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

Comparative Analysis of Monitoring and Enforcement Impact Measures

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Prepared for the Environmental Protection Agency's Office of Enforcement and Compliance Assurance (OECA) by Jay P. Shimshack

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Executive Summary

This report quantitatively characterizes noncompliance and assesses the deterrence impacts of enforcement for major industrial organic and inorganic chemical facilities' water pollution performance. We use four cutting-edge metrics. The goal of the analysis is to facilitate *cross-measure* comparisons of the relative accuracy and utility of the metrics. The four metrics considered are: (1) statistically valid noncompliance rates, (2) noncompliance indexes, (3) regulated discharge measures, and (4) noncompliance duration measures. The four metrics are used to characterize environmental performance and noncompliance in three contexts: -1- at a single point in time; -2- over an 8 year time horizon; and -3- for determining the deterrent effects of enforcement activities. This is the first study to compare the studied metrics simultaneously for a single medium and sector.

Key findings and recommendations include:

For characterizing environmental performance at a single point in time:

(1) noncompliance rates are more effective than other metrics;

(2) broad-based 'any noncompliance' rates should be calculated based upon the most comprehensive data available on the facilities' full range of compliance obligations;

(3) because noncompliance for a subset of pollutants or violations does not imply noncompliance for other pollutants or violations, broad-based noncompliance rates should be supplemented with pollutant or violation specific noncompliance rates.

For characterizing environmental performance over time:

(1) noncompliance rates are more effective than other metrics;

(2) broad-based 'any noncompliance' rates should be calculated based upon the most comprehensive data available in all periods on the facilities' full range of compliance obligations;

(3) because noncompliance for a given pollutant or violation type does not necessarily trend with noncompliance for other pollutants or violation types. broad-based noncompliance rates should be supplemented with pollution or violation specific noncompliance rates.

(4) because noncompliance and discharges, even for single pollutants, are not necessarily strongly correlated (i.e., regulated discharges over a sector may decline while violations remain unchanged –or- regulated discharges may remain unchanged while noncompliance decreases), noncompliance rates should be supplemented with regulated discharge metrics and perhaps noncompliance indexes.

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For measuring the deterrence effects of enforcement:

(1) regression models based on regulated discharges best assess deterrence effects;

(2) because the specific and general deterrence effects of enforcement on discharges vary by pollutant, discharge-based deterrence models should evaluate as many distinct pollutants as is cost effective;

(3) because the specific and general deterrence effects of enforcement on noncompliance are not necessarily the same as the specific and general deterrence effects on discharges, discharge-based deterrence models should be supplemented with models based on noncompliance status indicators;

(4) noncompliance rates should not be used for assessing the deterrence effects of environmental enforcement because these models have low statistical power, poor theoretical properties, and preclude the separate analysis of specific and general deterrence.

We also advise the Agency to consider expanding the availability of historical compliance and discharges data. It is the author's opinion that the amount and quality of external research conducted on compliance, deterrence, and environmental performance would increase significantly with more complete and accessible historical data.

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Commonly Used Abbreviations

BOD	Biochemical Oxygen Demand
DMR	Discharge Monitoring Report
E90	Numeric Effluent Violation
ICIS	Integrated Compliance Information System
NC	Noncompliance
PCS	Permit Compliance System
QNCR	Quarterly Noncompliance Report
RNC	Reportable Noncompliance
SNC	Significant Noncompliance
TRC	Technical Review Criteria
TSS	Total Suspended Solids

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Glossary: Terms are defined as used in this report. Other definitions are both possible and reasonable.

Noncompliance (NC) characterizations:

Significant Noncompliance (SNC) – the most serious level of violation noted in EPA databases. The determination of significant noncompliance is complex. In brief, for major facilities, under the Clean Water Act, SNC can be triggered by TRC effluent violations (see below), non-receipt of discharge monitoring reports, compliance schedule violations, and single event violations (typically violations detected during a regulatory inspection). *See* EPA's ECHO data base for more information. http://www.epa-echo.gov/echo/index.html

Reportable Noncompliance (RNC) – reporting violations that do not trigger SNC.

Effluent Violation (E90) – an effluent exceedance, including a violation that does not trigger SNC because it addresses non-SNC eligible contaminants or does not meet TRC frequency and severity criteria.

Technical Review Criteria Violation (TRC) – a violation representing multiple substantial effluent violations within the last 6 months. For example, TRC eligible monthly average violations must be greater than 40% above monthly average limits for certain conventional pollutants and greater than 20% above monthly average limits for certain toxic and non-conventional pollutants.

Noncompliance Metrics:

Noncompliance rate – the percent of evaluated facilities in noncompliance for a given period of time. Noncompliance rates are never facility-specific; they are population-specific and simultaneously characterize many facilities at once.

Noncompliance index – the total number of violations (of various types) for a given period of time. Noncompliance indexes may be facility-specific or averaged over many facilities to provide a mean index for a population and time period.

Noncompliance indicator – a 0/1 variable indicating the presence of noncompliance of a certain type for a given period of time. Noncompliance indicators are always facility-specific; averaging noncompliance indicators over many facilities yields a noncompliance rate for that time period.

Noncompliance duration –the number of months in violation over a given longer period of time. Noncompliance duration measures may be facility-specific or averaged over many facilities to provide a mean noncompliance duration measure for a population and time period.

Regulated discharges – actual pollution discharges for a given period of time, expressed as a percentage of permitted levels. Regulated discharges can be facility-specific or averaged over many facilities to provide mean regulated discharges for a population and time period.

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1. Introduction

OECA and other environmental agencies are increasingly called upon to measure and evaluate the effectiveness of their enforcement activities. This report supports this endeavor by quantitatively characterizing noncompliance and assessing the deterrence impacts of enforcement using four cutting-edge metrics. The goal of the analysis is to facilitate *cross-measure* comparisons of the relative accuracy and utility of the metrics. This is the first study to compare metrics simultaneously for a single medium and sector.

We analyze water pollution performance for major industrial organic and inorganic chemical facilities. The four metrics considered are: (1) statistically valid noncompliance rates, (2) noncompliance indexes, (3) regulated discharge measures, and (4) noncompliance duration measures. Statistically valid noncompliance rates assess the percent of evaluated facilities in noncompliance for a given period of time. Noncompliance indexes evaluate the extent of noncompliance for a given facility at a given point in time. Regulated discharge measures gauge actual conventional water pollution discharges in relation to permitted levels. Noncompliance duration metrics evaluate the number of facility months with a violation over the past year.

This investigation has three components. First, we characterize environmental performance and noncompliance at a single point in time using the four metrics described above. We use both database-generated noncompliance indicators and actual Permit Compliance System (PCS) conventional water pollutant significant noncompliance (SNC), discharge, and limit information. Results indicate that the noncompliance metrics may generate substantially different results, and each measure has objective strengths and weaknesses.

Second, we characterize pollution and noncompliance over an 8 year time horizon. Results suggest that the cutting-edge metrics not only characterize noncompliance differently at single points in time, but that they do not necessarily trend together. For example, we find that some noncompliance metrics for conventional water pollutants significantly decrease over time but that the total pounds of conventional water pollutants exhibit no clear time trend.

Third, we determine the deterrence effects of enforcement activities using the four metrics. The metrics again produce variable results. We pay particular attention to this deterrence assessment task, since regulatory deterrence is a key driver of compliance behavior. The conventional wisdom is that the effectiveness of a legal threat depends on the likelihood that a lawbreaker will be caught, the nature and severity of the punishments, and the speed of apprehension. A significant body of theoretical and empirical literature exists to support these views. See, for example, USEPA (2007). We explore two types of enforcement deterrence: specific and general. Specific deterrence involves identifying and returning individual violators to compliance and motivating them to continue to identify and meet their legal obligations. Law enforcement agencies have long believed, however, that their actions have impacts beyond the facilities directly sanctioned. This general deterrence motivates other persons or facilities subject to the same or similar laws or requirements to also identify and meet their legal obligations.

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For all deterrence impact measures, we use statistical models that were designed to be as technically rigorous as possible while using only EPA data. These quantitative measurement frameworks follow both the modern published literature and previous published reports in this monitoring, enforcement, and environmental compliance series closely. See, for example, Shimshack and Ward (2005), Shimshack and Ward (2008), Shimshack (2008 Task 3 report), and Shimshack (2008 Task 4 report).

This report's results contribute to the ongoing goal of improving the Agency's ability to measure and evaluate the effectiveness of its enforcement and monitoring activities. The type of assessments presented here may aid internal management, along with other relevant factors. For example, the results may help Agency personnel identify those noncompliance metrics that most credibly capture current states of noncompliance and trends over time. The results may also help Agency personnel select and implement measures that more completely capture the deterrence effects of enforcement activities. Many current methods for evaluating the effectiveness of environmental regulatory activities are incomplete. For example, outcome measures like pounds of pollution directly reduced through consent decree agreements and court settlements do not typically capture deterrence, and especially general deterrence.

In the longer term, this report's findings and recommendations may also eventually facilitate justifiable statements to external stakeholders about enforcement impacts. Such impacts include both measured compliance and pollution outcomes.

2. Noncompliance Metrics and Deterrence Models

This section reviews key features of the metrics and models used in the analysis. We first present the basic noncompliance metrics in detail. We then present the deterrence models. More detailed discussions of these regression models, including technical issues, causality, attribution, and statistical concerns can be found in earlier reports in this series. See Shimshack (2008 Task 3 report) and Shimshack (2008 Task 4 report). Note, however, that the deterrence regression models used in this report do attempt to isolate causality and attempt to attribute deterrence to regulatory actions as much as possible. The techniques may not perfectly isolate causality in all instances, but the approaches do attempt to minimize attribution problems stemming from both omitted variable and reverse causality concerns.

