends to decay.

  The results of the general deterrence literature indicate that environmental facilities learn from the experiences of their neighbors, and this learning impacts compliance behavior. However, the main results of Shimshack and Ward [2005]

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[7] This restriction is very likely a result of implementation costs and benefits, although this white paper does not attempt to determine the costs or practicality of implementing any specific information gathering, deterrence measurement, or statistical analysis.

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and the sensitivity analyses of Shimshack and Ward [2007] also show that facilities regularly update their beliefs about regulatory stringency. At least for the studied pulp and paper sector, regulator reputation begins to decay within a year after a fine for water pollution violation. Within 2 years of a fine, general deterrence has decayed by more than 50%. Therefore, regulators must maintain a monitoring and enforcement presence to induce consistent environmental performance over time. This result is not inconsistent with Gunningham et al.'s [2005] findings that spillover effects may operate through "implicit general deterrence," where the perceived threat of legal sanctions is a function of enforcement history and the mere existence of regulations. Enforcement history is itself significantly determined by relatively recent regulator behavior.

- There are limits to the "reach" of the reputation effect underlying general deterrence.

  Theory suggests that plants learn primarily from the experiences of their most similar neighbors (Sah [1991]). Indeed, empirical evidence suggests that the "reach" of the regulator reputation effect underlying general deterrence is restricted to a single regulatory entity. For example, Gray and Shadbegian [2005] found that plants seem inclined to respond to general deterrence created by the experiences of facilities in the same state, but not in neighboring states.

- Deterrence varies across enforcement and monitoring instruments; inspections, intermediate enforcement actions, administrative fines, and criminal actions have different compliance impacts.

  Inspections, intermediate enforcement actions, administrative fines, and criminal actions have different compliance impacts. Unfortunately, relative deterrence effects seem somewhat sensitive to context. For example, there is no consensus on whether the marginal inspection induces greater compliance than the marginal penalty. Two largely consistent results, however, do emerge. First, criminal actions seem to affect environmental behavior more significantly than administrative or civil actions. See, for example, Miller [2005] and Cohen [1999]. Second, most evidence suggests no detectable consistent difference between deterrence associated with state actions and federal actions (Earnhart [2004c], Glicksman and Earnhart [2007]).

- Sanctions should generally increase for repeat offenders, but important caveats exist.

  Theory suggests that sanctions should increase with the number of violations, supporting current agency practice. See, for example, Polinsky and Shavell [1998] and Polinsky and Shavell [2000]. There is some empirical evidence to support this theoretical recommendation (Miller [2005]). However, the agency should carefully consider the application of this rule to recidivists who can demonstrate extremely high costs of compliance. Targeting these facilities for stringent

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sanctions may be socially wasteful and may achieve significantly less environmental benefits than an equivalent resource allocation towards facilities that are able to reduce emissions more cost effectively.

Recommendations

All recommendations are based upon the author's subjective professional assessment of the related literature and the state of knowledge.

How can OECA measure the general and specific deterrent impacts of compliance monitoring and enforcement?

- OECA should consider closely replicating statistical database analyses for measuring the specific and general deterrence effects of monitoring and enforcement.

  Replication of existing quantitative studies for new sectors, contaminants, and time periods could importantly contribute to the state of knowledge on deterrence, and general deterrence in particular. The database analysis studies in Section 4 and Table 3 are concrete examples for replication. Particular notable studies for consideration include Gray and Shadbegian [2005] and the first half of Shimshack and Ward [2007]. These studies themselves, coupled with the technical appendix to this document, should in theory allow replication by statistically trained agency personnel. Perhaps a small pilot study for a sector with a relatively small number of similar major facilities could be performed to gauge internal feasibility.

- OECA should consider closely replicating qualitative survey analyses for measuring the specific and general deterrence effects of monitoring and enforcement.

  Replication of existing qualitative studies for new sectors, contaminants, and time periods could importantly contribute to the state of knowledge on deterrence, and general deterrence in particular. The survey analysis studies in Section 4 and Table 3 are concrete examples for replication. Particular notable studies for consideration include Oregon DEQ [2004] and Thorton et al. [2005]. These studies themselves, coupled with the actual surveys, should in theory allow replication by agency personnel. Perhaps a small pilot survey to gauge internal feasibility would be an appropriate start.

