The Effectiveness of Environmental Monitoring and Enforcement: A Review of the Empirical Evidence

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Introduction

Regulatory punishment for pollution violations is a mainstay of nearly every industrialized nation's environmental policy. Moreover, economists and policy-makers generally believe that effective pollution regulations require recurrent inspections and sanctions. Scholars and policy-makers cite enforceable regulations as the dominant factor in dramatic improvements in developed countries' environmental quality over the last three and a half decades (Kagan, Gunningham, and Thornton 2003; U.S. Office of Management and Budget [USOMB] 2005).

Traditional monitoring and enforcement, however, is becoming controversial. Throughout the industrialized world, the policy community increasingly advocates for a move away from conventional regulation and toward voluntary programs and information policies. Many nations' enforcement numbers have declined. For example, U.S. Environmental Protection Agency (EPA) civil enforcements have declined significantly since the 1990s. Many environmental agencies are also increasingly called upon to justify their compliance assurance programs. For example, a recent Office of Management and Budget review of the nation's civil environmental enforcement program assessed EPA performance as merely "adequate" and recommended that the EPA strengthen its enforcement management program (USOMB 2005).

Recent survey evidence suggests that a traditional regulatory structure with rigorous monitoring and enforcement remains the number one motivator for many facilities' environmental compliance decisions. For example, while the survey of S&P 500 firms by Khanna and Anton (2002) indicated that secondary environmental practices like total quality management were

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largely attributable to market factors, more fundamental practices like environmental staffing, audits, and internal policies were attributable to legal and regulatory factors. Doonan, Lanoie, and LaPlante (2005) discovered that 70 percent of Canadian plant managers rated the government as the single most important source of environmental pressure. May (2005) showed that traditional regulation had a considerably stronger influence on managers' deterrence viewpoints than nonmandatory programs. Finally, in the survey of 493 U.S. industrial sources by Delmas and Toffel (2008), respondents indicated that regulators and legislators had a greater influence on environmental performance than community organizations, activist groups, and the media.

Does the quantitative empirical evidence concerning environmental monitoring and enforcement support theoretical economic predictions and the findings from the survey literature? This article addresses this question by reviewing the existing empirical evidence on the impacts of environmental monitoring and enforcement on subsequent pollution discharges and compliance behavior. Our focus is on recent studies that are the most relevant to today's policy environment, although we also discuss insights from particularly notable early papers.[1] Since the literature primarily studies U.S. institutions, our review focuses mainly on the effects of EPA and U.S. state-level activities.

Our discussion is organized as follows. We first provide some background and context by describing the U.S. regulatory setting as well as trends in enforcement indicators. This is followed by a brief discussion of the economic theory concerning environmental enforcement. We next examine the recent empirical evidence linking regulator actions to environmental compliance and pollutant emissions. The article concludes with a discussion of policy implications and directions for future research.

Background and Context

To help illustrate the issues concerning environmental monitoring and enforcement in the United States, this section presents some institutional context. U.S. environmental monitoring and enforcement occurs in a decentralized setting with federal oversight.[2] The overall regulatory structure is provided by the U.S. Code of Federal Regulations and the EPA. However, many permitting, inspection, and sanction activities are conducted by state-level regulatory agencies to which such authority has been delegated. In some cases, EPA regional offices may directly oversee specific facilities, typically because states have declined regulatory responsibility.[3]

[1]Readers interested in syntheses of earlier work should consult Cohen's (1999) literature review or the EPA Compliance Information Project's (1999) Literature Summaries. This latter report is available at http://www.epa.gov/compliance/resources/reports/compliance/research/index.html, EPA-300B07001.

[2]As noted in the introduction, since most of the empirical literature examines U.S. institutions, we focus here on U.S. institutions. However, this regulatory setting is broadly similar to those in many other developed countries.

[3]Primary oversight responsibility, or "primacy," varies by pollution medium and statute. For core programs of the Clean Water Act, nearly all states have primacy. For core programs of the Clean Air Act (e.g., Title IV and Title V), all states and even some local authorities have primacy. All states except Wyoming have primacy for the Safe Drinking Water Act; the Federal Insecticide, Fungicide, and Rodenticide Act; and several other major acts. EPA more frequently maintains primary permitting and enforcement authority under newer or higher priority environmental statutes.

Monitoring Activities and Strategies

Major facilities regulated under high-profile environmental laws such as the Clean Air Act (CAA), the Clean Water Act (CWA), and the Environmental Planning and Community Right-to-Know Act (EPCRA) are required to file regular self-monitoring reports, which are the primary sources of information on compliance and emissions. Since self-reported violations tend to be treated with administrative penalties, while deliberate falsification of reports can result in significant criminal prosecutions of both employees and managers, researchers generally consider facility self-reports to be truthful. On-site state or EPA inspections help ensure the accuracy of self-reports and verify the maintenance and operation of abatement equipment. For smaller facilities and less prominent regulations, compliance and emissions data are observed only during regulatory inspections.

Regulator monitoring activities, formally called evaluations in the CAA context and inspections under other statutes, consist of facility visits. Nearly all monitoring activities are media or statute specific, but more comprehensive multiple-media investigations are permissible under the law. Monitoring activities range from quick visual inspections lasting a few hours to rigorous evaluations lasting one month or more. Many inspections include examinations of emissions as well as evaluations of abatement equipment installation, operation, and maintenance. Other regulator monitoring activities may include reviews of self-reporting records and procedures, extensive interviews, and regulator sampling of pollution emissions.

Current EPA compliance monitoring strategies recommend that major CAA stationary sources receive a full compliance evaluation at least once every two years and that minor CAA sources that emit more than 80 percent of the threshold for classification as a major source receive a full compliance evaluation at least once every five years (U.S. Environmental Protection Agency [USEPA] 2001a). Concerning the CWA, current EPA compliance monitoring strategies recommend that major CWA sources receive a comprehensive inspection at least once every two years and that minor CWA sources receive an inspection at least once every five years (USEPA 2007). However, these are merely targets for the frequency of compliance monitoring; they are not legally binding requirements.

Enforcement Actions and Stringency

Enforcement actions for violations range from telephone and letter warnings to fines and criminal prosecutions. Informal enforcement actions are typically levied by local authorities. While a few state environmental agencies have the authority to issue small on-site administrative penalties akin to traffic tickets, fines and other formal sanctions are typically imposed by the administrative law judges that comprise state or regional EPA administrative courts. Significant appeals or atypical violations may be referred to centralized EPA administrative courts or to the Washington, DC-based independent Environmental Appeals Board. Some especially serious violations or high-level appeals may be referred to states' attorneys general and the federal Department of Justice for civil prosecution. Criminal referrals are also possible, although such action is most often reserved for cases involving deliberate efforts to operate outside the regulatory environment, deliberately deceptive behavior such as record falsification, or cases causing unusual harm to human health (Uhlmann 2010).

The EPA establishes legal guidelines, on a statute-by-statute basis, for enforcement stringency. In general, these guidelines state that sanction severity should increase with the duration and extent of noncompliance. Significant or unresolved violations are supposed to receive a formal enforcement response, typically including a formal Notice of Violation detailing the infringement and an administrative order officially requiring a return to compliance.[4] Once a violation rises to the level of a financial penalty, guidelines dictate that the magnitude of the fine should be a function of (1) the economic benefit to the facility that results from the violation; (2) the seriousness of the violation and the magnitude of its potential harm to human health or the environment; (3) the facility's ability to pay; (4) the company's compliance and enforcement history; (5) fairness and consistency; and (6) discretionary adjustments (USEPA 2001b). When judicial actions are considered, the guidelines add matters of willfulness and court victory probabilities to the punishment principles described above (USEPA 1989). Note, however, that the guidelines give strong priority to administrative penalties over civil and criminal referrals since resource considerations generally suggest levying the minimum penalty necessary to achieve a given compliance objective.