2a. Noncompliance Metrics

Our four metrics for characterizing noncompliance are: (1) statistically valid noncompliance rates, (2) noncompliance indexes, (3) regulated discharge measures, and (4) noncompliance duration measures. Metric details are discussed below.

- *Statistically valid noncompliance rates:*

Noncompliance rates assess the percent of evaluated facilities in noncompliance for a given period of time.

We use three noncompliance rates developed from EPA database-generated indicators:

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-1- The first noncompliance rate considers the percent of facilities with *any* recorded noncompliance in a given period. Component parts include database-generated significant noncompliance (SNC) for reporting and compliance scheduling, biochemical oxygen demand (BOD), total suspended solids (TSS), toxics, single event violations, and non-SNC violations (RNC reporting and E90 effluent violations).

-2- The second noncompliance rate considers the percent of facilities with any SNC violation.

-3- The third noncompliance rate considers the percent of facilities with any non-SNC violation.

Note that the second and third rates do not necessarily sum to the first rate. This is because facilities may simultaneously have more than one database-generated violation in a given period.

We consider eight narrower noncompliance rates for the PCS conventional water pollution SNC, discharge, and limit data:

-1- The first noncompliance rate considers the percent of facilities with *any* BOD SNC or TSS SNC or E90 effluent violation for BOD or TSS in a given period.

-2- The second noncompliance rate considers the percent of facilities with BOD or TSS SNC for discharge monitoring report (DMR) non-receipt, as identified by pollution-specific quarterly noncompliance reports (QNCRs).

-3- and -4- The third and fourth rates consider the percent of facilities with BOD SNC and TSS SNC for effluent violations, where SNC is again determined by pollution-specific QNCR indicators.

-5- and -6- The fifth and sixth rates consider the percent of facilities with BOD monthly average effluent violations and TSS monthly average effluent violations, where monthly average violations are determined by comparing average discharges to permitted average limits. These latter measures are inclusive of the rare BOD and TSS SNC violation periods.

-7- and -8- Finally, the seventh and eighth rates consider the percent of facilities with BOD non-monthly average violations and TSS non-monthly average violations, where non-average violations are determined by comparing maximum discharges to permitted maximum limits.

Note that all noncompliance rates considered in this report are census-based. In other words, each rate is calculated for all facilities in our population. In principle, all calculations and qualitative conclusions relevant to noncompliance rates would still be valid when applied to a statistical random sample from a population of interest.

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- *Noncompliance indexes:*

Noncompliance indexes partially evaluate the extent of noncompliance for a given facility at a given point in time.

The noncompliance index developed from EPA database-generated indicators consists of the facility-specific sum of recorded violations for a given period. Violations include SNC for BOD, SNC for TSS, SNC for toxics, SNC for compliance schedule violations, SNC for DMR non-receipt, SNC for single event violations, the rare SNC violations for unexplained reasons, and non-SNC violations. Non-SNC violations most frequently reflect E90 effluent violations, including E90 violations for non-SNC eligible contaminants like PH and temperature. Non-SNC violations, however, sometimes reflect late or incomplete DMR reporting noncompliance (reportable noncompliance RNC).

The noncompliance index for the narrower PCS conventional water pollution SNC, discharge, and limit data consists of the facility-specific sum of BOD and TSS violations for a given period. Violations include QNCR-recorded SNC for BOD, QNCR-recorded SNC for TSS, QNCR-recorded SNC for DMR non-receipt (of BOD and TSS reports), non-SNC effluent violations for BOD monthly averages, non-SNC effluent violations for TSS monthly averages, BOD non-monthly average violations, and TSS non-monthly average violations. Note all non-SNC BOD and TSS violations from this data source are for effluent violations detected by comparing discharges to permitted levels.

- *Regulated Discharges:*

Regulated discharges gauge conventional water pollution discharges for a given facility in relation to permitted levels.

Regulated discharges for the PCS conventional water pollution and limit data consist of four measures for a given period of time:

-1- The first discharge metric considers monthly average BOD discharges as a percent of permitted levels.

-2- The second discharge metric considers monthly average TSS discharges as a percent of permitted levels.

-3- The third metric considers non-monthly average (monthly maximum) BOD discharges as a percent of permitted levels.

-4- The fourth metric considers non-monthly average TSS discharges as a percent of permitted levels.

For all four regulated discharge measures, the maximum pollution ratio across discharge points is selected if the facility operates multiple discharge points in a single period. This

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convenient normalization facilitates more transparent noncompliance and deterrence comparisons across facilities.

- *Noncompliance Duration:*

Noncompliance duration metrics assess the number of months each facility is in violation during a given year.

We consider 6 noncompliance duration metrics for the PCS conventional water pollution SNC, discharge, and limit data:

-1- The first metric considers the number of months with QNCR-recorded BOD SNC in the previous year (12 months).

-2- The second metric considers the number of months with QNCR-recorded TSS SNC in the previous year.

-3- and -4- The third and fourth metrics consider the number of months with BOD effluent violations for monthly average discharges and TSS effluent violations for monthly average discharges in the previous year. These latter two measures include the rare BOD or TSS SNC violation periods.

-5- and -6- The final two metrics consider the number of months with BOD and TSS violations for monthly maximums.

We use each of the metrics described above to characterize pollution discharges and noncompliance for a single point in time. The goal is to perform a cross-measure comparison of the metrics for understanding static environmental performance. We then use each of the metrics to characterize pollution discharges and noncompliance across time. The objective is to perform a cross-measure comparison of the metrics for understanding trends in environmental performance. Finally, we use each of the metrics to evaluate the deterrence effects of enforcement activities.

While the first two tasks entail straight-forward computations, the final task requires a more sophisticated statistical regression analysis. That analysis is detailed in the next section.

2b. Deterrence Models

Analyzing the impact of regulatory activity on environmental performance is framed in terms of deterrence. Under classic deterrence theory, facilities decide how much effort to invest in pollution abatement by comparing the marginal benefits and marginal costs of polluting. Marginal benefits of polluting or violating reflect increased production possibilities and decreased abatement expenditures. Marginal costs of polluting or violating are the expected damages associated with regulatory activity and possible community and customer backlash. Greater regulatory activity, as measured by recent enforcement actions, is hypothesized to

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increase a plant's expected compliance, decrease a plant's expected noncompliance, and decrease a plant's expected pollution (on average).

Model Intuition: Specific Deterrence

The goal of specific deterrence measurement is to identify the average effect of enforcement actions on the subsequent environmental performance of the sanctioned facility itself. The basic intuition of the specific deterrence models is quasi-experimental. Essentially, the models compare observations in which there was an agency action in the recent past to observations in which there was no agency action in the recent past.

For example, denote time periods with an enforcement action levied against a given facility in the past year as $S_{enforce}$ and time periods without an enforcement action levied against the given facility in the past year as $S_{no\ enforce}$. Note that even sanctioned facilities have numerous time periods that lack enforcement actions in the recent past. For this setup, specific deterrence models intuitively compare:

> the average difference between environmental performance during post-sanction and other periods ($S_{enforce}$ and $S_{no\ enforce}$), *for sanctioned facilities*
>
> -to-
>
> the average difference between environmental performance during these same periods ($S_{enforce}$ and $S_{no\ enforce}$), *for unsanctioned facilities.*

The difference between these two average differences, referred to as the "difference in differences" in the policy evaluation literature, represents the intuition of the average specific deterrence effect of an enforcement action in the recent past. The actual statistical identification of deterrence effects can be more subtle, but the basic intuition still holds.

Model Intuition: General Deterrence

The goal of general deterrence measurement is to identify the average spillover effect of enforcement actions on the subsequent environmental performance of other facilities in same state and sector as the sanctioned facility. The intuition of the general deterrence models remains quasi-experimental. Models still compare observations in which there was an agency action in the recent past to observations in which there was no agency action in the recent past.

For example, denote time periods with an enforcement action levied against other facilities in the same state and sector in the past year as $G_{enforce}$ and time periods without an enforcement action at other facilities in the same state and sector in the past year as $G_{no\ enforce}$. Note that even states and sectors with enforcement actions will have numerous periods without an enforcement action in the recent past. For this setup, general deterrence models intuitively compare:

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the average difference between environmental performance during post-sanction and other periods ($G_{enforce}$ and $G_{no\ enforce}$), *for affected facilities*

-to-

the average difference between environmental performance during these same periods ($G_{enforce}$ and $G_{no\ enforce}$), *for unaffected facilities.*

The difference in differences (the difference between these two average differences) represents the intuition of the average general deterrence effect of an enforcement action on neighboring facilities in the recent past. The actual statistical identification of general deterrence effects can be more subtle, but the basic intuition still holds.

Basic Regression Model

The overall empirical strategy for measuring specific and general deterrence is to link enforcement actions to the noncompliance metrics described in Section 2a. The less technically inclined reader can skip the next subsections and proceed to Section 3. For the more mathematically and statistically inclined reader, the basic regression model is:

$y_{it} = \alpha_i + \gamma_t + \mathbf{D}_{it}\boldsymbol{\delta} + \mathbf{X}_{it}\boldsymbol{\beta} + \varepsilon_{it}$,   where:

i indexes the unit of observation (a facility).

t indexes time (months or years).

y_{it} represents facility i's noncompliance metric in period t.

α_i is a facility-specific indicator that represents unobserved time invariant facility characteristics like size, capacity, industrial sub-category, and profitability.

γ_t is a year-specific indicator that represents unobserved time effects common to all evaluated facilities like technological change, sector maturation, and economic fluctuations over time.

$\mathbf{D}_{it}$ represents the presence of lagged EPA/state enforcement activities (the key explanatory variables). In the specific deterrence model, D_{it} is the presence or count of lagged EPA/state enforcement or monitoring activities directed at facility i in the recent past. In the general deterrence model, D_{it} is the presence or count of lagged EPA/state enforcement activities directed at other plants in plant i's state and sector in the recent past.