- OECA should consider expanding existing qualitative survey analyses for measuring specific and general deterrence effects.

  Replication of Oregon DEQ [2004] and Thorton et al. [2005] to other sectors and time periods could importantly contribute to the state of knowledge on deterrence, and general deterrence in particular. However, it is also possible that modestly expanding such surveys may significantly increase the state of knowledge about

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the "reach" and decay of reputation effects underlying general deterrence. OECA might consider asking respondents: (1) How long do deterrence fears from regulatory activity last? (2) If the regulated plant observed a significant enforcement action on another facility in the same state and industry last year, would that plant change its processes or environmental behavior? (3) If the regulated plant observed a significant enforcement action on another facility in the same industry but in a different state, would that plant change its processes or environmental behavior? (4) If the regulated plant observed a significant enforcement action on another facility in a different industry but in the same state, would that plant change its processes or environmental behavior? (5) If the regulated plant observed a significant enforcement action on another facility 2, 3, 4, etc. years ago, would that plant change its processes or environmental behavior? (6) If the regulated plant did not observe a significant enforcement action on another facility last year (or 2, 3, etc. years ago), would that plant change its processes or environmental behavior? (7) If the regulated plant was aware of enforcement and monitoring actions at other facilities, was that plant approximately aware of the sanctioned or inspected plants' pollution levels? (8) If so, did this knowledge impact its responses to sanction awareness?

- For both quantitative and qualitative methods, studies based upon a universal metric are not advised.

  No comprehensive assessment of an entire regulated universe is recommended, as implementation costs for a credible analysis would be prohibitive. Every study reviewed in Sections 3 and 4 of this document examines specific regulations for a limited number of sectors, and most study few regulations/contaminants for few industries (see, for example, Earnhart [2004a], Gray and Shadbegian [2005], Shimshack and Ward [2005], Thorton et al. [2005], Gunningham et al. [2005], and Gray and Shadbegian [2007]). In addition to implementation concerns, studies based upon universal compliance assessment provide no additional information for future policy over those with statistically valid samples since the regulated universe changes over time. Finally, results from broad studies would likely obscure, rather than illuminate, important heterogeneity in deterrence and compliance assessment.

- Specific compliance rates and deterrence metrics should be statistically valid.

  Generating near-census compliance metrics for major facilities is technically possible for those sector/contaminant combinations with relatively complete and accurate self-reported data. Quantitative studies such as Shimshack and Ward [2005], Shimshack and Ward [2007], and Glicksman and Earnhart [2007] used near-censuses. In other instances, randomly selected samples would yield statistically valid results. Qualitative survey results with credible sector-specific random sampling include Oregon DEQ [2004], Gunningham et al. [2005], and May [2005].

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What data currently collected by EPA could be used to measure deterrence?

- OECA should consider utilizing the extensive data already available to the EPA for quantitative compliance and deterrence evaluations.

  Extensive Permit Compliance System water pollution discharges and violations data, Continuous Emissions Monitoring System air pollution discharges and violations data, Toxic Releases Inventory toxics data, RCRA Biennial Reporting System hazardous waste violations data, and Compliance Data System air pollution violations data are available for analysis. In many cases, near-censuses of major facilities can be obtained. See, for example, Shimshack and Ward [2005], Shimshack and Ward [2007], and Glicksman and Earnhart [2007]. Published studies have examined a relatively small number of sectors for few periods, and considerable insight would be gained by further analysis. The studies reviewed in this document, coupled with the technical appendix, should in theory allow replication to new sectors, contaminants, and time periods by statistically trained agency personnel. Note that some quantitative assessment methods use only EPA collected data (see, for example, the first half of Shimshack and Ward [2007]).

- OECA should consider collecting new data from qualitative survey analyses.

  As discussed above, replication and modest extension of existing qualitative studies for new sectors, contaminants, and time periods could importantly contribute to the state of knowledge on deterrence, and general deterrence in particular. All of the collected data would be new, but no additional data beyond the information collected in the survey would be required.

What confounding factors impact deterrence and deterrence assessment?