Scale and Scope of Oversight

Estimates suggest that the EPA and delegated states are responsible for overseeing more than forty-one million entities regulated under fifty-eight programs from fourteen key environmental statutes. Much of the oversight is directed toward approximately twenty-four thousand CAA major facilities; twenty thousand CAA synthetic minor facilities;[5] seven thousand CWA major facilities; two thousand Resource Conservation and Recovery Act (RCRA) hazardous waste treatment, storage, or disposal facilities; and thirty thousand RCRA large-quantity hazardous waste generators. According to the EPA's Office of Inspector General, the agency has limited knowledge of the precise size of the regulated universe and how that size has changed over time (USEPA 2005). However, a comparison of the EPA's "2001 Regulatory Universe Identification Table" numbers with recent numbers from the agency's enforcement and compliance databases suggests that over the past decade the number of active permits for CAA major facilities decreased, the number of active permits for CAA synthetic minor facilities increased, the number of active permits for CWA major facilities increased, and the number of active permits for major RCRA facilities decreased.

Trends in Enforcement Indicators

This section presents several estimates of environmental enforcement in the United States. All estimates are based on the content of EPA databases.

Budgets and Staffing Levels

Given the scale and scope of environmental enforcement, it is not surprising that the United States, as well as other industrialized nations, has devoted substantial resources to this issue.

[4]Technical definitions of "significant" violations are complex and vary by statute.
[5]Synthetic "minors" are midsize facilities that have the potential to emit above the threshold required to achieve "major" status but have agreed to emit below that threshold.

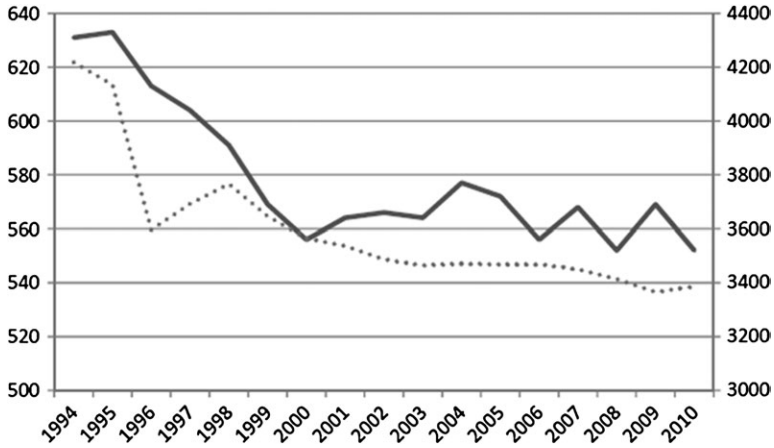

Figure 1 EPA enforcement: real budgets and full-time equivalents (FTEs), 1994–2010. Data from EPA budgets by fiscal year. The solid line represents budget allotments for Office of Enforcement and Compliance Assurance (OECA) activities, measured in millions of U.S. dollars along the left-side *y*-axis. The dotted line represents staffing levels for OECA activities, measured in FTEs along the right-side *y*-axis.

Prior to 1994, EPA monitoring and enforcement was decentralized, so reliable budget information for this time period is unavailable. Between 1994 and 2010, real EPA operating enforcement budgets averaged $580 million, not including state expenditures. However, as shown in Figure 1, both real EPA enforcement budgets and the agency's Office of Enforcement and Compliance Assurance staffing levels (in full-time equivalents) have declined over time.

Number of Inspections

The number of federal and regional EPA inspections fell rapidly in the early 1990s, from about twenty thousand to fifteen thousand inspections, but had rebounded back above twenty thousand by 1997. As shown in Table 1, federal and regional EPA inspection numbers declined in the early 2000s but have generally trended upward in the last several years.

Administrative Actions

Administrative actions, ranging from warnings to notices of violation and fines, represent the bulk of EPA penalty activity. Historical data suggest that the number of federal and regional EPA administrative actions peaked in the early 1990s before stabilizing at around three thousand actions during the late 1990s. Table 2 summarizes EPA formal administrative actions

Table 1 Number of federal and regional EPA inspections: 1998–2008

1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
23,200	21,800	20,400	17,600	17,700	18,900	21,000	21,000	23,000	22,000	20,000

Notes: Data from EPA annual results for compliance assurance and enforcement activity. Available at http://www.epa.gov/compliance/data/results/annual/index.html. Older data available at http://epa.gov/oecaerth/resources/reports/endofyear/eoy2002/mosfy2002ceaenfactivity.pdf. Many state inspections are not included here, so these numbers understate overall regulator monitoring activity at any given point in time. In addition, comprehensive data on the average rigor of inspections over time are not readily available.

Table 2 Number of federal and regional EPA formal administrative actions: 2001–2008

	2001	2002	2003	2004	2005	2006	2007	2008
All actions	2,702	2,434	2,599	2,936	2,660	4,944[a]	2,550	2,368
Subset with fines	1,422	1,366	1,585	2,008	2,106	4,566[a]	2,179	1,984
Median fine (when assessed)	$5,000	$3,600	$3,500	$3,100	$3,000	$500	$1,900	$2,300
CAA actions	358	309	285	344	517	3,050[a]	687	494
Subset with fines	172	152	151	245	444	3,007[a]	666	471
Median fine (when assessed)	$10,000	$10,300	$4,100	$3,000	$2,000	$500	$800	$1,500
CERCLA actions	151	138	131	120	98	95	82	57
Subset with fines	23	29	25	29	25	34	35	27
Median fine (when assessed)	$3,000	$4,800	$8,900	$6,000	$9,000	$10,800	$5,700	$11,200
CWA actions	685	891	830	888	946	664	613	601
Subset with fines	376	495	553	675	763	577	511	489
Median fine (when assessed)	$3,000	$2,000	$2,100	$2,000	$3,000	$3,500	$3,000	$3,000
EPCRA actions	460	207	256	308	183	168	170	155
Subset with fines	312	151	201	283	146	146	164	127
Median fine (when assessed)	$5,000	$10,000	$9,300	$5,000	$11,000	$10,600	$10,100	$11,800
RCRA actions	230	268	225	390	389	412	418	447
Subset with fines	188	211	176	360	366	399	399	427
Median fine (when assessed)	$5,800	$1,900	$6,900	$600	$500	$500	$500	$500
TSCA actions	169	185	254	269	184	186	204	209
Subset with fines	137	166	224	240	157	161	176	168
Median fine (when assessed)	$5,500	$3,300	$1,800	$2,900	$3,100	$4,600	$4,000	$3,300

Notes: Data from EPA Enforcement and Compliance History Online (ECHO) database. Available at http://www.epa-echo.gov/echo/. Informal sanctions, as well as many state administrative actions, are not included in the table. Thus the numbers in the table understate activity at any given point in time and are therefore better used to assess trends rather than total enforcement activity. CAA - Clean Air Act; CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act; CWA - Clean Water Act; EPCRA - Emergency Planning and Community Right to Know Act; RCRA - Resource Conservation and Recovery Act; TSCA - Toxic Substances Control Act.

[a]Many administrative penalties in 2006 were for multiprogram violations that are listed in the data source under CAA violations.

since that time. The 2006 spike in formal administrative actions represents a unique, one-time enforcement initiative targeting animal feeding operations. Approximately fifty percent of 2006 enforcement actions were levied under this initiative.