$\mathbf{X}_{it}$ represents seasonality indicators to control for within-year variation.

ε_{it} represents the regression error term addressing the difference between the outcome predictions of the regression line and the actual outcome data.

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δ, β represent regression coefficients. Notably, δ represents the marginal impact of an additional enforcement action on subsequent noncompliance metrics.

Regression Model Details

Detailed technical discussions of the statistical approaches, especially for the more complex models, can be found in earlier reports in this series. *See* Shimshack (2008 Task 3 report) and Shimshack (2008 Task 4 report). In this subsection we briefly identify and justify our key modeling assumptions for the statistically inclined reader.

For nearly all deterrence regression analyses, we use fixed effects regressions. The key assumptions underlying the fixed effects approach in our context are that technical change is relatively modest, regulations are fairly static, and managerial attitudes are not evolving rapidly for most facilities over the sample period.

Like most regression models, the fixed effects regression approach produces a single regression coefficient for each independent variable. For example, the coefficient on a fine variable represents the marginal impact of a recent sanction on noncompliance averaged across all facilities. However, the fixed effects model allows the regression intercept to differ across facilities. This accounts for the average "individuality" of each facility and controls for all facility-specific confounding factors that are approximately constant across time like size, profitability, management and industrial sub-category.

We use the fixed effects model for three reasons:

-1- First, the model controls for the individuality of each facility as described above. Consequently, detailed non-EPA data on facility and community characteristics are not required for credible empirical results.

-2- Second, the model was the preferred specification in earlier reports in this series because it yielded the most consistent regression results across models with different variables (Shimshack 2008 Task 3 report, Shimshack 2008 Task 4 report).

-3- Third, the fixed effects model is valid in the presence of certain types of correlation between important explanatory variables and the facility-specific regression parameters. Most notably, fixed effects models generate statistically valid results if regulators target enforcement activities toward facilities that pollute or violate more on average than other facilities. Ordinary least squares and many other common regression models do not generate statistically valid results under these highly probable circumstances.

When the dependent variable (noncompliance metric) is continuous, like regulated discharges, noncompliance indexes, and noncompliance duration, we use linear fixed effects regression models. When the dependent variable is discrete, however, like a 0/1 noncompliance status indicator, we use non-linear conditional fixed effects logit models. Non-linear models,

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their technical details, and their justification are described in more detail in Shimshack (2008 Task 3 report) and Shimshack (2008 Task 4 report).

Regression Details for Evaluating the Impact of Enforcement on Noncompliance Rates

The only exception to the regression approach described above is when we evaluate the impact of enforcement on noncompliance rates. In contrast to all other metrics, noncompliance rates are not facility-specific. They characterize the percent of regulated facilities in noncompliance for each period so there is only one aggregate observation for each time period. Consequently, we cannot run regression models with observations at the facility/month level. We have only one observation for each month so we run standard linear regressions where we regress the noncompliance rate in period t on the total number of enforcement actions in the recent past. We also include other controls like year specific indicators and seasonality indicators, but we do not include facility-specific fixed effects.

3. Data and Sector Selection

After consulting with OECA personnel, we selected the inorganic and organic chemical industry for analysis. As required by the statement of work, the key industry selection criteria were (1) the use of data developed and refined for previous reports in this series, (2) model suitability, and (3) aggregate environmental impact. These criteria left the pulp and paper sector, the petroleum refining sector, and the chemicals sector. The large industrial facilities in each of these sectors have the most complete environmental performance data, share salient characteristics with the sectors analyzed in the academic literature that serve as the basis for our modeling choices, and have significant environmental impacts.

We ruled out petroleum refining because lessons from this sector were the least likely to generalize to other industries. Refineries have very high historical noncompliance rates relative to other industries. We also ruled out pulp and paper because it has been heavily studied in the past. Noncompliance characterizations, average discharges, and enforcement deterrence impacts for the industrial organic and inorganic chemicals sectors, however, have not been comprehensively studied in the literature. Consequently, the measurement outcomes found in this report may be new to the relevant literature.

We first selected major chemical facilities by identifying those facilities with Standard Industrial Code Major Group 28: Chemicals and Allied Products. We only chose majors, since non-majors are not required to track pollution discharges every month. Majors also tend to be more similar to one another than non-majors. Rough similarity across facilities is important since a key component of the regression models is a behavioral comparison of facility/time pairs with a recent enforcement action and facility/time pairs without a recent enforcement action. Comparison facilities should be broadly similar.

From the universe of major chemical plants, we chose the subset of facilities with Standard Industrial Codes 2869 and 2819, industrial organic chemicals and industrial inorganic

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chemicals.[1] We eliminated less common types of chemical facilities like pigment manufacturers since these facilities often differ significantly from the typical industrial chemicals plant. This criterion yielded 161 facilities. In order to facilitate meaningful cross-metric comparisons, we then further restricted our sample to only those plants with relatively complete data for conventional water pollution SNC, discharges, and limits over time. This criterion narrowed the sample to 113 facilities. Finally, we selected only those facilities in states with 5 or more major chemicals facilities with relatively complete data. Recall that general deterrence impact measures require multiple facilities in a state to be meaningful. The final sample contained 90 facilities.

Our sample period for conventional water pollution SNC, discharge, and limit data from the PCS spanned January of 1998 to May of 2006. Enforcement action data spanned a longer period from January 1996 to May of 2006, allowing for a complete set of lagged enforcement measures. Both sample periods were chosen due to data availability at the time of Task 4 of this compliance and deterrence report series.

In addition to conventional water pollution data, we also collected complete noncompliance status data from OTIS. We collected this data only for quarter 1 of 2006, since this was the only available quarter that completely overlapped with the data developed and refined under previous work. Ideally, we would access historical OTIS compliance data, but that system only tracks compliance for 3 years from the present.

4. Results and Discussion

In this section, we present our results and discuss objective differences between the four metrics. We first present calculated results for characterizing noncompliance at a single point in time. The goal is to evaluate cross-measure comparisons of the metrics for understanding static environmental performance. We then present calculated results for characterizing noncompliance over time. The goal is to evaluate cross-measure comparisons of the metrics for understanding trends in environmental performance. Finally, we present regression results for enforcement deterrence analyses. The goal is to evaluate cross-measure comparisons of the metrics for investigating the impacts of enforcement actions.

4a. Characterizing Static Noncompliance

We first characterize noncompliance at a single point in time using noncompliance status data from OTIS. These data contain information on significant noncompliance (SNC) for BOD, SNC for TSS, SNC for Toxics, SNC for compliance schedule/reporting violations, SNC for single event violations, SNC for unexplained reasons, and non-SNC violations. Non-SNC violations most frequently represent E90 effluent violations, including violations for pollutants ineligible for SNC contributions. Non-SNC violations may also represent lesser reporting violations for late or incomplete reports.

[1] Our selection criteria were based upon SIC codes rather than North American Industry Classification System (NAICS) codes because historical Permit Compliance System data is based upon SIC codes. The vast majority of facilities, however, fall under NAICS Code 325. A large majority fall under NAICS Code 3251.

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Static Noncompliance Metrics: Results

Table 1 presents our OTIS results for *statistically valid noncompliance rates* in quarter 1 of 2006 (Jan-Mar 2006).[2] Each row represents the percent of our 90 organic and inorganic chemical facilities with the corresponding violation.

Table 1. Statistically Valid Noncompliance Rates for Quarter 1 of 2006: OTIS NC Data

Percent of Regulated Universe with Database Generated SNC and/or RNC and/or E90:	46.7%
Percent of Regulated Universe with Database Generated SNC Violation	8.9%
Percent of Regulated Universe with Database Generated non-SNC Violation	40.0%

We find that:

- Nearly 47 percent of facilities had some database recorded violation in 2006:1.
- Nearly 9 percent of facilities had a SNC violation for BOD, TSS, toxics, single event violations, DMR non-receipt, or other reason.
- 40 percent of facilities had some non-SNC violation.

Note that SNC and non-SNC violation rates do not sum to the 'any noncompliance' rate, since facilities may have both a SNC and a non-SNC violation in the same quarter.

Table 2 presents our OTIS results for a *noncompliance index* in quarter 1 of 2006. For each facility, this noncompliance index is calculated as the sum of SNC BOD violations, SNC TSS violations, SNC toxic violations, SNC non-receipt violations, SNC single event violations, SNC for unexplained reasons, and non-SNC violations. Each individual component takes a maximum value of 1 and the maximum index value is 7.

Table 2. Noncompliance Index for Quarter 1 of 2006: OTIS NC Data

Mean Noncompliance Index with Database Generated NC Indicators	0.49
Index Components: SNC for BOD, SNC for TSS, SNC for Toxics, SNC for compliance schedule/DMR violations, SNC for single event violations, SNC for unexplained reasons, non-SNC violations (E90 effluent and RNC reporting violations)	

Table 2 indicates that the average facility in our sample had a noncompliance index score of 0.49, which is consistent with a noncompliance rate near 50 percent and a single violation for each violator in the period. The maximum noncompliance index score was 2, indicating that no plant had more than 2 of the violations described above simultaneously. This noncompliance index likely represents a lower bound on violation counts, since database documentation

[2] Note that this definition differs from the EPA fiscal year quarter definition, where quarter 1 represents Oct-Dec.

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indicates that SNC and non-SNC status for a given pollutant or other violation typically represents the most significant violation only.

We next turn to evaluating our noncompliance metrics using PCS conventional water pollution SNC, discharge, and limit data. We do not evaluate regulated pollutants and noncompliance duration using OTIS data, since results for considered pollutant parameters should be very similar (ideally identical) to the presented PCS data. Before examining the regulated pollutant and noncompliance duration measures, however, we reconsider the noncompliance rate and noncompliance index measures using only BOD and TSS data derived from the PCS.