- OECA should consider important confounding factors when assessing deterrence.

  The literature suggests that plant characteristics like size, industrial sub-category, age, and abatement technology may influence compliance decisions. Similarly, firm characteristics like managerial attitudes, organizational structure, and ownership may influence environmental behavior. Finally, community and customer characteristics may influence compliance choices. Therefore, OECA studies should consider these confounders when analyzing specific and general deterrence. In qualitative settings, this can be done by collecting plant-specific information from respondents and controlling for these covariates when analyzing survey results. In quantitative settings, two possible methods exist. First, panel data techniques can control for factors that don't vary much over time (and most of those listed above are relatively static over multiple year periods). With these techniques, the researcher does not need data on these confounding variables. Earnhart [2004c], Shimshack and Ward [2005], and Shimshack and Ward [2007] demonstrated this approach. Sections A.1 and A.2 of the technical appendix

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briefly discuss such methods for the interested reader. Alternatively, quantitative analyses can include observations on plant, firm, and community characteristics. Some of this data is collected by the EPA, but some is not. This may represent a disadvantage of this particular quantitative approach for OECA replication.

Other recommendations

- If universal compliance rates must be constructed, they should be weighted by priorities.

  As discussed above, universal or even broadly defined compliance rates are not recommended. Examining the relationships between such broad metrics and enforcement and monitoring activities is unlikely to yield statistically valid deterrence assessments. If such metrics are essential for agency reporting to constituents, however, they should be constructed to overweight sector/contaminant combinations that have particularly important environmental benefits. Priorities can be determined, for example, by a panel of internal and external experts that rank sector/contaminant combinations in terms of environmental implications. These rankings can than be used to construct weights for use in developing the broad-based compliance metric.

- As general deterrence importantly motivates environmental compliance, the Agency should consider more vigorously publicizing its actions.

  General deterrence requires that facilities know about monitoring and enforcement actions at other regulated entities (Oregon DEQ [2004], Gunningham et al. [2005], Thorton et al. [2005], Shimshack and Ward [2005], Shimshack and Ward [2007]). Enforcement and compliance alerts are infrequent and highly aggregated, suggesting that plants may not be sufficiently informed of monitoring and enforcement at facilities like theirs. The qualitative general deterrence literature somewhat supports this hypothesis, as many company officials were unaware of sanction details even for high profile cases. See, for example, Thorton et. al [2005] and Gunningham et al. [2005]. Therefore, the agency should perhaps consider pilot programs that release sector-specific monitoring and enforcement details. Modern communications technology suggests that the costs of such information dissemination may be decreasing. Of course, it is possible that facilities actually overestimate their perceived risk of sanction. Therefore, the effects of such pilot programs should be carefully monitored.

- The agency should examine the net social benefits or environmental gains from its current inspection targeting regime.

  Inspection targeting plays an important role in agency behavior, and this is borne out in the specific deterrence literature. See, for example, Helland [1998]. At the industry level, inspection targeting is primarily a function of national priorities. Resource devotion to these priorities, however, significantly cannibalizes

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resources from core monitoring activities. At least for major programs like air, water, and hazardous waste, facility-specific inspection targeting is typically determined by statutory requirements for inspection frequency, suspicion of high environmental discharges due to ambient environmental quality observations, citizen complaints, and offense history.

However, overly compromising random targeting and core programs may induce many facilities that can easily reduce emissions to fail to do so. These entities simply do not expect frequent evaluations since targeting is devoted to priority sectors and previously identified "bad" actors. While targeting priority sectors and bad actors may significantly reduce emissions for this small subset of sources, general deterrence is most effective when randomness across both space and time plays a key role. In other words, randomness may not necessarily achieve large reductions at any given facility, but it is quite likely to induce reductions at a very large number of facilities due to general deterrence. If randomness is part of the targeting process, even facilities that typically comply (or even typically over-comply) may remain especially vigilant since there is some possibility of monitoring in any given period. This conclusion is borne out in the tax literature. See, for example, Andreoni et al. [1998], for a survey.

- OECA or related offices should consider modestly funding new academic research.