Even ignoring the spike in 2006, the number of administrative actions accompanied by monetary penalties has trended upward overall. This is especially true for violations under the CAA and the RCRA. The magnitude of levied administrative penalties (i.e., the size of the fines), however, has declined overall, especially for CAA and RCRA violations. The vast majority of penalties remain modest. Median administrative penalties for the period 2001–2008 were approximately $550 for CAA violations; $7,850 for Comprehensive Environmental Response, Compensation, and Liability (also known as Superfund) violations; $3,000 for CWA violations; $7,200 for EPCRA violations; $600 for RCRA violations; and $3,600 for Toxic Substances Control Act violations.

Table 3 Civil Judicial Cases: 1998–2008

Year	Number of referrals to Department of Justice	Total penalties (in million 2009 U.S. dollars)	Approximate median penalty (when assessed, in nominal U.S. dollars)
1998	411	$83.6	No data
1999	403	$182.4	No data
2000	368	$68.7	No data
2001	327	$123.3	$200,000
2002	342	$76.3	$225,000
2003	268	$84.3	$155,000
2004	265	$138.3	$163,000
2005	259	$140.6	$154,000
2006	286	$87.2	$165,000
2007	278	$41.4	$333,000
2008	280	$88.1	$177,000

Notes: Referrals data from EPA annual results for compliance assurance and enforcement activity. Available at http://www.epa.gov/compliance/data/results/annual/index.html. Older data available at http://epa.gov/oecaerth/resources/reports/endofyear/eoy2002/mosfy2002ceaenfactivity.pdf. Total penalty data from Office of Enforcement and Compliance Assurance National Enforcement Trends. Median penalty data from EPA ECHO database. Available at http://www.epa-echo.gov/echo/.

Judicial Cases

Tables 3 and 4 present recent data on civil and criminal judicial cases. Relative to the number of formal administrative actions, especially when state actions not included in Table 2 are considered, the number of judicial cases is small. Penalties are often large, however, and criminal cases frequently include jail time. Table 3 shows that since the late 1990s, there has been a significant downward trend in the number of referrals to the Department of Justice for civil environmental cases. Total and median civil penalties exhibit no obvious trend over time. Table 4 shows that environmental criminal prosecutions, sentences, and fines experienced a peak in the late 1990s but have declined since.

Overall Trends and Themes

The summary statistics in the above figure and tables demonstrate substantial variability in environmental monitoring and enforcement across time. An additional theme is variability across state authorities, as inspection frequencies, sanction probabilities, and fine distributions differ substantially across states.[6] Cross-state differences in company and industry composition imply that federal compliance monitoring strategies and enforcement management guidelines are not precise rules in practice. Furthermore, regulatory agencies are influenced by budget allocations, local economic conditions (Deily and Gray 1991), pressures from local interest groups (Peltzman 1976), and local political pressures (Kleit, Pierce, and Hill 1998).

[6]Ideally we would provide statistical summaries of this heterogeneity. However, data quality and space constraints prevent us from doing so. Furthermore, simple summary statistics on cross-state monitoring and enforcement activity per facility or per violation can be misleading due to differences in industrial composition, violation definition, and other confounders.

Table 4 Criminal judicial cases: 1994–2008

Year	Cases initiated	Sentences (in years)	Fines (in million 2009 U.S. dollars)
1994	525	99	$53.4
1995	562	74	$32.8
1996	548	93	$105.3
1997	551	195.9	$226.5
1998	636	172.9	$122.1
1999	471	208.3	$79.5
2000	477	146.2	$152.7
2001	482	212	$114.9
2002	484	215.2	$74.4
2003	471	146.2	$82.9
2004	425	77.3	$53.6
2005	372	186	$110.5
2006	305	154	$45.8
2007	340	64	$65.6
2008	319	57	$63.3

Notes: Data from the EPA's Office of Enforcement and Compliance Assurance and Office of Criminal Enforcement, Forensics, and Training Annual Reports and National Enforcement Trends.

An Economic Approach to Evaluating Environmental Monitoring and Enforcement

Before considering the empirical evidence on plant responses to environmental monitoring and enforcement, it is useful to review the economic theory concerning enforcement. This theory is broadly based on the public enforcement of law literature initially developed by Becker (1968) and Stigler (1970); adapted to an environmental context by Russell, Harrington, and Vaughan (1986); and reviewed by Polinsky and Shavell (2000). In this framework, a plant that may imperfectly control emissions gains some economic benefit from a lower pollution abatement effort. The plant weighs the benefits of a lower abatement effort against the potential costs from regulatory punishment if it is caught in noncompliance. This trade off implies that the plant's choice concerning its pollution abatement effort will be a function of (1) its perceived probability of a violation given its chosen abatement effort; (2) its perceived probability of detection by the regulator if it violates; (3) its perceived probability of a penalty if a violation is detected; and (4) its perceptions about the likely magnitude of the penalty if it is levied.[7]

Enforcement Models

Empirical enforcement models measure deterrence, that is, the tendency for a plant's compliance status or pollution emissions to respond to enforcement activity. Nearly all studies use

[7]The theoretical literature on enforcement includes more sophisticated game-theoretic models of interactions between regulators and firms. See, for example, Landsberger and Meilijson (1982), Harrington (1988), and Polinsky and Shavell (1998). These theories, however, focus more on regulator behavior than on plant responses to regulation and have therefore not served as the basis for the empirical papers reviewed here.

observational data on enforcement actions and compliance status and/or pollution emissions for many facilities over many months or years. The basic statistical strategy is to use regression models to examine relationships between a compliance indicator or a continuous pollution measure and (1) the plant's perceived probability of an inspection or sanction (or both) at a given point in time; (2) inspection and compliance actions directed toward the plant in the recent past; and (3) control variables. If a plant perceives an increase in the probability of an inspection, the probability of a sanction, and/or the severity of the sanction, the models predict that compliance will increase and pollution will decrease due to the enhanced regulatory threat. If a plant observes that it has experienced more inspections or enforcement actions in the recent past, then compliance actions are hypothesized to increase and pollution actions are hypothesized to decrease for two reasons. First, such actions may cause the plant to identify easily correctable maintenance problems or process modifications that reduce pollution. Second, such actions may raise the plant's perceived probability of future inspections and enforcement actions.

Measurement Challenges

Three challenges commonly arise when empirically measuring the deterrence effects of environmental monitoring and enforcement: omitted variable bias, difficulties in measuring perceptions, and reverse causality. The issue of omitted variable bias can arise if factors not included in the model simultaneously influence both regulatory activity and plant-level compliance. For example, communities sensitive to environmental concerns may pressure regulators to monitor and enforce frequently. Such communities may also directly pressure plants to comply. If community factors are excluded from the model, then any measured positive statistical relationship between enforcement activity and compliance rates may overstate the true deterrence effect since the measured relationship would also include the direct effects of community pressures on compliance. To minimize the omitted variable difficulty, some studies (e.g., Gray and Deily 1996; Earnhart 2004b; Gray and Shadbegian 2005, 2007) include extensive plant characteristics, firm characteristics, community characteristics, and economic conditions assembled from other data sources. Other studies (e.g., Earnhart 2004a; Shimshack and Ward 2005, 2008) employ statistical techniques designed to correct for the impact of such factors.