Table 3 presents our PCS results for *statistically valid noncompliance rates* in quarter 1 of 2006 using only data for the conventional water pollutants BOD and TSS. Each row still presents the percent of our 90 organic and inorganic chemical facilities with the corresponding violation.

Table 3. Effluent Specific Noncompliance Rates for Quarter 1 of 2006

Percent of Regulated Universe with any BOD or TSS SNC and/or E90 violation:	13.3%
Percent of Regulated Universe with BOD or TSS reporting SNC (DMR non-receipt)	3.3%
Percent of Regulated Universe with BOD SNC	0.0%
Percent of Regulated Universe with TSS SNC	0.0%
Percent of Regulated Universe with any BOD E90 violation for monthly average discharges	2.2%
Percent of Regulated Universe with any TSS E90 violation for monthly average discharges	2.2%
Percent of Regulated Universe with BOD E90 violation for non-monthly average discharges	1.1%
Percent of Regulated Universe with TSS E90 violation for non-monthly average discharges	6.7%

We find that more than 13 percent of our facilities had some BOD or TSS related violation. Approximately 3 percent of facilities had a SNC violation for non-receipt of BOD and/or TSS discharge monitoring reports. We find no BOD or TSS effluent-related SNC. This is similar but not identical to OTIS data, which indicated that 1 percent of facilities (1 plant) had a BOD effluent-related SNC violation and 1 percent of facilities (1 plant) had a TSS effluent-related SNC violation during the period. Just over 2 percent of our sample had BOD non-SNC monthly average violations and 2 percent had TSS monthly average non-SNC violations. 1 percent of facilities had BOD monthly maximum violations and nearly 7 percent had TSS monthly maximum effluent violations.

Table 4 presents our PCS results for a *noncompliance index* in quarter 1 of 2006 using only data for the conventional water pollutants BOD and TSS. For each facility, this noncompliance index is calculated as the sum of SNC BOD violations, SNC TSS violations, SNC for BOD/TSS DMR non-receipt, non-SNC BOD effluent monthly average violations, non-SNC TSS effluent monthly average violations, BOD monthly maximum effluent violations, and TSS monthly maximum effluent violations. Each individual component takes a maximum value of 1 and the maximum possible index value is 7.

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Table 4. Noncompliance Index for Effluent Specific NC for Quarter 1 of 2006

Mean Noncompliance Index with Effluent Specific Data	0.16
Index Components: SNC for BOD, SNC for TSS, SNC for DMR non-receipt, non-SNC BOD E90 monthly average violations, non-SNC TSS E90 monthly average violations, BOD non-monthly average violations, TSS non-monthly average violations	

The average facility had a noncompliance index score of 0.16, which is consistent with a noncompliance rate near 13 percent and slightly more than 1 violation for each violator in the period. The maximum noncompliance index score was 2, indicating that no plant had more than 2 of the violations described above simultaneously.

Table 5 presents our PCS results for *regulated discharges* metrics for BOD and TSS in quarter 1 of 2006. Results suggest a considerable amount of beyond compliance behavior for our sample of major chemical facilities. Further, results imply that TSS limits are more binding, on average, than BOD limits in our sample.

Table 5. Regulated Discharges as a Percent of Permitted Levels for Quarter 1 of 2006

Mean Monthly Average BOD Discharges as a percent of permitted levels	32.4%
Mean Monthly Average TSS Discharges as a percent of permitted levels	38.8%
Mean Monthly Maximum BOD Discharges as a percent of permitted levels	30.9%
Mean Monthly Maximum TSS Discharges as a percent of permitted levels	34.0%

Mean monthly average BOD discharges were approximately 32 percent of permitted levels and mean monthly average TSS discharges were approximately 39 percent of permitted levels. Non-monthly average constraints were less binding on the whole. Mean monthly maximum BOD discharges were approximately 31 percent of permitted levels and mean monthly maximum TSS discharges were 34 percent of permitted levels.

Table 6 presents our PCS results for *noncompliance duration* metrics for BOD and TSS violations as of quarter 1 of 2006.

Table 6. Noncompliance Duration for Quarter 1 of 2006: Months in Effluent Specific NC

Mean Months with BOD SNC in previous year	0.04
Mean Months with TSS SNC in previous year	0.02
Mean Months with any BOD E90 violations for monthly average discharges	0.17
Mean Months with any TSS E90 violations for monthly average discharges	0.17
Mean Months with BOD violations for non-monthly average discharges	0.19
Mean Months with TSS violations for non-monthly average discharges	0.18

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The mean number of facility months in BOD SNC over the previous year was 0.04 and the mean number of facility months in TSS SNC over the previous year was 0.02. Roughly speaking, 0.04 months in BOD SNC over the previous year translates into 0.33% of facilities in BOD SNC during any given month of 2005. There were considerably more non-SNC violations. The mean number of months with non-SNC monthly average BOD violations was 0.17. This translates into 1.4% of facilities with non-SNC BOD violations in any given month of 2005. Results for non-SNC TSS monthly average violations were similar, and results for non-SNC non-monthly average BOD and TSS violations were somewhat higher.

Static Noncompliance Metrics: Discussion

Results from the preceding section suggest several objective lessons for characterizing static noncompliance within a sector and medium. We begin by discussing lessons from *noncompliance rates* and *noncompliance indexes*:

- First, noncompliance rates that consider significant noncompliance (SNC) violations alone and non-SNC violations alone generate substantially different results. Approximately 1/5 of our sample's noncompliance represents SNC violations. Non-SNC violations, typically for E90 effluent violations that don't directly trigger SNC, represent approximately 80 percent of sample's noncompliance.

- Second, results suggest that noncompliance indexes such as the ones explored in this report constructed from database elements typically provide little information beyond the information contained in basic noncompliance rates. Very few facilities have multiple recorded SNC and non-SNC violations at a given time, so noncompliance indexes approximately reproduce noncompliance rates. This is likely an artifact of data management rather than reality, since visual inspection and database documentation indicates that violations of a given type are usually only recorded for the most flagrant noncompliance.[3]

- Third, generalized OTIS derived noncompliance rates and indexes differ significantly from the more specific PCS derived conventional pollution noncompliance rates and indexes. For our sample quarter, there were approximately three times as many violations for all parameters/violations than for BOD and TSS violations alone.

We now discuss lessons from *noncompliance duration* and *regulated discharge* measures:

- First, as measures for characterizing static noncompliance, noncompliance duration metrics provide little information beyond noncompliance rates. Simply dividing the

[3] As discussed further in the recommendations section of the report, this limitation is not an intrinsic index characteristic. If an index was constructed from non-database elements or constructed from individual data elements in an ad hoc manner, it might provide novel evidence on the extent of noncompliance both within a given period of time and across time. In other words, limitations in our context are driven primarily by the structure and form of the utilized data.

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number of months in violation in the preceding year by 12 months returns the average monthly noncompliance rate for that year.

- Second, regulated discharges provide different information than noncompliance metrics. Mean conventional pollutant discharges of 30-40 of permitted levels might suggest that noncompliance is extremely rare. Yet, we find that nearly 50 percent of our sample facilities had some noncompliance in our sample quarter and 13 percent had some noncompliance for conventional pollutants.

To be clear, noncompliance duration measures provide little novel information beyond rates for characterizing noncompliance at a given point in time *when averaged across facilities*. For an individual facility, a noncompliance duration measure may provide information about that facility's environmental performance relative to other facilities. This facility specific information may be useful, for example, for inspecting targeting or other internal management purposes. The process of aggregation over facilities is what duplicates the noncompliance rate information.

4b. Characterizing Noncompliance over Time

We characterize noncompliance over time using PCS conventional water pollution SNC, discharge, and limit data. We do not evaluate any trends over time using the more general OTIS since this data system only tracks compliance for the most recent 3 years. Only 2006:1 OTIS data overlaps with our more specific PCS data.

Noncompliance Metrics over Time: Results

We first discuss our conventional pollutant PCS results for *statistically valid noncompliance rates* and *noncompliance indexes* over the first quarter (Jan-Mar) of the years 1999-2006. We compare the same quarter of each year to control for seasonality. Figure 1 summarizes key results graphically and Table 7 presents more complete details.

Figure 1. BOD/TSS Noncompliance Rates and Indexes: Quarter 1 of 1999-2006

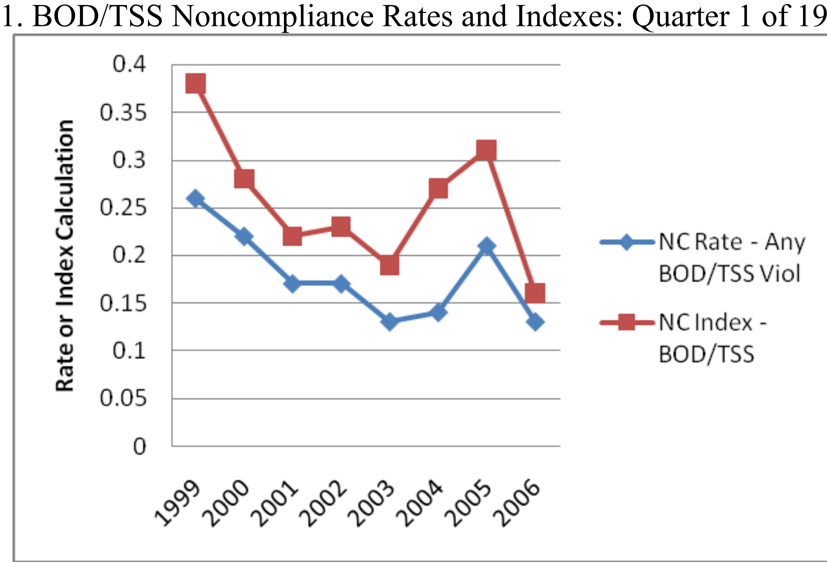

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Table 7. NC Rates and NC Indexes over Time: Effluent Specific