As reviewed in the findings section of this document, many conclusions are definitively supported by the existing literature on domestic environmental deterrence. However, many insights could be gained by funding further external research. Studies examining commonly over-looked features of the enforcement process, like enforcement-induced beyond compliance behavior and general deterrence mechanisms, may fill particularly import knowledge gaps.

Important unresolved questions include: (1) How, exactly, do firms learn about regulator reputation and how do they update their threat perceptions? (2) Which factors in the theoretically-postulated causal chain of deterrence most drive compliance behavior? (3) Does the absolute level of enforcement or the number of enforcement actions *per violation* matter more for general deterrence? (4) How do repeat offenders systematically differ from their peers? (5) What do differences between typical facilities and recidivists imply for optimal targeting and sanctioning? (6) How does general deterrence interact with other compliance factors? (7) What does an optimal inspection targeting regime look like for domestic environmental performance?

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Technical Appendix: Methodologies for Quantitatively Assessing Deterrence

A.1 Continuous Self-Reported Data (Emissions)

The particular methodological approach to measuring general and specific deterrence depends on the data generating process. A relatively simple panel-data technique is appropriate for regimes with continuous self-reported emissions data over many facilities and several time periods. For example, water pollution data from the Permit Compliance System, air pollution data from the Continuous Emissions Monitoring System, and toxics data from the Toxic Releases Inventory fit this empirical framework. Here, a measure of continuous emissions like discharges as a percent of the standard is regressed on lagged firm-specific enforcement and monitoring variables, lagged enforcement and monitoring activity at other facilities, seasonality indicators, year indicators, and firm-specific fixed effects. The first regressions in Shimshack and Ward [2007] illustrate the method.

The key methodological issue here is the fixed effects specification. By including a facility-specific constant in the regression model, fixed effects exploit the panel structure of the data. In essence, fixed effects automatically control for all facility-specific factors that do not significantly vary over time. This reduces the data requirements substantially, as common deterrence determinants like industrial classification, industrial sub-category, plant-specific technology, most community characteristics, ownership factors, management style, and geographic conditions do typically change substantively over the medium-run. Many authors have not employed fixed effects because they were specifically interested in assessing the impact of these time invariant factors on compliance. Such determinants, however, are not necessary if the goal is simply to accurately assess the deterrence effects of enforcement and monitoring activities. Other techniques, like random effects, exploit the panel structure of the data as well, but numerous papers have statistically rejected the random effects specification for these purposes. A key additional advantage of the fixed effects model is that it prevents bias from an important type of inspection and enforcement targeting. Specifically, fixed effects remove any bias associated with enforcement or inspection targeting based upon the plant's overall environmental performance.

A.2 Discrete Self-Reported Data (Violations)

The above methodology encounters statistical problems when the dependent variable is limited – ie. when the dependent variable is a discrete 0/1 indicator variable indicating compliance or non-compliance. Water pollution violation data from the Permit Compliance System, air pollution violation data from the Continuous Emissions Monitoring System, hazardous waste violation data from the RCRA Biennial Reporting System, and air pollution violation data from Compliance Data System fit this empirical framework. Here, a discrete measure like a 0/1 violation indicator is regressed in binary probit model on lagged firm-specific enforcement and monitoring variables, lagged enforcement and monitoring activity at other facilities, seasonality indicators, year indicators, state indicators, firm characteristics, and Chamberlain [1980] conditional

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random effects. The regressions in Shimshack and Ward [2005] illustrate the method in practice.

The key methodological issue here is the Chamberlain conditional random effects specification. While standard plant-level fixed effects are desirable, they yield biased estimates in binary models like the probit and are therefore no longer appropriate when the dependent variable is limited. Chamberlain's conditional random effects achieve the same intuitive outcome as fixed effects for monitoring and enforcement variables. Essentially, they remove any bias associated with enforcement or inspection targeting based upon the plant's overall environmental performance. While the theory is beyond the scope of this report, practical implementation amounts to including plant-specific average inspections, plant-specific average enforcement actions, and plant-specific average violations as explanatory variables in the model. Since the model no longer contains facility fixed-effects to account for facility-specific time invariant factors, one must include available plant data. Particularly desirable control variables include industrial classification, industrial sub-category, plant size, and community characteristics.