The issues of measuring perceptions and reverse causality are more difficult to address. The first issue arises because plants' perceptions about the likelihood of inspections and enforcement are not observable to researchers. The second issue arises through regulator targeting of plants. Because plants with more frequent noncompliance are often targeted for more frequent inspections and enforcement actions, simple statistical associations often show a negative correlation between enforcement and compliance. This result mistakenly suggests that inspections and enforcement actions are counterproductive and that the best way to improve a violating plant's behavior is actually to stop inspecting or sanctioning it.

To address the complications associated with measuring perceptions and reverse causality, some empirical studies use one or more of the following three approaches. First, some studies (especially early studies) examine the relationships between current environmental performance and lagged values of a plant's monitoring and enforcement actions, rather than the relationships between current environmental performance and current values of inspections

and sanctions (e.g., Magat and Viscusi 1990). The use of lags mitigates some reverse causality concerns. That is, while it is likely that current noncompliance induces regulator actions now or in future years, it seems unlikely that current noncompliance could "cause" regulator actions to occur in prior years. Lagged monitoring and enforcement variables also partially address the issue of measuring perceptions. If a plant's perceptions about the probability of receiving an inspection or sanction are largely a function of its own direct experience with the regulator, then lagged regulator actions may effectively "stand in" for the plant's "threat" perceptions. A potential disadvantage of the lagged variable approach is that the conditions that contributed to the plant's compliance decision in the past may persist over time. If this is the case, then current compliance could be closely associated with lagged compliance, which again raises the issue of reverse causality.

An alternative approach to addressing the issues of measuring perceptions and reverse causality is the use of proxy variables. Here, empirical models of deterrence include observable characteristics other than lagged inspections or enforcement at the plant to stand in for plant perceptions about regulatory stringency and expected sanctions. Some studies (Alberini and Austin 1999, 2002; Stafford 2002, 2003; Sigman 2009) examine plant compliance responses to exogenous legal mandates affecting inspection frequency or penalty magnitudes. Other studies (e.g., Shimshack and Ward 2005, 2008) examine plant responses to lagged inspections and enforcement actions directed toward *other* plants regulated by the same authority (typically the state agency). The key assumption in these latter studies is that plants learn about the probability of monitoring or sanctions by observing the regulator's recent history at other plants.[8]

The final approach to addressing the issues of measuring perceptions and reverse causality is the predicted probability method. These studies (e.g., Deily and Gray 1991; Gray and Deily 1996; Laplante and Rilstone 1996; Earnhart 2004a, 2004b; Keohane, Mansur, and Voynov 2009; Langpap and Shimshack 2010) statistically predict a given plant's probability of an inspection or enforcement action in a given time period, much like a facility itself might do. Inspection or sanction predictions are based on observed factors like time since last inspection, community characteristics, lagged enforcement and monitoring actions directed toward the facility, facility characteristics, firm characteristics, state indicators, and year indicators. In some cases, lagged enforcement actions throughout the state are also included in the prediction regressions. Researchers then explore relationships between compliance and statistical predictions of inspections and sanctions, rather than actual inspections or sanctions.[9]

Empirical Evidence on Deterrence Effects

This section reviews the empirical evidence on the deterrence effects of monitoring and enforcement. We first examine evidence concerning air pollution, water pollution, and toxic and

[8]The proxy variable approach is equivalent to running a just-identified reduced form version of a deterrence model with the proxy as an instrument. Advantages include limited statistical structure, limited bias in the presence of weak instruments, and transparent exclusion restrictions. Furthermore, reduced form coefficients are often of direct economic and policy interest.

[9]The predicted probability method is equivalent to a two-stage least squares implementation of instrumental variables. Advantages include direct mapping to a structural economic model of deterrence and the statistical power associated with parametric structure.

hazardous waste. This is followed by an examination of insights from the closely related literature on occupational safety and health.

Deterrence Impacts of the CAA

Empirical studies on the deterrence impacts of CAA monitoring and enforcement actions have consistently found that recent regulator activity influences air pollution compliance. For example, Gray and Deily (1996) and Deily and Gray (2007) examined enforcement and compliance data for forty-one large steel mills between 1976 and 1989, a period of rapid decline in the U.S. steel industry. The 1996 study analyzed the impact of enforcement actions on compliance with air pollution regulations, while the 2007 study performed a joint analysis of enforcement and compliance with environmental and worker health and safety regulations. Both studies detected a statistically significant and large impact of regulatory activity (either inspections or other enforcement actions) when a lagged measure of regulatory activity (an indicator variable for whether or not the plant had any activity in the prior two years) was used. The 2007 study found that being the target of any EPA enforcement activity in the prior two years increased the probability of a plant's being in compliance by about thirty-two to thirty-three percent relative to those plants that had not been the targets of any enforcement activity. This effect is larger than in most other studies, but it is important to note that the overall compliance rate in the data sample was only thirty-eight percent.

Gray and Shadbegian (2005) examined air pollution compliance responses to EPA/state inspections and enforcement actions for 116 pulp and paper mills for the period 1979–1990. Their results indicated that plants increased their compliance rates by approximately ten percent in response to a typical regulatory action. This result held roughly equally for inspections and enforcement instruments. Additionally, the authors found that enforcement responses varied across plants. For example, pulp mills were less sensitive to inspections than paper mills. Plants owned by larger parent companies were less sensitive to inspections but more sensitive to enforcement actions.

Rather than focusing on compliance rates, Nadeau (1997) found that EPA regulatory activity can also affect the duration of a plant's noncompliance periods. Using data on air pollution compliance at 175 U.S. pulp and paper plants from 1979 to 1989, Nadeau tested whether the number of quarters a plant was in violation of air pollution statutes was related to the amount of regulatory activity it faced. The study distinguished between monitoring activity (inspections and emissions tests) and enforcement activity (administrative, civil, judicial, and penalty actions). A ten-percent increase in a plant's predicted threat of enforcement actions was associated with a four- to five-percent reduction in the duration of the violation. The results for predicted inspection activity, however, were largely insignificant, with a ten-percent increase in a plant's predicted threat of inspections being associated with a zero- to four-percent reduction in the duration of noncompliance.

For most industrial facilities, air pollution compliance is systematically observable to researchers, but pollution emissions are not. However, in a study of electric utility facilities for which emissions data were available, Keohane, Mansur, and Voynov (2009) demonstrated that the impacts of enforcement on air emissions can be significant. This study is also unusual because it examined the effects of litigation by regulators, rather than administrative enforcement. The authors reviewed the responses of 249 coal-fired power plants to the threat of being

included in EPA lawsuits alleging violation of New Source Review regulations and found that plants that faced a one-standard-deviation-higher predicted probability of a lawsuit reduced their sulfur dioxide emissions by ten percent relative to plants facing a lower predicted probability of being sued. However, the authors also found that the forty-six plants that were eventually sued experienced no further pollution reductions, suggesting that plants responded more to the threat of lawsuits than to the lawsuits themselves.

Deterrence Impacts of the CWA

Empirical studies of the deterrence impacts of CWA monitoring and enforcement actions have found that regulator activity influences water pollution discharges and compliance. Magat and Viscusi (1990) explored the impact of EPA inspections on conventional water pollution compliance at seventy-seven pulp and paper mills for the period 1982–1985. They found that a given facility's probability of noncompliance was about twice as high if the facility had not been inspected in the previous quarter (the overall compliance rate in their sample was seventy-five percent). The impacts on pollution discharges were also large; on average, an inspection reduced a facility's subsequent conventional water pollution discharges by approximately twenty percent.