	% of facilities with any BOD or TSS violation	% of facilities with reporting SNC for BOD or TSS	% of facilities with BOD SNC	% of facilities with TSS SNC	% of facilities with any BOD E90 for monthly average discharges	% of facilities with any TSS E90 for monthly average discharges	% of facilities with BOD violation for max. discharges	% of facilities with TSS violation for max. discharges	Mean Effluent Specific NC Index
Quarter									
1999:1	0.26	0.09	0.01	0.06	0.08	0.07	0.06	0.07	0.38
2000:1	0.22	0.13	0.02	0.02	0.02	0.03	0.02	0.04	0.28
2001:1	0.17	0.01	0.02	0.02	0.04	0.01	0.06	0.08	0.22
2002:1	0.17	0.06	0.02	0.03	0.02	0.06	0.03	0.03	0.23
2003:1	0.13	0.04	0.00	0.01	0.03	0.02	0.06	0.03	0.19
2004:1	0.14	0.07	0.00	0.00	0.06	0.04	0.04	0.06	0.27
2005:1	0.21	0.06	0.02	0.02	0.06	0.04	0.06	0.08	0.31
2006:1	0.13	0.03	0.00	0.00	0.02	0.02	0.01	0.07	0.16

At least for the most aggregate metrics, noncompliance appears to be trending slightly down over time. The trend in the 'any violation' noncompliance rate presented as the blue (diamond marked) line in Figure 1 and presented in the second column of Table 7 is statistically significant. The noncompliance index presented as the red (square marked) line in Figure 1 and presented in the final column of Table 7 visually tracks the noncompliance rate closely, as perhaps expected, but the trend is not statistically significant due to greater overall variability.

The middle columns of Table 7 indicate that the overall trend in noncompliance rates is driven primarily by falling significant noncompliance (SNC) violations for monitoring report non-receipt, TSS SNC violations, and TSS effluent violations. BOD violations do not trend meaningful up or down, primarily due to low overall BOD violation rates. Figure 2, below, graphically presents several of the pollutant specific significant noncompliance (SNC) rates. The green (triangle marked) line reveals falling SNC reporting violations and the red (square marked) line reveals downward trending TSS SNC violations. BOD SNC violations track TSS SNC violations reasonably closely after the first sample year, but the trend for these violations is not statistically significant.

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Figure 2. BOD/TSS Significant Noncompliance Rates: Quarter 1 of 1999-2006

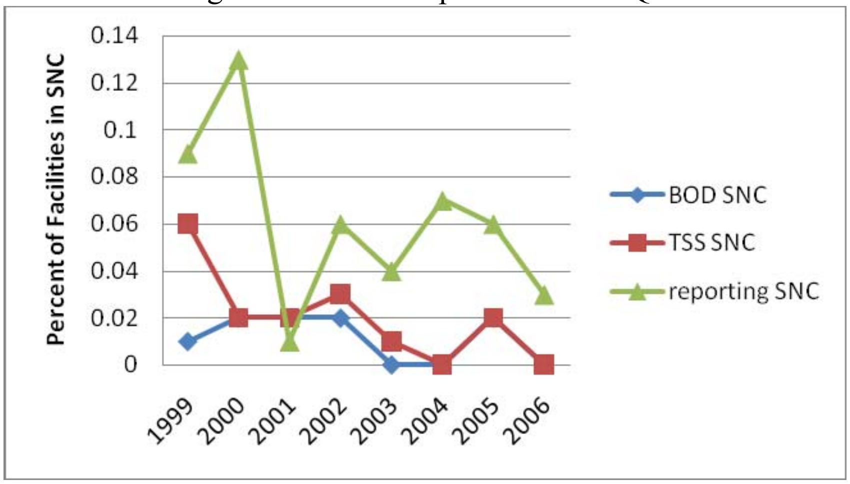

Table 8 presents our PCS results for *noncompliance duration* and *regulated discharge* metrics:

Table 8. Regulated Discharges and NC Duration over Time: Effluent Specific

Quarter	Mean monthly average BOD (as fraction of permitted levels)	Mean monthly average TSS (as fraction of permitted levels)	Mean monthly maximum BOD (as fraction of permitted levels)	Mean monthly maximum TSS (as fraction of permitted levels)	Mean # of months with BOD SNC last year	Mean # of months with TSS SNC last year	Mean # of months with BOD violations last year (monthly average metrics)	Mean # of months with TSS violations last year (monthly average metrics)
1999:1	0.45	0.50	0.43	0.51	0.16	0.19	0.24	0.26
2000:1	0.38	0.42	0.37	0.50	0.13	0.31	0.30	0.41
2001:1	0.41	0.38	0.41	0.47	0.12	0.04	0.14	0.20
2002:1	0.35	0.63	0.31	0.36	0.06	0.03	0.14	0.17
2003:1	0.39	0.40	0.37	0.35	0.06	0.09	0.08	0.12
2004:1	0.39	0.45	0.34	0.42	0.00	0.07	0.19	0.14
2005:1	0.41	0.45	0.40	0.44	0.01	0.01	0.24	0.17
2006:1	0.32	0.39	0.31	0.34	0.04	0.02	0.17	0.17

The duration measures in columns 6-9 of Table 8 reveal statistically significant downward trends for TSS months in violation, but no significant downward trend for BOD months in violation. Columns 2-5 reveal no statistically significant trends for any of the regulated discharge measures. However, the conventional water pollutants BOD and TSS do tend to track each other. For example, as demonstrated in Figure 3, there is a statistically significant positive correlation between BOD maximum discharges as a percent of permitted levels, TSS maximum discharges as a percent of permitted levels, and BOD average discharges as a percent of permitted levels. TSS monthly average discharges generally track all three other conventional pollutant discharge metrics, but one substantial outlier in 2002 weakens the statistical correlation.

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Noncompliance Metrics over Time: Discussion

Results from the preceding section suggest several objective lessons for characterizing environmental performance over time within a sector and medium. We begin by discussing lessons from *noncompliance rates* and *noncompliance indexes*:

- First, noncompliance rates for different pollutants and violation types do not necessarily trend together. Figure 2 indicates that year to year fluctuations in reporting SNC violations do not track effluent SNC violations in any obvious fashion. Even for effluents alone, results in Figure 2 demonstrate that significant trends can exist for one pollutant's noncompliance rates (TSS) and not for another pollutant's noncompliance rates (BOD). This result is consistent with the literature, which indicates that pollution discharges are often jointly determined but compliance decisions may be driven by only a subset of pollutants. See, for example, Shimshack and Ward (2008).

- Second, noncompliance indexes may provide additional information beyond rates alone for characterizing noncompliance through time. Figure 1 reveals that the wedge between overall noncompliance rates and the extent of noncompliance as measured by a noncompliance index widened between 2001 and 2005. This is suggestive, but not definitive, evidence supporting a hypothesis that the number of the number of violations per violator may have increased for this period even though the total number of violators displayed no clear trend. Collectively, results suggest that while noncompliance indexes may not provide statistically useful information at a single point in time (since index magnitudes are so similar to noncompliance rates), such indexes may still provide insights into relative changes in the extent of violations through time (as revealed by the wedge between noncompliance rates and noncompliance indexes).

We now discuss lessons from *noncompliance duration* and *regulated discharge* metrics:

- First, as measures for environmental performance over time, duration metrics provide little information beyond noncompliance rates. Duration measures divided by 12 months return monthly noncompliance rates for the evaluated year. As discussed above, however, this facility specific information may be useful for inspecting targeting or other internal management purposes. The process of aggregation over facilities is what duplicates the duration rate information.

- Note that we find statistically significant downward trends for TSS noncompliance duration measures but not for BOD duration measures, paralleling the pollutant specific rates in Figure 2.

- Second, regulated discharges may provide important additional information for characterizing environmental behavior through time, since regulated discharges do not necessarily trend with noncompliance rates. We find that noncompliance is falling over time, especially for TSS, but that pollution discharges do not trend in any obvious fashion. Figure 3 is a graph of regulated BOD/TSS discharges from Quarter 1 of 1996-2006. Figure 4 plots the any BOD/TSS noncompliance rates from Figure 1 on the same

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Figure 3. BOD/TSS Regulated Discharges: Quarter 1 of 1999-2006