A.3 An Alternative Specification for Self-Reported Continuous or Discrete Data

Another approach to analyzing the specific and general deterrence effects is illustrated in Gray and Shadbegian's [2005] compliance-enforcement models (Table 5). This is a flexible approach which works for both discrete dependent variables like a 0/1 compliance indictor and continuous variables like discharges as a percent of the standard. Water pollution data from the Permit Compliance System, toxic discharges from the Toxic Releases Inventory, air pollution data from the Continuous Emissions Monitoring System, hazardous waste violation data from the RCRA Biennial Reporting System, and air pollution violation data from the Compliance Data System fit this empirical framework. Here, the dependant variable is regressed on a contemporaneous threat of enforcement, a contemporaneous threat of inspection, lagged firm-specific actual enforcement and monitoring variables, lagged enforcement and monitoring activity at other facilities, seasonality indicators, year indicators, state indicators, and firm characteristics.

The key to this specification is the recovery of the threat variables. The goal of this process is to remove any bias associated with inspection and enforcement targeting. The threat variables are based upon first-stage predictions of facility-specific monitoring and enforcement actions. One first-stage analysis regresses inspections on targeting factors like the time since last inspection, community characteristics, state indicators, and year indicators. First-stage regressions for enforcement actions proceed similarly. Importantly, all first-stage regressions must also include a variable that does not directly belong in the second-stage emissions or compliance regressions. Such a variable can be difficult to identify, but it is necessary for statistical identification. The first stage regressions are used to predict probabilities of enforcement for this plant this period. These predictions are then included directly in the second-stage emissions or compliance regression. Again, since the model does not contain facility fixed-effects to account for

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facility-specific time invariant factors, one must include available facility data in the second stage regressions. Particularly desirable control variables include industrial classification, industrial sub-category, plant size, and community characteristics.

A.4 Discrete Data: Compliance Status Only Observed with Inspections

Unfortunately, none of the above models are appropriate when discrete 0/1 compliance status is only observed in the presence of an inspection. Most RCRA hazardous waste data, and nearly all minor program data, fit this empirical framework. In this context, the relevant information is selectively identified, and simply assessing the impact of enforcement and monitoring actions on observed compliance will yield substantially biased results. The necessary solution is the bivariate probit with selection model, also known as the censored probit model. Here, the dependent 0/1 compliance variable is regressed on lagged firm-specific actual enforcement and monitoring variables, lagged enforcement and monitoring activity at other facilities, seasonality indicators, year indicators, state indicators, and firm characteristics. However, this second stage regression is only conducted after a first-stage regression corrects for selectivity bias. Stafford [2002] illustrates the method in practice.

The key to the censored bivariate probit is the correction for sample selection. Since targeting of inspections occurs, the compliance status among those that are inspected will not represent the compliance status of the underlying population as a whole. Therefore, a correction is necessary so that the measured effect of enforcement on compliance reflects the impact for the entire sample rather than the biased impact for the observed sample. Van de Ven and Van Pragg [1981] develop the theoretical underpinnings of the bivariate probit with selection model, but the details are beyond the scope of this report. Implementation, however, is relatively straightforward with modern statistical packages like STATA™ (where the command is 'heckprob'). The basic intuition is that a first-stage probit on the entire sample (not just inspection/compliance status violations) predicts inspections. A second stage probit uses this prediction to control for sample selection when estimating the desired relationships between compliance and enforcement actions. Importantly, the model allows for correlations between the two-stages as well. A practical concern, similar to the one for the regulatory threat model discussed in Section A.3, is that the first-stage selection regression must include a variable that does not directly belong in the second-stage emissions or compliance regression. Also, the second-stage regression must include a variable that does not directly belong in the first-stage regression. Such variable can be difficult to identify, but they are necessary for statistical identification.