Earnhart (2004a, 2004b) examined conventional water pollution discharges for forty Kansas wastewater treatment plants, and Glicksman and Earnhart (2007) studied similar data for four hundred chemical facilities.[10] All three studies found that enforcement actions, especially monetary fines, consistently reduced relative discharges. They also collectively concluded that deterrence effects varied by regulator type, with federal inspections and sanctions deterring more violations on average than similar state actions.

Shimshack and Ward (2005) analyzed the compliance responses of 217 pulp and paper mills to fines and other regulatory actions for the period 1988–1996. They found that an additional fine induced about a two-thirds reduction in the statewide water pollution violation rate in the year following the fine. Nonmonetary sanctions had no noticeable impact on compliance, and an additional fine induced substantially greater compliance than an additional inspection. In a related study of 251 pulp and paper mills that examined "relative discharges" rather than compliance status for the 1990–2004 period, Shimshack and Ward (2008) also found significant deterrence effects of enforcement. In this case, statewide conventional water pollution discharges fell by approximately seven percent in the year following a fine being imposed at any plant in the state.

In contrast to the other studies reviewed here, Langpap and Shimshack (2010) explored the impacts of private, rather than public, enforcement actions. They investigated the deterrence effects of private citizen suits, as well as the extent to which private citizen suits crowd out, or crowd in, public monitoring and public enforcement. They found that private enforcement actions significantly enhanced environmental compliance but that direct deterrence effects were significantly weakened by the net crowding out of public enforcement.

[10]These studies did not examine compliance status directly (the overall compliance rate in the sample was 95 percent). Rather, they focused on the "relative discharges" at the plants (i.e., the actual levels of discharges divided by the permitted levels).

Hazardous and Toxic Waste

The literature also suggests that monitoring and enforcement can significantly influence hazardous waste emissions and compliance. Stafford (2002, 2003) analyzed a large sample of more than eight thousand, four hundred facilities regulated under the RCRA. The 2002 study found that a federally mandated rule change that increased possible financial penalties for noncompliance ten- to twentyfold resulted in an approximately fifteen percent reduction in plants' violation probabilities. The 2003 study showed that strict liability rules, state environmental spending, and allocating a higher percentage of employees to regional offices decreased pollution-related violations. However, the study found that these activities also increased record-keeping violations. Several interpretations are possible, but this latter result may suggest that penalties decrease plants' incentives to report completely and accurately.

Other studies have found that increased threats of lawsuits have affected toxic waste discharges and hazardous industrial site cleanup. Alberini and Austin (1999, 2002) explored the response of toxic waste discharges to differences in the liability laws imposed on polluters. The 1999 study found that the impacts of manufacturing activities on the number of spills for some chemicals varied by legal regime, suggesting that enhanced legal threats encouraged firms to handle some toxic materials more carefully. The 2002 study also found that strict liability rules were associated with reductions in the severity and frequency of toxic releases but that the effects varied by firm size. Sigman (2009) found that especially stringent liability laws can have far-reaching consequences. Laws that raised the threat of lawsuits for developers of contaminated former industrial sites increased vacancy rates and reduced industrial land prices in central cities.

Occupational Safety and Health

Experience in other regulatory areas also provides some insights into the nature of deterrence effects. In particular, several studies have examined the deterrence impacts of workplace regulatory activity by the Occupational Safety and Health Administration (OSHA), looking at both the frequency of inspections and the magnitudes of the penalties imposed. One finding (beyond the significant overall impact of OSHA inspections on the number of workplace injuries) is that inspections that do not impose any penalty seem to have little or no deterrence effect (Gray and Scholz 1993; Gray and Mendeloff 2005). If anything, an inspection without a penalty seemed to signal that "business as usual" was sufficient, resulting in worsening injury performance in the years following the nonpenalty inspection.

OSHA-related research also finds considerable variation in the deterrence effects of regulatory activity, which depends on the characteristics of both the plant being inspected and the inspection itself. For example, smaller and nonunionized plants tend to be more responsive to OSHA inspections (Gray and Mendeloff 2005). Inspections that arise from worker complaints have deterrence effects that are not greatly affected by whether a penalty was imposed, unlike inspections that are randomly assigned by OSHA, which show a bigger impact for penalty inspections (Scholz and Gray 1997). Finally, repeated inspections of the same facility appear to result in some reductions in workplace hazards, but the largest impacts come from the plant's first inspection, suggesting a diminishing benefit from multiple inspections of the same plant over time (Gray and Jones 1991).

General versus Specific Deterrence

The studies discussed above have examined the empirical magnitudes of deterrence and, in some cases, assessed differences in deterrence across plants and regulatory instruments. Several recent studies have explored the *mechanisms* underlying environmental deterrence. In particular, recent studies have emphasized the distinctions between specific and general deterrence. Specific deterrence refers to the extent to which regulatory actions deter subsequent violations at the inspected or sanctioned facility. General deterrence refers to the extent to which regulatory actions aimed at one facility generate spillover effects that impact the environmental performance at other facilities.[11]

Shimshack and Ward (2005) provided early evidence on the regulator reputation-building effects of general deterrence. They found that a fine on one plant strongly influenced other plants' beliefs about the regulator's toughness, thus magnifying the impact of any given fine. They observed a two-thirds reduction in the statewide water pollution violation rate in the year following a fine, and they found that nearly all of this deterrence effect was attributable to general deterrence. The average spillover effect of a fine on other plants in the same state and industry was almost as strong as the impact on the sanctioned facility itself.

In a study of air pollution compliance for 521 U.S. manufacturing plants, Gray and Shadbegian (2007) took the analysis of general deterrence further by incorporating information on the exact location of each plant. They found that inspections at one plant tended to increase compliance at both the inspected facility and nearby facilities. They also found that general deterrence effects were restricted by state boundaries. That is, inspections at plants that were nearby, but located in a different state, did not increase compliance. These results suggest that jurisdictional boundaries may be important determinants of the "reach" of the regulator reputation effect that underlies general deterrence.

Enforcement and Overcompliance

Economists generally view enforcement as a tool to secure compliance with regulations. Thus, the interpretation of the effects of monitoring and enforcement that are found in the literature would appear to be that pollution reductions are achieved when plants have reduced emissions to the legal threshold. However, Shimshack and Ward (2008) demonstrated that EPA enforcement actions not only reduced pollution by decreasing violations but also significantly increased overcompliance. They found that when regulators issued fines to other plants, plants with discharges that were typically below legally permitted levels were induced to go further beyond compliance. They also found that noncompliant plants often responded to sanctions on other facilities by reducing their discharges well below the levels required for compliance. Shimshack and Ward (2008) further demonstrated that this behavior can be economically rational when plants have stochastic discharges or jointly produced multiple pollutants. That is, in periods of high-perceived regulator stringency, plants may lower their

[11]Some authors (e.g., Earnhart 2004a, 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. In this article, however, all facility-specific responses to monitoring and enforcement are considered to be specific deterrence, and only impacts on facilities other than the sanctioned facility are considered to be general deterrence.

target discharges below allowable levels to reduce the risk of accidental violation and to reduce the risk of violation for a jointly produced pollutant. Overall, the authors found that most of the large measured impact of fines on pollution discharges was due to plants going beyond compliance, rather than plants in violation seeking to come into compliance.

Policy Implications and Research Needs

Three conclusions can be drawn from this review of the literature on environmental monitoring and enforcement. First, environmental monitoring and enforcement activities generate substantial specific deterrence, as targeted facilities increase compliance and reduce emissions for several periods following regulator actions. Second, environmental monitoring and enforcement generates substantial general deterrence, with monitoring and enforcement activity spilling over to increase compliance and reduce emissions at other facilities in the regulatory jurisdiction. Third, monitoring and enforcement not only improves compliance but also encourages greater pollution reductions at plants that are already in compliance.