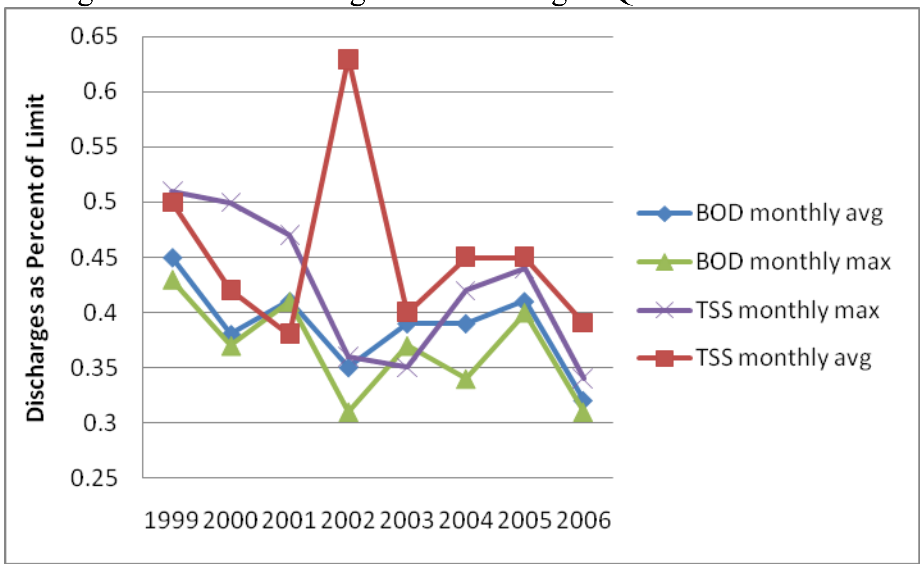
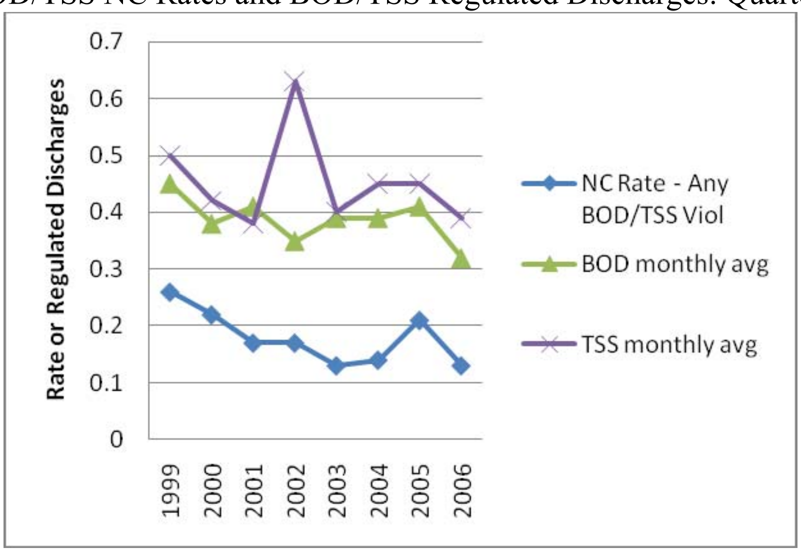


Figure 4. BOD/TSS NC Rates and BOD/TSS Regulated Discharges: Quarter 1 of 1999-2006



4c. Enforcement Deterrence Analysis

In this subsection, we characterize enforcement deterrence using the regression models described in Section 2. All analyses are from PCS conventional water pollution significant noncompliance (SNC), discharge, and limit data. Note that we do not evaluate enforcement deterrence using the more general OTIS since this data system only tracks compliance and environmental behavior for 3 years. For our deterrence evaluation purposes, three years of compliance and discharge data is insufficient.

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The short three year OTIS time series is insufficient for deterrence measurement in part because it limits statistical power. In technical terms, power is the ability of a statistical model to reject a hypothesis when it is in fact false. In practical terms, power is the ability of a model to provide results that are statistically meaningful and generalizable outside of the evaluated sample. Power is primarily a function of sample size (here, the number of facilities times the number of time periods) and the variability within the sample. In the short time series context, statistical power is limited because we do not typically observe enough enforcement actions and enough enforcement variability across facilities to make statistically credible and practically meaningful inferences.

A short time series also prevents the use of important statistical techniques that control for detailed facility and community characteristics without EPA data. Recall that our statistical techniques intuitively compare (a) the average difference between environmental performance during post-sanction and other periods for sanctioned facilities and (b) the average difference between environmental performance outcomes during these same periods for unsanctioned facilities. When the number of observation periods is small, such a comparison is difficult because (a) there are few sanctioned facilities, (b) even for sanctioned facilities, there are few "treatment" periods with enforcement actions, and (c) even for sanctioned facilities, there are few "control" periods without enforcement actions.

Enforcement Deterrence: Results

Table 9 summarizes our enforcement deterrence results for *statistically valid noncompliance rates.* Full numerical results are presented in Appendix Table A1. Recall that, in contrast to all other metrics, noncompliance rates are not facility specific and there is only one measure per period. Since noncompliance rates represent the percent of facilities in violation at a given time, each period's rate is an average of noncompliance indicators across all facilities. Consequently, the regression models for assessing the impact of enforcement on noncompliance rates are based upon 90 monthly observations (rather than 9090 facility-month observations for other regressions). Table 9 results show no practical or statistical relationship between lagged enforcement and subsequent noncompliance rates.

Table 9. Enforcement Deterrence Results: Change in NC Rates

	Coefficient – Penalties 1-12 months ago on all facilities	Coefficient – Penalties 13-24 months ago on all facilities	Practical and Statistical Evidence for Deterrence
Any BOD or TSS violation	-0.0001	0.0004	NO
BOD monthly avg. violation	0.0016	0.0007	NO
TSS monthly avg. violation	-0.0006	0.0006	NO
BOD monthly max. violation	0.0011	-0.0005	NO
TSS monthly max. violation	0.0025	0.0024	NO

NOTES: * indicates statistical significance at 10 percent level.

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Noncompliance rates have significant weaknesses for measuring the deterrence effect of enforcement. These weaknesses are discussed in the next subsection. Nevertheless, the facility-specific component parts of noncompliance rates, which we call *noncompliance status indicators*, may be useful. Table 10 summarizes our results for these metrics, and full numerical results are presented in Appendix Table A2:

Table 10. Enforcement Deterrence Results: Change in Noncompliance Status Indicators

	Regression Coefficient – Penalty 1-12 months ago on this plant	Regression Coefficient – Penalty 13-24 months ago on this plant	Practical and Statistical Evidence for Specific Deterrence	Coefficient – Penalty 1-12 mos. ago on other facility in state/sector	Coefficient – Penalty 13-24 mos. ago on other facility in state/sector	Practical and Statistical Evidence for General Deterrence
BOD monthly avg. violation	0.0478	0.4029	NO	-0.2254	-0.1318	NO
TSS monthly avg. violation	-0.4473	-0.4057	NO	-0.3680*	0.0798	YES
BOD monthly max. violation	0.0334	0.3424	NO	-0.0831	-0.2049	NO
TSS monthly max. violation	-0.3888	-0.9409*	YES	-0.1139	0.0362	NO

NOTES: * indicates statistical significance at 5 percent level.

Table 10 results suggest some specific and general deterrence of penalties for subsequent conventional water pollution noncompliance. Note that negative coefficients in Table 10 indicate that lagged penalties are associated with reduced BOD or TSS noncompliance. We find statistically significant evidence for specific deterrence from penalties for TSS monthly maximum violations. We also find statistically significant evidence for general deterrence from penalties for TSS monthly average violations. We find no evidence for deterrence effects of enforcement on BOD noncompliance for our sample.

We also examine the impact of enforcement on a *noncompliance index*. Numerical results for the noncompliance index regression are presented in Appendix Table A3. Index elements include SNC violations for BOD/TSS DMR non-receipt, SNC for BOD effluent violations, SNC for TSS effluent violations, non-SNC monthly average violations for BOD, non-SNC monthly average violations for TSS, monthly maximum violations for BOD, and monthly maximum violations for TSS. All estimated coefficients are negative, suggesting that lagged penalties are associated with reduced BOD or TSS noncompliance index scores. However, none of the results are statistically significant. In short, we find no strong evidence for specific or general deterrence of penalties for subsequent noncompliance index scores.

Table 11 summarizes our enforcement deterrence results for *regulated discharges*. Full numerical results are presented in Appendix Table A4:

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Table 11. Enforcement Deterrence Results: Change in Regulated Discharges

	Regression Coefficient – Penalty 1-12 months ago on this plant	Regression Coefficient – Penalty 13-24 months ago on this plant	Practical and Statistical Evidence for Specific Deterrence	Coefficient – Penalty 1-12 mos. ago on other facility in state/sector	Coefficient – Penalty 13-24 mos. ago on other facility in state/sector	Practical and Statistical Evidence for General Deterrence
BOD monthly avg discharges	-0.0453*	-0.0101	YES	-0.0026	-0.0028	NO
TSS monthly avg discharges	-0.0844*	-0.1105*	YES	-0.0161*	-0.0009	YES
BOD max discharges	-0.0535*	-0.0073	YES	-0.0057	-0.0072	NO
TSS max discharges	-0.0433	-0.1636*	YES	-0.0173*	0.0022	YES

NOTES: * indicates statistical significance at 5 percent level.

Table 11 results suggest important specific and general deterrence of penalties for subsequent conventional water pollution discharges. Note that all estimated coefficients are negative, implying that lagged penalties are consistently associated with reduced BOD and TSS discharges. We find statistically significant evidence for specific deterrence from penalties for both BOD and TSS discharges, and for both monthly average measurements and monthly maximum measurements. We also find statistically significant evidence for general deterrence from penalties for TSS discharges (both monthly averages and maximums), but not for BOD discharges.

Table 12 summarizes our enforcement deterrence results for *noncompliance duration metrics*. Full numerical results are presented in Appendix Table A5:

Table 12. Enforcement Deterrence Results: Change in Noncompliance Duration

	Regression Coefficient – Penalty 1-12 months ago on this plant	Regression Coefficient – Penalty 13-24 months ago on this plant	Practical and Statistical Evidence for Specific Deterrence	Coefficient – Penalty 1-12 mos. ago on other facility in state/sector	Coefficient – Penalty 13-24 mos. ago on other facility in state/sector	Practical and Statistical Evidence for General Deterrence
# of mos. in past year with BOD monthly avg violation	-0.2432*	0.0052	YES	-0.0212*	-0.0274*	YES
# of mos. in past year with TSS monthly avg violation	-0.2608*	-0.2892*	YES	-0.0355*	-0.0165	YES
# of mos. in past year with BOD monthly max violation	0.1899*	-0.0285	YES	-0.0164*	-0.0187*	YES
# of mos. in past year with TSS monthly max violation	-0.1653*	-0.4073*	YES	-0.0554*	-0.0266*	YES

NOTES: * indicates statistical significance at 5 percent level.

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Table 12 results suggest important specific and general deterrence of penalties for subsequent noncompliance duration. Note that all estimated coefficients are negative, implying that lagged penalties are consistently associated with reduced BOD and TSS noncompliance duration. We find statistically significant evidence for specific deterrence from penalties for both BOD and TSS noncompliance duration, and for both monthly average measurements and monthly maximum measurements. Further, we find statistically significant evidence for general deterrence from penalties for both BOD and TSS noncompliance duration.