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Table 1:
Studies Comparing Regulatory Factors to Other Compliance Determinants

Author(s)	Outlet	Title	Sector(s)	Key Metric	Methodology	Key Results
Khanna Anton	*Corporate Environmental Strategy* 2002	What is Driving Corporate Environmentalism: Opportunity or Threat?	156 S&P 500 firms across multiple industrial sectors	Firms' adoption of environmental management practices, including environmental staffing, audits, internal policies, TQEM, and public environmental reporting.	Quantitative Analysis	First-order environmental practices like environmental staffing, audits, and internal policies were more motivated by regulatory pressures than other factors. Less significant environmental practices, like TQEM and environmental reporting, were more influenced by market pressures.
Kagan Gunninham Thorton	*Law and Society Review* 2003	Explaining Corporate Environmental Performance: How Does Regulation Matter?	14 pulp and paper mills in AUS, NZ, CAN, WA, and GA	Managers' environmental attitudes and behavior, and self-reported BOD, TSS, and AOX water pollution discharges.	Qualitative Survey / Quantitative Analysis	Regulation is primarily responsible for large environmental gains at pulp and paper facilities over the past 3 decades. However, community pressure is also responsible for observed differences in environmental behavior across facilities.
Doonan Lanoie LaPlante	*Ecological Economics* 2005	Determinants of Environmental Performance in the Canadian Pulp and Paper Industry: An Assessment from Inside the Industry	86 Canadian pulp and paper mills	Managers' environmental attitudes and behavior, as determined by: 1. self-rating of environmental pressures, 2. integration of management strategies, 3. resources devoted to environmental management.	Qualitative Survey	70 percent of managers rated the government as the single most important source of deterrence pressure. The government and the public, but not financial and consumer markets, are the most important determinants of environmental behavior.

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Table 1 Continued:
Studies Comparing Regulatory Factors to Other Compliance Determinants

Author(s)	Outlet	Title	Sector(s)	Key Metric	Methodology	Key Results
Delmas Toffel	*UC Berkeley, Center for Responsible Business, Working Paper* 2005	Institutional Pressures and Environmental Strategies	493 US industrial sources across several sectors that report TRI releases	Firms' adoption of two environmental management practices: the international ISO14001 standard and US voluntary environmental programs.	Qualitative Survey / Quantitative Analysis	The influence of regulators and legislators was the leading institutional pressure affecting firms' environmental performance. Corporate organization structure explains important differences in firms respond to external and internal pressure.
May	*Public Administrative Review* 2005	Regulation and Compliance Motivation: Examining Different Approaches	144 marinas and 61 boatyards in CA and WA	Managers' commitment to address water quality problems, as determined by: 1. presence of best management practices, 2. self-rating of environmental priorities, and 3. self-rating of environmental actions.	Qualitative Survey	Traditional regulation had a considerably stronger influence on managers' deterrence viewpoints than voluntary approaches. The "duality" of deterrent fears and civic obligations motivated compliance more than other factors.

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Table 2: Studies Measuring the Specific Deterrence of Domestic Environmental Monitoring and Enforcement

Author(s)	Outlet(s)	Title(s)	Sector(s)	Key Metric	Methodology	Key Results
Magat Viscusi	*Journal of Law and Economics* 1990	Effectiveness of the EPA's Regulatory Enforcement: The Case of Industrial Effluent Standards	77 major US pulp and paper plants, 1982-1985	Response of BOD discharges and BOD compliance with CWA NPDES permits to EPA/state inspections.	Quantitative Analysis of Permit Compliance System (PCS) database.	Significant specific deterrence from inspections (as a proxy for all enforcement activity). Lagged inspections had statistically significant negative impact on BOD compliance and continuous BOD emissions.
Deily Gray	*Journal of Environmental Economics and Management* 1991	Enforcement of Pollution Regulations in a Declining Industry	49 US steel plants, 1976-1986	Response of plant-closing probabilities to all EPA/state enforcement actions.	Quantitative Analysis of Permit Compliance System (PCS) database.	Significant impacts of enforcement actions. A 12 percent increase in the predicted probability of EPA/state enforcement over the entire sample period increased the likelihood that a plant will close by 1 percent.
Gray Deily	*Journal of Environmental Economics and Management* 1996	Compliance and Enforcement: Air Pollution Regulation in the US Steel Industry	41 US steel plants, 1980-1989	Response of criteria air pollution compliance to EPA/state inspections and aggregate enforcement actions.	Quantitative Analysis of Compliance Data System (CDS) database.	Significant specific deterrence from inspections and enforcement actions. Actual lagged inspections and enforcement actions directly increased criteria air pollution compliance. The predicted threat of inspections and enforcement actions, however, did not influence compliance in a statistically significant fashion.