Policy Implications

What do these findings imply for economics and policy? First, the literature consistently finds that there are large deterrence effects from environmental regulations that have "teeth."[12] That is, a large amount of the observed variation in environmental performance can be attributed to the traditional economic incentives resulting from monitoring and enforcement actions, rather than to corporate social responsibility, altruism, or nonregulatory pressures. This suggests that significant increases in environmental quality might be achieved through small incremental investments in environmental monitoring and enforcement. If current standards are not overly stringent and enforcement costs are moderate, the resulting enforcement-induced changes in plant behavior may translate into large social welfare gains.

A related, but somewhat less definitive, implication of the literature is that current incremental environmental compliance costs may be small, at least for the pollutants and large facilities commonly studied in the literature. Sanctions, especially fines, are infrequent relative to the number of violations, and levied fines tend to be small relative to penalties allowable under the law. Yet, the marginal penalty appears to spur large and rapid changes in environmental performance. This suggests that plants may devote more attention to equipment maintenance and operational efficiency, spill avoidance, and employee training after regulator actions and during periods of high-perceived regulatory scrutiny.[13] These activities do not

[12]For example, Magat and Viscusi (1990) found that an average inspection was associated with a subsequent 20-percent reduction in the inspected plant's conventional water pollution discharges, Gray and Shadbegian (2005) found that an average sanction was associated with a subsequent 10-percent reduction in the sanctioned plant's probability of CAA noncompliance, and Shimshack and Ward (2005) found that an average fine was associated with a subsequent 7-percent reduction in water pollution discharges at every plant in the same state and sector as the fined plant.

[13]A qualitative survey literature lends some support to this hypothesis. Thornton, Gunningham, and Kagan (2005) found that enforcement served reminder and reassurance functions that led to increased attention to pollution prevention. Carlough (2004) found that plants increased attention toward treatment technologies, environmental personnel additions, and employee training in the presence of enhanced regulatory scrutiny.

rely on large direct expenditures such as those required for new installations of major pollution control equipment.

The collective findings of the literature also suggest that current state and federal environmental assessment methods incompletely measure the impacts of monitoring and enforcement activities on compliance and pollution. The EPA currently uses measures such as inspection counts, numbers of sanctions, total value of penalties collected, and pounds of pollution reduced through consent decrees or court settlements. One possible shortcoming of this approach is related to the issue of reverse causality discussed above: Penalties and other sanctions tend to be higher when overall environmental performance is worse, so a regulator who is successful at reducing violations may appear to be less effective. An equally significant issue is that these indicators fail to capture some deterrence effects that the literature suggests may be large. More specifically, current assessment measures fail to capture the impact of current inspections, sanctions, and fines on *future* environmental performance at the sanctioned facility as well as the *spillover effects* of these actions on the environmental performance at other facilities. Finally, the EPA's current assessment methods fail to capture *beyond compliance* effects that result in pollution reductions at plants that were already in compliance.

It would be helpful for the EPA and other environmental agencies to consider replicating existing quantitative database analyses or qualitative survey studies (subject to cost considerations) in order to improve their assessment and understanding of the benefits of monitoring and enforcement activities. The EPA and other environmental agencies can also improve the quantity and quality of future research by providing researchers with better access to complete cross-sections and long time-series data on environmental compliance, emissions, and enforcement. The use of randomized trials might also improve the current state of knowledge in this area. Here, public agency pilot programs might assign "control" facilities to a status quo enforcement program and randomly selected "treatment" facilities to specially designed monitoring and enforcement programs. Comparisons of the two groups' pollution and compliance outcomes might help clarify deterrence impacts in different contexts.

Unresolved Issues and Directions for Future Research

Where might researchers direct future efforts in this area? A good starting point would be to take a closer look at the questions related to the deterrence effects of environmental monitoring and enforcement that have been only partially addressed or remain unanswered. These include: How large is the deterrence impact in international contexts? How do plant characteristics influence the strength of enforcement responses? Should enforcement resources be targeted to repeat violators? How does deterrence vary across regulatory instruments? How does the plant learning process underlying general deterrence function in the real world? Are the benefits of environmental monitoring and enforcement activities greater than the costs of such activities? How do pollution prevention impacts from a marginal dollar invested in enforcement activity compare to pollution prevention impacts from a marginal dollar invested in less traditional regulatory approaches?

Deterrence in International Contexts

While there are similarities between the U.S. and other developed countries' regulatory institutions, environmental enforcement intensities and strategies vary across countries.

Differences in resources and experience between developing and developed countries can be particularly dramatic. Yet, with just a few exceptions, most of the empirical literature on environmental deterrence has focused only on the United States. Laplante and Rilstone (1996) found that inspections and the predicted threat of inspections reduced the conventional water pollution discharges of forty-seven Canadian pulp and paper mills by approximately twenty-eight percent. A survey by Doonan, Lanoie, and LaPlante (2005) revealed that seventy percent of Canadian pulp and paper plant managers rated the government as the single most important source of environmental pressure. Dasgupta et al. (2001) found that inspections of manufacturing facilities in Zhenjiang, China, reduced common water pollutants by between 0.4 and 1.2 percent and reduced air particulates by approximately 0.3 percent. Almer and Goeschl (2010) found that criminal prosecutions in fifteen German states deterred subsequent environmental crimes and that standing trial had larger deterrence effects than conviction probabilities and the magnitudes of fines. Despite these contributions, more research on countries other than the United States is clearly needed to increase understanding of deterrence in an international context.

How Do Industry and Plant Characteristics Affect Deterrence?

We have some empirical evidence concerning how the deterrence impacts of monitoring and enforcement vary across industries, time periods, and facility characteristics. Gray and Shadbegian (2005) found that even within a given sector and time period (pulp and paper mills in the 1980s), the effects of enforcement on compliance differed across industrial subcategory, size, and ownership structure. Earnhart (2009) found that deterrence effects substantially varied across facilities' capacity utilization and permit conditions. Outside the environmental sector, Feinstein (1989) explored Nuclear Regulatory Commission safety inspections but did not detect any specific or general deterrence effect of enforcement oversight. We still have a lot to learn about what systematically drives enforcement response variability. Moreover, this information is critical to internal management at environmental agencies, as it could assist in targeting enforcement and monitoring activities so they generate the biggest "bang for the buck."

Targeting Enforcement

A related unresolved issue is the efficiency of targeting enforcement resources toward plants with significant offense histories.[14] If enforcement generates pollution reductions primarily by a few "bad apples," regulators could save resources by focusing almost exclusively on the worst-performing facilities. However, Shimshack and Ward (2008) showed that at least for the pulp and paper industry, the majority of observed enforcement responses actually came from facilities that violate infrequently. Furthermore, a working paper by Shimshack and Ward (2010) showed empirically that targeting more enforcement resources toward repeat offenders may be inefficient. The intuition here is that frequent violators may have higher compliance costs and are therefore less likely to respond to enforcement actions.

[14]Helland (1998) provides evidence for environmental inspection targeting, and statutory provisions advocate for environmental enforcement targeting.