Enforcement Deterrence: Discussion

Results from the preceding section suggest several objective lessons for characterizing the deterrence effects of enforcement within a sector and medium. We begin by discussing lessons from *noncompliance rates*.

In short, noncompliance rates are poor metrics for evaluating the impact of enforcement on environmental performance. Noncompliance rates are averages across the population of facilities, so they are not facility specific. The statistical power of the corresponding enforcement deterrence model is therefore extremely low. All facility observations for a given period of time are collapsed into a single number for each period, so the sample size and the sample variability shrink dramatically. Consequently, the ability of the model to generate statistically meaningful results decreases substantively.

Also, the theoretical link between enforcement actions and subsequent behavior in the rate-based deterrence model is tenuous. Rate-based deterrence regressions assess the impact of total enforcement actions on total noncompliance averaged across all facilities. For a given period, however, most facilities are neither subject to an enforcement action in the recent past themselves nor are they subject to an enforcement action in the recent past in their own state. It is therefore not clear that we should expect the majority of facilities in this model to respond to enforcement.

Finally, rate-based deterrence assessments preclude separate analyses of specific and general deterrence.

While noncompliance rates are poorly suited for deterrence analysis, the facility-specific noncompliance status indicators that make up the rates may be useful. These measures capture the spirit of noncompliance rates, but they are facility specific and therefore not subject to the problems that arise from aggregation across facilities. Lessons from these *noncompliance indicators* and the similar *noncompliance index* include:

- First, the impact of enforcement on noncompliance indicators varies by pollutant, so measured deterrence effects for different pollutants likely differ. For example, we find statistically significant specific and general deterrence from penalties for TSS violations, but no deterrence for BOD violations.

- Second, index-based models may provide additional deterrence information beyond indicator-based models alone but may sacrifice statistical power. While noncompliance

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- Third, a countervailing weakness of index-based deterrence models is that index components not responding to enforcement actions may simply add statistical noise. It is possible to find no statistical impact of enforcement on noncompliance indexes when statistically important deterrence actually exists for some components. For example, our indicator-based models reveal that enforcement actions significantly deter TSS violations yet our index-based models reveal insignificant deterrence effects of enforcement. In this case, the index-based model's statistical signal (from reduced TSS violations) may be obscured by BOD statistical noise.

The key lesson from *regulated discharge* metrics is that the specific and general deterrence effects of enforcement on discharges are not necessarily the same as the specific and general deterrence effects on noncompliance. Regulated discharge metrics importantly add to the analysis of deterrence:

- First, they allow for enforcement-induced changes in beyond compliance environmental performance. The literature has demonstrated that such behavior is common, and that over-compliance responds to changes in enforcement activity through mechanisms of discharge randomness and discharge jointness. See, for example, Bandyopadhyay and Horowitz (2006) and Shimshack and Ward (2008).

- Second, regulated discharge metrics may pick up enforcement deterrence impacts on the magnitude of effluent violations that are undetectable with indicator metrics. In other words, enforcement may reduce the size of violations without reducing the number of violations, and only regulated discharge metrics will identify such effects.

- Third, regulated discharges may more closely correlate with environmental quality than noncompliance.

We now discuss lessons from *noncompliance duration* metrics. The key message is that deterrence models based upon duration measures may provide new insights but may do so at the cost of poorer isolation of causal effects:

- An advantage of duration metrics is that they are inherently more variable than corresponding 0/1 noncompliance indicator variables, so they may add to the statistical power of deterrence assessment models. In our context, for example, we found no evidence for deterrence effects of enforcement actions on BOD pollutants using indicator-based models but we did find evidence with duration-based models. Note, however, that BOD deterrence magnitudes remain significantly smaller than TSS deterrence magnitudes.

- Despite advantages related to statistical power, results from duration-based measures may be particularly susceptible to reverse causality concerns. Recall that a deterrence

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5. Key Findings

Table 13 summarizes our key cross-measure comparison findings. The findings consider the relative strengths of different metrics for (1) assessing environmental behavior at a single point in time, (2) assessing environmental behavior over time, and (3) measuring the deterrence impacts of enforcement. Relative performance of the metrics is rated as (1) most useful, (2) highly useful, (3) possibly useful, and (4) poor:

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Table 13. Summarizing Cross-Measure Comparison Findings

Metric	**Usefulness for Characterizing Static Environmental Performance**	**Usefulness for Characterizing Environmental Performance Over Time**	**Usefulness for Measuring the Deterrence Effects of Enforcement**
Noncompliance Rate	Most useful metric. Most useful when applied to a broad-based NC measure and to specific violation and pollutant NC measures, since NC may differ for different violation types and pollutants.	Most useful metric. Most useful when applied to a broad-based NC measure and to specific violation and pollutant NC measures, since violation types and pollutants may not trend together.	Poor metric. Since the metric is not facility specific, models have poor statistical power and poor theoretical properties.
Noncompliance Indicator	Poor metric. Since the metric is facility specific, it cannot be used to summarize environmental performance across facilities.	Poor metric. Since the metric is facility-specific, it cannot be used to summarize trends in environmental performance across facilities.	Highly useful metric. Most useful when applied to specific violation types and pollutant indicators, since deterrence effects may vary across pollutants and violation types.
Noncompliance Index	Poor metric. Provides little information beyond NC rate metrics.	Possibly useful metric. May provide new information on trends in the number of violations per violator.	Possibly useful metric. Provides new information, but does so at the possible expense of statistical power.
Regulated Discharges	Possible useful metric. Average NC does not necessarily reveal information on average discharges, so regulated discharge metrics useful.	Highly useful metric. Trends in NC do not necessarily reveal information on trends in regulated discharges, so regulated discharge metrics useful.	Most useful metric. Provides deterrence information on compliance and beyond compliance behavior, deterrence magnitudes, and is most closely associated with environmental quality.
Noncompliance Duration	Poor metric. Provides little information beyond NC rate metrics.	Poor metric. Provides little information beyond NC rate metrics.	Possibly useful metric. Provides new information, but does so at the possible expense of poorer isolation of causal effects.

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Are key findings transferable to other sectors?

By design, the population studied in this report is one large industrial sector. *Numerical* results presented here are not necessarily transferable to other sectors, including other industries with large facilities. The specific noncompliance characterizations at a point in time, the trends in noncompliance over time, and the deterrence effects of enforcement actions presented in Tables 1-12 and A1-A5 are not necessarily applicable to any population other than major industrial organic and inorganic chemical facilities.

However, the key *cross-metric* findings summarized in Table 13 typically do transfer to other sectors, especially to other large industries where data collection and processing efforts are similar.[4] Table 13 findings are primarily based upon data definitions, data form, metric definitions, simple theory, and conservative assumptions about the relationships between noncompliance and discharges. As long as the type and form of the data analyzed for new sectors roughly parallels the type and form of the data analyzed here for the industrial chemicals sector, the general findings in Table 13 likely transfer.

One notable exception to the generalizability of the results in Table 13 regards noncompliance indexes. In this report, we find that noncompliance indexes constructed from selected database elements typically return limited information beyond noncompliance rates. Indexes are therefore considered poor metrics for characterizing noncompliance. As discussed above, however, this limitation is not an intrinsic index characteristic. If an index was constructed from non-database elements or constructed from individual data elements in an ad hoc manner, it might provide novel evidence on the extent of noncompliance both within a given period of time and across time. In other words, limitations in our context are driven primarily by the structure and form of the utilized data.

6. Key Subjective Recommendations

This section contains recommendations for OECA consideration. The majority of the recommendations regard metrics for assessing environmental behavior at a single point in time, environmental behavior over time, and the deterrence impacts of enforcement. All recommendations are based upon the author's subjective assessment of the current report's key findings, results of previous reports in this monitoring, enforcement, and environmental compliance series, and the broader state of knowledge.

Recommendations for Characterizing Static Environmental Performance

- Noncompliance rates assess static environmental performance more effectively than other metrics, especially noncompliance indexes and noncompliance duration measures.

  First, noncompliance rates are readily interpretable. Second, alternatives have significant disadvantages. Noncompliance indexes do not accurately reflect the extent of noncompliance due to data management issues and duration measures simply recover the

[4] It is the author's opinion that the findings in Table 13 may in principle generalize to small or nonindustrial facilities as well. However, data similar to those analyzed here would have to be collected for these facilities.

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same information as rates. Regulated discharges do provide additional information, especially on beyond compliance behavior, but they obscure noncompliance and are difficult to interpret at any given point in time.

- A broad-based 'any noncompliance' rate should be calculated for the period based upon the most comprehensive data available.

  Noncompliance rates based upon a small sample of pollutants, like BOD and TSS, may significantly understate total noncompliance. Violations for reporting, inspection-driven single events, toxics, and other pollutants are considerably more common for our sector than for conventional water pollutants.

- Broad-based 'any noncompliance' rates for the period should be supplemented with pollutant or violation specific noncompliance rates.

  Noncompliance for a subset of pollutants or violations does not imply noncompliance for other pollutants or violations, even among pollutants with highly correlated discharges. Therefore, noncompliance rates should be subdivided to reveal which pollutants drive noncompliance for a given sector and period. These pollutant specific rates may facilitate improved regulator targeting or other internal management decisions.

Recommendations for Characterizing Environmental Performance over Time

- Noncompliance rates assess trends in environmental performance more effectively than other metrics, especially noncompliance duration measures.

  Noncompliance rates are easily interpretable in both static and dynamic contexts. Several alternative metrics have significant disadvantages for assessing trends over time. For example, noncompliance duration measures return the same information as noncompliance rates.