Table 2 Continued: Studies Measuring the Specific Deterrence of Domestic Environmental Monitoring and Enforcement

Author(s)	Outlet(s)	Title(s)	Sector(s)	Key Metric	Methodology	Key Results
Nadeau	*Journal of Environmental Economics and Management* 1997	EPA Effectiveness at Reducing the Duration of Plant-Level Noncompliance	175 US pulp and paper plants, 1979-1989	Response of time spent in violation of air pollution statutes to EPA/state inspections and enforcement actions.	Quantitative Analysis of Compliance Data System (CDS) database.	Significant specific deterrence from enforcement actions. A 10 percent increase in a plant's predicted threat of enforcement actions resulted in a 4 to 5 percent reduction in the air pollution violation length. The predicted threat of inspections, however, did not influence the duration of noncompliance in a statistically significant fashion.
Earnhart	*Journal of Environmental Economics and Management* 2004 and *Review of Economics and Statistics* 2004	Regulatory Factors Shaping Environmental Performance on Corporate Environmental Performance and Panel Data Analysis of Regulatory Factors Shaping Environmental Performance	40 Kansas wastewater treatment facilities, 1990-1998	Response of BOD discharges to EPA/state inspections and enforcement actions.	Quantitative Analysis of Permit Compliance System (PCS) database, with supplemental data from EPA and Kansas enforcement docket databases.	Significant specific deterrence from imposed inspections and enforcement actions. Actual inspections and enforcement actions were associated with decreased BOD discharges. The predicted threat of inspections and enforcement actions, however, did not consistently influence discharges in a statistically significant fashion.

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Table 2 Continued: Studies Measuring the Specific Deterrence of Domestic Environmental Monitoring and Enforcement

Author(s)	Outlet(s)	Title(s)	Sector(s)	Key Metric	Methodology	Key Results
May	*Public Administrative Review* 2005	Regulation and Compliance Motivation: Examining Different Approaches	144 marinas and 61 boatyards in CA and WA, 2002	Response of managers' deterrence fears to regulator inspections and sanctions.	Qualitative Survey	Significant specific deterrence from inspections. Facilities inspected in the last 5 years had higher deterrent fears than those not inspected. However, past sanctions for water quality violations were not associated with higher deterrence fears.
Gray Shadbegian	*Law and Policy* 2005	When and Why Do Plants Comply? Paper Mills in the 1980s	116 US pulp and paper mills, 1979-1990	Response of air pollution compliance to EPA/state inspections and enforcement activities. They also examined the factors that influence responsiveness to monitoring and enforcement activities.	Quantitative Analysis of Compliance Data System (CDS) database, with substantial firm characteristic data from other sources.	Significant, but heterogeneous, specific deterrence from inspections and enforcement actions. An additional lagged predicted enforcement action or inspections results in an approximately 10 percent increase in air pollution compliance.
Keohane Mansur Voynov	*Yale University Working Paper* 2006	Determinants of Environmental Performance in the Canadian Pulp and Paper Industry: An Assessment from Inside the Industry	249 US electric power plants, 1996-2000	Response of plants' sulfur dioxide emissions and utilization rates to threat and imposition of federal New Source Review lawsuits.	Quantitative Analysis of DOJ and EPA suit databases, with substantial firm characteristic data from other sources.	Significant specific deterrence from NSR lawsuits. The threat of an NSR lawsuit significantly decreased air pollution emissions. Actually levied suits, however, had little effect on firm's air emissions. Findings suggest that firms sought to avert enforcement ahead of time, but actual suits did not contribute to any further improvements in air quality

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Table 2 Continued: Studies Measuring the Specific Deterrence of Domestic Environmental Monitoring and Enforcement

Author(s)	Outlet(s)	Title(s)	Sector(s)	Key Metric	Methodology	Key Results
Glicksman Earnhart	*Stanford Environmental Law Journal* 2007	The Comparative Effectiveness of Government Interventions on Environmental Performance in the Chemical Industry	Qualitative: 267 US chemical plants Quantitative: 499 major US chemical plants, 1995 to 2001	Response of plants' composite BOD and TSS discharges to EPA/state inspections and enforcement actions.	Qualitative Survey / Quantitative Analysis of PCS database.	Significant specific deterrence. 75 percent of survey respondents reported that fines were an effective environmental deterrent and 87 percent reported that inspections were definitely or probably effective ways to induce compliance. In the statistical analysis, both inspections and enforcement actions result in decreased aggregate BOD and TSS emissions.