Furthermore, it may be more expensive for regulators to maintain a given level of threat for frequent violators, as threats must be carried out more often for frequent violators than for infrequent violators. More research is needed here, but the results to date are broadly consistent with a tax literature that shows that some random and diverse audits are necessary for achieving maximum compliance.[15]

Relative Impacts of Different Regulatory Tools

Regulators can alter the frequency and severity of inspections, sanctions, administrative fines, civil judicial cases, and criminal judicial cases. They can also adjust plant standards (allowable pollution levels).[16] Multiple regulatory tools imply that enforcement agencies might be able to achieve greater compliance at the same cost by simply reallocating resources from one monitoring and enforcement instrument to another. However, the literature suggests that the relative impacts of different monitoring and enforcement tools vary across pollution media, industrial context, and time period. In addition, even the basic deterrence impacts of actual and threatened litigation are poorly understood. For example, while a large-scale cross-media analysis by Miller (2005) found that criminal actions appeared to affect environmental behavior more significantly than administrative or civil actions, studies that systematically explore the impacts of legal cases and institutions are rare. In short, we have yet to fully understand the consistent relative deterrence impacts of different pollution control instruments, which means that we do not yet understand how to most effectively manage resource use by environmental agencies.

Deterrence Mechanisms

While recent research has begun to explore the mechanisms underlying specific and general deterrence, many of the details and their implications remain poorly understood. The extent to which plants are aware of infractions and penalties at other facilities is a direction for future research, although Thornton, Gunningham, and Kagan (2005) showed that plants are at least partially aware of severe legal penalties imposed on noncompliant plants in the same industry. However, exactly how firms learn about regulatory threats and whether various econometric approaches for predicting such threats are reliable are largely unresolved issues. At present, agency enforcement and compliance alerts are infrequent and highly aggregated, suggesting that plants may not be fully informed of monitoring and enforcement at similar facilities. Of course, it is possible that facilities overestimate their perceived risks from monitoring and enforcement, in which case more accurate and widely publicized information about regulatory activity might actually serve to weaken deterrence. Resolving these types of issues would help us understand whether greater publicity of regulators' compliance records and enforcement activity would reduce violations and emissions.

[15]See Andreoni, Erard, and Feinstein (1998) for a survey of this literature.

[16]While the focus of this article is monitoring and enforcement, Decker (2003) provides evidence that regulators also use access to permits and standard setting as tools to secure compliance and enhance environmental performance.

Monitoring, Enforcement, and Compliance Costs

While the literature shows that the environmental benefits of environmental monitoring and enforcement actions are large on average, there has been very little research exploring regulator implementation costs and plant compliance costs for different enforcement actions or approaches. Magat and Viscusi (1990) performed a back-of-the-envelope benefit–cost assessment for inspections in the pulp and paper industry in the early 1980s. They concluded that any final conclusions about benefits and costs probably hinged on whether plants needed to make capital investments to attain compliance or whether changes in operating procedures would be sufficient. Additional research in a variety of contexts is crucial for understanding how the social benefits of enforcement compare to the social costs of enforcement.

Traditional versus Alternative Regulatory Strategies

A final direction for future research would be to compare the marginal compliance and environmental quality contributions of a dollar invested in traditional monitoring and enforcement versus a dollar invested in the recently popular alternative regulatory strategies. Thus far, the literature exploring the impacts of voluntary, informational, or cooperative compliance programs on environmental performance has produced mixed results, with some studies finding that these programs generate environmental benefits and others finding that they do not.[17] Furthermore, very few studies have considered enforcement and alternative pollution control strategies simultaneously. Harrison (1995) compared overall mean compliance measures for Canadian and U.S. pulp and paper mills and concluded that the lower Canadian compliance rates suggested that the more cooperative Canadian regulatory approach may be less effective. Surveys by May and Winter (1999) and Lo, Fryxell, and Van Rooij (2009) suggested that cooperative strategies and "accommodation" may have been less effective than inspections and "coercion" in the Danish agricultural and Chinese industrial sectors, respectively. However, Foulon et al. (2002) found that inclusion on a public list of noncompliant pulp and paper mills in British Columbia produced incentives for pollution control that were similar to a regulatory fine. Innes and Sam (2008) concluded that voluntary and traditional monitoring and enforcement programs may be complements rather than substitutes, finding that plants with higher rates of government oversight were more likely to voluntarily participate in a pollution reduction program. They also found that program participants experienced a reduction in inspections and sanctions of approximately forty percent during the years following their enrollment, suggesting that plants may participate in voluntary initiatives in an effort to reduce future regulatory oversight. However, pollution emissions among program participants fell significantly after enrollment, indicating that in this case, the complementarities between traditional and voluntary enforcement produced positive results.

Conclusions

The empirical evidence that has been reviewed here suggests that monitoring and enforcement are significant determinants of pollution prevention and environmental compliance.

[17]See Khanna (2001), Lyon and Maxwell (2002), and Koehler (2007) for literature reviews.

First, environmental monitoring and enforcement activities generate substantial specific deterrence, reducing future violations at the targeted firm. Second, environmental monitoring and enforcement activities generate substantial general deterrence, reducing future violations at facilities other than the targeted one. Third, environmental monitoring and enforcement activities generate not only reductions in violations but also significant reductions in emissions. This last result holds even for industries where compliance is generally high.

However, there remains a need for continued research on deterrence. More focus on social trade offs and regulatory efficiency is especially needed. We still have much to learn, and many issues related to resource allocation within environmental enforcement and compliance assurance agencies remain to be addressed.

References

Alberini, A., and D. Austin. 1999. Strict liability as a deterrent in toxic waste management. *Journal of Environmental Economics and Management* 38: 20–48.

———. 2002. Accidents waiting to happen: Liability policy and toxic pollution releases. *Review of Economics and Statistics* 84: 729–41.

Almer, C., and T. Goeschl. 2010. Environmental crime and punishment: Empirical evidence from the German penal code. *Land Economics* 86: 707–26.

Andreoni, J., B. Erard, and J. Feinstein. 1998. Tax compliance. *Journal of Economic Literature* 36: 818–60.

Becker, G. 1968. Crime and punishment: An economic analysis. *Journal of Political Economy* 76: 169–217.

Carlough, L. 2004. *General deterrence of environmental violation: A peek into the mind of the regulated public.* Portland: State of Oregon Department of Environmental Quality.

Cohen, M. 1999. Monitoring and enforcement of environmental policy. In *International yearbook of environmental and resource economics volume III,* ed. Tom Tietenberg, and Henk Folmer, 44–106. Northampton, MA: Edward Elgar.

Dasgupta, S., B. Laplante, N. Mamingi, and H. Wang. 2001. Inspections, pollution prices, and environmental performance: Evidence from China. *Ecological Economics* 36: 487–98.

Decker, C. 2003. Corporate environmentalism and environmental statutory permitting. *Journal of Law and Economics* 46: 103–29.

Deily, M., and W. Gray. 1991. Enforcement of pollution regulations in a declining industry. *Journal of Environmental Economics and Management* 21: 260–74.

———. 2007. Agency structure and firm culture: OSHA, EPA, and the steel industry. *Journal of Law, Economics, and Organization* 23: 685–709.

Delmas, M., and M. Toffel. 2008. Organizational responses to environmental demands: Opening the black box. *Strategic Management Journal* 29: 1027–55.

Doonan, J., P. Lanoie, and B. LaPlante. 2005. Determinants of environmental performance in the Canadian pulp and paper industry: As assessment from inside the industry. *Ecological Economics* 55: 73–84.

Earnhart, D. 2004a. Panel data analysis of regulatory factors shaping environmental performance. *Review of Economics and Statistics* 86: 391–401.

———. 2004b. Regulatory factors shaping environmental performance at publicly owned treatment plants. *Journal of Environmental Economics and Management* 48: 655–81.

———. 2009. The influence of facility characteristics and permit conditions on the effectiveness of environmental regulatory deterrence. *Journal of Regulatory Economics* 36: 247–73.