- Broad-based 'any noncompliance' rates for assessing environmental performance over time should be supplemented with pollutant or violation specific noncompliance rates.

  Noncompliance for a given pollutant or violation type does not necessarily trend with noncompliance for other pollutants or violation types. Therefore, noncompliance rates for assessing environmental performance over time should be subdivided to reveal which pollutants or violations drive changes in noncompliance for the sector. These pollutant specific trends may facilitate improved regulator targeting or other internal management decisions.

- Noncompliance rates for assessing environmental performance over time should be supplemented with regulated discharge metrics.

  Noncompliance and discharges, even for single pollutants, are not necessarily strongly correlated. Regulated discharges over a sector may decline while violations remain

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unchanged or regulated discharges may remain unchanged while noncompliance decreases. Trends in regulated discharge metrics reveal important changes in beyond compliance behavior, violation magnitudes, and overall environmental impact that are obscured by noncompliance rates alone.

- Noncompliance rates for assessing environmental performance over time might be supplemented with noncompliance indexes for each period.

  Noncompliance indexes for characterizing noncompliance over time may provide important additional information beyond rates and regulated discharges alone. For example, rates only identify changes in the number of violators while noncompliance indexes may reveal changes in the number of violations per violator.

Recommendations for Measuring the Deterrence Effects of Enforcement

- Regression models based on regulated discharge metrics best assess the deterrence impacts of environmental enforcement.

  Discharge-based models allow for enforcement-induced changes in beyond compliance environmental performance. Also, regulated discharge metrics may pick up enforcement deterrence impacts on the magnitude of effluent violations that are undetectable with indicator metrics. Regulated discharges may more closely correlate with environmental quality than noncompliance. Finally, several alternative metrics, including noncompliance rates, noncompliance indexes, and noncompliance duration measures have significant statistical and practical disadvantages for assessing the deterrence effects of enforcement.

- Discharge-based deterrence models should evaluate as many distinct pollutants as is cost effective.

  The specific and general deterrence effects of enforcement on discharges vary by pollutant. Therefore, assessing the comprehensive impacts of specific and general deterrence requires the analysis of as many common contaminants as is practically feasible.

- Discharge-based deterrence models should be supplemented with models based on noncompliance status indicators.

  The specific and general deterrence effects of enforcement on noncompliance are not necessarily the same as the specific and general deterrence effects on discharges. Therefore, important additional information can be gained by analyzing the enforcement impacts on noncompliance. Models based on noncompliance status indicators should include a regression with a broad-based 'any noncompliance' dependent variable and regressions with noncompliance for specific pollutants as dependent variables.

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- Noncompliance rates should not be used for assessing the deterrence effects of environmental enforcement.

  Discharge-based regression models and noncompliance indicator-based regression models are most suitable for assessing the deterrence effects of enforcement. Index-based models and duration-based models are not ideal, but may be used in certain circumstances. Regressions based on noncompliance rates, however, should not be used to assess the deterrence effects of environmental enforcement. These models have low statistical power, poor theoretical properties, and preclude the separate analysis of specific and general deterrence.

Other Recommendations

- The Agency should consider expanding the availability of historical compliance and discharges data.

  Modern OTIS data only track compliance and environmental behavior for 3 years. Publicly accessible PCS/ICIS discharges and limit data are available for the most recent 5 years or less. Small temporal samples limit statistical power and prevent the important use of several important statistical techniques. It is the author's opinion that the amount and quality of external research conducted on compliance, deterrence, and environmental performance would increase significantly with more complete and accessible historical data.

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7. References

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Appendix A. Numerical Enforcement Deterrence Results

APPENDIX NOTES1: Observations for all regressions in Table A1 are by month. Regressions are linear, since the dependent variables are continuous. The dependent variables for all regressions are listed in column headings. The key explanatory variables are the number of fines across the universe of facilities in the recent past. T-statistics are in parentheses. A superscript * indicates statistical significance at the 10% significance level. ** indicates significance at the 5% significance level. *** indicates significance at the 1% significance level.

Table A1. Measuring Specific and General Deterrence of Fines: Change in Noncompliance Rates

	Dependent Variable: Any BOD or TSS SNC or non-SNC violation rate	Dependent Variable: BOD monthly avg. violation rate this period	Dependent Variable: TSS monthly avg. violation rate this period	Dependent Variable: BOD monthly max. violation rate this period	Dependent Variable: TSS monthly max. violation rate this period
Fines 1-12 months ago on all plants	-0.0001 (-0.02)	0.0016 (1.24)	-0.0006 (-0.46)	0.0011 (0.72)	0.0025 (1.46)
Fines 13-24 months ago on all plants	0.0004 (0.13)	0.0007 (0.53)	0.0006 (0.44)	-0.0005 (-0.30)	0.0024 (1.39)
Season Indicator Variables	Yes	Yes	Yes	Yes	Yes
Year Indicator Variables	Yes	Yes	Yes	Yes	Yes
Facility-Specific Fixed Effects	No	No	No	No	No

APPENDIX NOTES2: For regressions in Tables A2-A5, observations for all regressions are by plant and month. Tables A2-A4 present results from linear fixed effects regressions, since the dependent variables are continuous. Table A5 presents results from discrete fixed effects conditional logit regressions, since the dependent variables are 0/1 indicator variables. The dependent variables for all regressions are listed in column headings. The key explanatory variables are 0/1 fine indicator variables. The specific deterrence variables equal 1 if the facility received a penalty in the recent past. The general deterrence variables equal 1 if another facility in the same industry and state received a fine in the recent past. T-statistics are in parentheses. A superscript * indicates statistical significance at the 10% significance level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

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Table A2. Measuring Specific and General Deterrence of Fines:
Change in Noncompliance Status Indicators

	Dependent Variable: # BOD monthly avg. violation this period	Dependent Variable: TSS monthly avg. violation this period	Dependent Variable: BOD monthly max. violation this period	Dependent Variable: TSS monthly max. violation this period
Fines 1-12 months ago on another plant in same state	-0.2254	-0.3680***	-0.0831	-0.1139
	(-1.47)	(-2.85)	(-0.65)	(-1.09)
Fines 13-24 months ago on another plant in same state	-0.1318	0.0798	-0.2049	0.0362
	(-0.98)	(0.73)	(-1.60)	(0.37)
Fines 1-12 months ago on this plant	0.0478	-0.4473	0.0334	-0.3888
	(0.15)	(-1.31)	(0.10)	(-1.24)
Fines 13-24 months ago on this plant	0.4029	-0.4057	0.3424	-0.9409***
	(1.35)	(-1.31)	(1.12)	(-2.68)
Season Indicator Variables	Yes	Yes	Yes	Yes
Year Indicator Variables	Yes	Yes	Yes	Yes
Facility-Specific Fixed Effects	Yes	Yes	Yes	Yes

Table A3. Measuring Specific and General Deterrence of Fines:
Change in a BOD/TSS Noncompliance Index

	Dependent Variable: BOD/TSS Noncompliance Index
Fines 1-12 months ago on another plant in same state	-0.0056
	(-1.09)
Fines 13-24 months ago on another plant in same state	-0.0053
	(-1.06)
Fines 1-12 months ago on this plant	-0.0245
	(-1.05)
Fines 13-24 months ago on this plant	-0.0197
	(-0.86)
Season Indicator Variables	Yes
Year Indicator Variables	Yes
Facility-Specific Fixed Effects	Yes

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Table A4. Measuring Specific and General Deterrence of Fines: Change in Regulated Discharges

	Dependent Variable: BOD Monthly Avg. Discharges	Dependent Variable: TSS Monthly Avg. Discharges	Dependent Variable: BOD Monthly Max. Discharges	Dependent Variable: TSS Monthly Max. Discharges
Fines 1-12 months ago on another plant in same state	-0.0026 (-0.73)	-0.0161*** (-3.74)	-0.0057 (-1.37)	-0.0173*** (-2.83)
Fines 13-24 months ago on another plant in same state	-0.0028 (-0.82)	-0.0009 (-0.22)	-0.0072* (-1.78)	-0.0022 (-0.38)
Fines 1-12 months ago on this plant	-0.0453*** (-2.82)	-0.0844*** (-4.33)	-0.0535*** (-2.85)	-0.0433 (-1.56)
Fines 13-24 months ago on this plant	-0.0101 (-0.65)	-0.1105*** (-5.94)	-0.0073 (-0.40)	-0.1636*** (-6.18)
Season Indicator Variables	Yes	Yes	Yes	Yes
Year Indicator Variables	Yes	Yes	Yes	Yes
Facility-Specific Fixed Effects	Yes	Yes	Yes	Yes

Table A5. Measuring Specific and General Deterrence of Fines: Change in Noncompliance Duration

	Dependent Variable: # of months with BOD monthly avg. violation in past year	Dependent Variable: # of months with TSS monthly avg. violation in past year	Dependent Variable: # of months with BOD monthly max. violation in past year	Dependent Variable: # of months with TSS monthly max. violation in past year
Fines 1-12 months ago on another plant in same state	-0.0212*** (-2.60)	-0.0355*** (-4.36)	-0.0164** (-1.99)	-0.0554*** (-6.54)
Fines 13-24 months ago on another plant in same state	-0.0274*** (-3.49)	-0.0165 (-2.10)	-0.0187** (-2.35)	-0.0266*** (-3.27)
Fines 1-12 months ago on this plant	-0.2432*** (-6.61)	-0.2608*** (-7.09)	-0.1899*** (-5.09)	-0.1653*** (-4.33)
Fines 13-24 months ago on this plant	0.0052 (0.15)	-0.2892*** (-8.03)	-0.0285 (-0.78)	-0.4073*** (-10.90)
Season Indicator Variables	Yes	Yes	Yes	Yes
Year Indicator Variables	Yes	Yes	Yes	Yes
Facility-Specific Fixed Effects	Yes	Yes	Yes	Yes

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