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Table 3: Studies Measuring the General Deterrence of Domestic Environmental Monitoring and Enforcement

Author(s)	Outlet(s)	Title(s)	Sector(s)	Key Metric	Methodology	Key Results
Thorton Gunningham Kagan	*Law and Policy* 2005	General Deterrence and Corporate Environmental Behavior	233 US firms across 8 industries, sometime between 2001 and 2004	Managers' knowledge of important 'signal cases' of enforcement, and self-reported responses to knowledge of enforcement actions levied against other firms.	Qualitative Survey	Significant general deterrence from enforcement actions. 89 percent of survey respondents could recall some enforcement actions at other firms, and 63 percent reported taking an environmental action in response to learning about such actions at other firms.
Gunningham Thorton Kagan	*Law and Policy* 2005	Motivating Management: Corporate Compliance and Environmental Protection	35 chemical and electroplating companies in WA and OH, sometime between 2001 and 2004	Managers' responses to knowledge of enforcement actions levied against other firms, and managers' interview responses to questions about reasons for environmental performance.	Qualitative Survey	Significant general deterrence from enforcement actions. The overall effect of sustained enforcement actions was important for deterrence. Learning about fines at other facilities focused firms attention on environmental issues or altered their long-run compliance motivations.
Shimshack Ward	*Journal of Environmental Economics and Management* 2005	Regulator Reputation, Enforcement, and Environmental Compliance	217 major US pulp, paper, or paperboard mills, 1990-1996	Response of plants' BOD and TSS compliance decisions to lagged enforcement and monitoring activity.	Quantitative Analysis of Permit Compliance System (PCS) database.	Significant specific and general deterrence from fines. An additional fine induced about a 2/3 reduction in the statewide conventional water pollution violation rate in the year following a fine. Non-monetary enforcement actions, however, had little influence on compliance.

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Table 3 continued: Studies Measuring the General Deterrence of Domestic Environmental Monitoring and Enforcement

Author(s)	Outlet(s)	Title(s)	Sector(s)	Key Metric	Methodology	Key Results
State of Oregon Department of Environmental Quality	State of Oregon Department of Environmental Quality 2004	General Deterrence of Environmental Violation: A Peek into the Mind of the Regulated Public	450 regulated companies in several industries in OR, 2002	Response of managers' self-reported environmental behavior to hearing about inspections and sanctions at other facilites.	Qualitative Survey	Significant specific and general deterrence. Inspections and penalties directly generated an average of 1.6 environmental changes per company. 2.6 additional changes per companies at other facilities after learning of regulatory action. Inspections induced greater deterrence than penalties.
Gray Shadbegian	*Journal of Regional Science* 2007	The Environmental Performance of Polluting Plants: A Spatial Analysis	521 US manufacturing plants, located within 50 miles of 3 major US cities, 1997	Response of toxic and conventional air pollution compliance and emissions to EPA/state inspections and enforcement activities.	Quantitative Analysis of IDEA and Emissions Inventory Databases.	Significant specific and general deterrence. Inspections significantly increased compliance with regulations (but not continuous emissions) for both the inspected plant and for nearby plants. General deterrence restricted to within state borders.
Shimshack Ward	*Journal of Environmental Economics and Management* forthcoming, 2007	Enforcement and Over-Compliance	251 major US pulp, paper, and paperboard mills, 1990-2004	Response of plants' BOD and TSS discharges to lagged enforcement and monitoring activity.	Quantitative Analysis of Permit Compliance System (PCS) database.	Significant general deterrence from fines. Statewide BOD and TSS discharges fell approximately 7 percent in the year following a fine. Most of the reduction was due to plants going further beyond compliance, rather than simply a reduction in violations.