Feinstein, J. 1989. The safety regulation of U.S. nuclear power plants: Violations, inspections, and abnormal occurrences. *Journal of Political Economy* 97: 115–54.

Foulon, J., P. Lanoie, and B. LaPlante. 2002. Incentives for pollution control: Regulation or information? *Journal of Environmental Economics and Management* 44: 169–87.

Glicksman, R., and D. Earnhart. 2007. The comparative effectiveness of government interventions on environmental performance in the chemical industry. *Stanford Environmental Law Journal* 26: 317–71.

Gray, W., and M. Deily. 1996. Compliance and enforcement: Air pollution regulation in the U.S. steel industry. *Journal of Environmental Economics and Management* 31: 96–111.

Gray, W., and C. Jones. 1991. Are OSHA health inspections effective? A longitudinal study in the manufacturing sector. *Review of Economics and Statistics* 73: 504–8.

Gray, W., and J. Mendeloff. 2005. The declining effects of OSHA inspections on manufacturing injuries, 1979–1998. *Industrial and Labor Relations Review* 58: 571–87.

Gray, W., and J. Scholz. 1993. Does regulatory enforcement work? A panel analysis of OSHA enforcement. *Law and Society Review* 27: 177–213.

Gray, W., and R. Shadbegian. 2005. When and why do plants comply? Paper mills in the 1980s. *Law and Policy* 27: 238–61.

———. 2007. The environmental performance of polluting plants: A spatial analysis. *Journal of Regional Science* 47: 63–84.

Harrington, W. 1988. Enforcement leverage when penalties are restricted. *Journal of Public Economics* 37: 29–53.

Harrison, K. 1995. Is cooperation the answer? Canadian environmental enforcement in comparative context. *Journal of Policy Analysis and Management* 14: 221–44.

Helland, E. 1998. The enforcement of pollution control laws: Inspections, violations, and self-reporting. *Review of Economics and Statistics* 80: 141–53.

Innes, R., and A. Sam. 2008. Voluntary pollution reductions and the enforcement of environmental law: An empirical study of the 33/50 program. *Journal of Law and Economics* 51: 271–96.

Kagan, R., N. Gunningham, and D. Thornton. 2003. Explaining corporate environmental performance: How does regulation matter? *Law and Society Review* 37: 51–89.

Keohane, N., E. Mansur, and A. Voynov. 2009. Averting enforcement: Evidence from new source review. *Journal of Economics and Management Strategy* 18 (1): 75–104.

Khanna, M. 2001. Economic analysis of non-mandatory approaches to environmental protection. *Journal of Economic Surveys* 15 (3): 291–324.

Khanna, M., and W. Anton. 2002. What is driving corporate environmentalism: Opportunity or threat? *Corporate Environmental Strategy* 9: 409–17.

Kleit, A., M. Pierce, and R. Hill. 1998. Environmental protection, agency motivations, and rent extraction. *Journal of Regulatory Economics* 13: 121–37.

Koehler, D. 2007. The effectiveness of voluntary environmental programs—A policy at a crossroads? *Policy Studies Journal* 35: 689–722.

Landsberger, M., and I. Meilijson. 1982. Incentive generating state dependent penalty system. *Journal of Public Economics* 19: 333–52.

Langpap, C., and J. Shimshack. 2010. Private citizen suits and public enforcement: Substitutes or complements? *Journal of Environmental Economics and Management* 59: 235-49.

LaPlante, B., and P. Rilstone. 1996. Environmental inspections and emissions of the pulp and paper industry in Quebec. *Journal of Environmental Economics and Management* 31: 19–36.

Lo, C., G. Fryxell, and B. Van Rooij. 2009. Changes in enforcement styles among environmental enforcement officials in China. *Environment and Planning A* 41: 2706–23.

Lyon, T., and J. Maxwell. 2002. Voluntary approaches to environmental regulation: A survey. In *Economic institutions and environmental policy,* ed. M. Frazini, and A. Nicita, 142–74. Aldershot, Hampshire: Ashgate Publishing.

Magat, W., and W. K. Viscusi. 1990. Effectiveness of the EPA's regulatory enforcement: The case of industrial effluent standards. *Journal of Law and Economics* 33: 331–60.

May, P. 2005. Regulation and compliance motivation: Examining different approaches. *Public Administration Review* 65: 31–44.

May, P., and S. Winter. 1999. Regulatory enforcement and compliance: Examining Danish agro-environmental policy. *Journal of Policy Analysis and Management* 18: 625–51.

Miller, A. 2005. *What makes companies behave? An analysis of criminal and civil penalties under environmental law.* Working Paper, New York University.

Nadeau, L. 1997. EPA effectiveness at reducing the duration of plant-level non-compliance. *Journal of Environmental Economics and Management* 34: 54–78.

Peltzman, S. 1976. Toward a more general theory of regulation. *Journal of Law and Economics* 19: 211–40.

Polinsky, A., and S. Shavell. 1998. On offense history and the theory of deterrence. *International Review of Law and Economics* 18: 305–24.

———. 2000. The economic theory of public enforcement of law. *Journal of Economic Literature* 38: 45–76.

Russell, C., W. Harrington, and W. J. Vaughan. 1986. *Economic models of monitoring and enforcement: Enforcing pollution control laws,* Resources for the Future, Washington, DC.

Scholz, J., and W. Gray. 1997. Can government facilitate cooperation? An informational model of OSHA enforcement. *American Journal of Political Science* 41: 693–717.

Shimshack, J., and M. B. Ward. 2005. Regulator reputation, enforcement, and environmental compliance. *Journal of Environmental Economics and Management* 50: 519–40.

———. 2008. Enforcement and over-compliance. *Journal of Environmental Economics and Management* 55 (1): 90–105.

———. 2010. *Repeat offenders, enforcement, and environmental compliance*. Working Paper, Tulane University.

Sigman, H. 2009. *Environmental liability and redevelopment of old industrial land*. NBER Working Paper No. 15017.

Stafford, S. 2002. The effect of punishment on firm compliance with hazardous waste regulations. *Journal of Environmental Economics and Management* 44: 290–308.

———. 2003. Assessing the effectiveness of state regulation and enforcement of hazardous waste. *Journal of Regulatory Economics* 23 27–41.

Stigler, G. 1970. The optimum enforcement of laws. *Journal of Political Economy* 78: 526–36.

Thornton, D., N. Gunningham, and R. Kagan. 2005. General deterrence and corporate environmental behavior. *Law and Policy* 27: 262–88.

Uhlmann, D. 2010. Environmental crime comes of age: The evolution of criminal enforcement in the environmental regulatory scheme. *Utah Law Review* 2009: 1223-52.

U.S. Environmental Protection Agency (USEPA). 1989. *Office of Water, The Enforcement Management System: National Pollutant Discharge Elimination System.*

———. 2001a. *Clean Air Act Stationary Source Compliance Monitoring Strategy.*

———. 2001b. *Office of Enforcement and Compliance Assurance, Combined Enforcement Policy for Section 112(r) of the Clean Air Act.*

———. 2005. *Office of Inspector General, Limited Knowledge of the Universe of Regulated Entities Impedes EPA's Ability to Demonstrate Changes in Regulatory Compliance.*

———. 2007. *Office of Enforcement and Compliance Assurance, Clean Water Act National Pollutant Discharge Elimination System Compliance Monitoring Strategy for the Core Program and Wet Weather Sources.*

U.S. Office of Management and Budget (USOMB). 2005. *Program assessment rating tool review of EPA enforcement of environmental laws.*