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

Task 3: Metrics and Model Calibration

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Executive Summary

This brief report presents simplified frameworks for quantitative database analysis of specific and general deterrence of environmental monitoring and enforcement. The goal of the report is to present metrics that are technically rigorous, yet cost-effective for future in-house use by the Environmental Protection Agency's Office of Enforcement and Compliance Assurance (OECA). Here, cost-effective means easily replicable with modest training.

Presented methods are based upon the recent published empirical literature. We focus on methods developed from existing peer-reviewed studies to ensure the basic approach is of known value to OECA, the EPA, EPA stakeholders, and other interested parties. Simplified frameworks for specific deterrence measurement follow noted publications by Gray and co-authors. Simplified frameworks for general deterrence measurement follow noted publications by Shimshack and Ward.

Two key findings emerge: (1) Simplified, cost-effective quantitative database methods exist to measure the specific and general deterrence of environmental monitoring and enforcement. (2) When benchmarked against data analyzed in the pre-existing literature, presented metrics produce deterrence effects approximately equal to those reported in published studies. In other words, the easily implemented methods discussed in this report typically produce similar results to the more sophisticated and expensively implemented academic methods.

Key recommendations, based upon the author's subjective professional assessment, are: (1) In the short-run, OECA and its contractors should apply this study's models to approximately 4 additional sector / pollution media combinations. (2) In the longer run, OECA should consider applying the simplified deterrence measurement models to additional datasets created from the extensive data available to the EPA. (3) Particular care should be paid to the issue of reverse causality in the estimation of specific deterrence effects. (4) If robust and theoretically consistent results emerge, deterrence estimates from the simplified models should help inform OECA and Agency management decisions, along with other relevant considerations.

1. Purpose and Scope

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

Specifically, this report presents and calibrates simplified frameworks for database analysis of specific and general deterrence of environmental monitoring and enforcement. In this context, specific deterrence refers to the effects of regulatory actions on the evaluated or sanctioned firm itself. General deterrence refers to the effects of regulatory actions aimed at one facility on the environmental performance of other similar facilities. The immediate goal of the report is to present and calibrate metrics that are technically rigorous, yet cost-effective for future in-house use by the Environmental Protection Agency's Office of Enforcement and Compliance Assurance (OECA). Here, cost-effective means easily replicable with modest training. The eventual goal of the broader project (summarized in Task 1-5 reports) is to improve the agency's ability to measure and evaluate the effectiveness of its enforcement and monitoring activities.

Presented metrics and methods are based upon the recent *published* environmental enforcement literature. We develop methods from existing peer-reviewed studies to ensure the basic approach is of known value to OECA, the EPA, EPA stakeholders, and other interested parties. Simplified frameworks for specific deterrence measurement follow noted publications by Gray and co-authors. Simplified frameworks for general deterrence measurement follow noted publications by Shimshack and Ward. The simplified frameworks are then calibrated with the data used in the corresponding publications.

As requested in the Statement of Work, this document is limited in scope. As such, it is most effectively considered not solely on its own, but as part of the Office of Research and Development (ORD) and the Office of Enforcement and Compliance Assurance's (OECA) broader compliance and deterrence research project. Readers of this report are strongly encouraged to first familiarize themselves with the associated "Monitoring, Enforcement, and Environmental Compliance: Understanding Specific and General Deterrence State-of-Science White Paper."[1] The white paper reviews the entire recent policy-relevant environmental compliance literature. Many of the theoretical foundations, statistical concepts, and practical considerations essential to understanding

[1] J. Shimshack, Monitoring, Enforcement, and Environmental Compliance: Understanding Specific and General Deterrence, State-of-Science White Paper Prepared for the Environmental Protection Agency's Office of Research and Development and Office of Enforcement and Compliance Assurance. Oct. 2007. Available online at: http://www.epa.gov/compliance/resources/reports/compliance/research/index.html .

this report's methods, findings, and recommendations are discussed in detail in the white paper and will not be repeated here.

As the Task 3 statement of work requires, this report identifies statistically rigorous, yet simplified and cost-effective, metrics for the database analysis of the deterrence effects of environmental monitoring and enforcement. Those metrics are then benchmarked against data analyzed in the pre-existing literature to examine if the estimated deterrence effects from simplified models approximately equal those reported in published studies. These two objectives are admittedly narrow, and several concepts important to the broader compliance and deterrence project are not fully explored here. First, this report is not intended, on its own, to establish the deterrence effects of monitoring and enforcement actions. The extensive peer-reviewed literature summarized in the associated State-of-Science White paper more comprehensively explored these questions. Second, many replication considerations represent important areas for future research for task 4, task 5, and beyond. These issues include the necessary sector size, characteristics, and data variability necessary for applying these models on new sectors in statistically valid ways. Additional subjects for future research include the appropriate replication frequency necessary to characterize a given sector's current deterrence level and the confounding factors (ie. facility size, industrial sub-category, marginal compliance costs) that may enhance specific and general deterrence.

2. Basic Model and Statistical Intuition
Theoretical foundations

Analysis of the impact of environmental regulatory activity on environmental performance is framed in terms of deterrence. Pollution sources 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 inspections or enforcement actions, is hypothesized to increase a plant's expected compliance and decrease a plant's expected pollution (on average).

Basic empirical model and intuition

The overall empirical strategy for identifying metrics for specific and general deterrence is to link inspections and enforcement actions to subsequent compliance and pollution behavior. The simplified deterrence measurement models developed in subsequent sections examine plant-level data for many plants in a given sector over several years. The dependent variable in our analyses is a 0/1 discrete compliance indicator or a continuous pollution measure for a given plant in a given time period. For example, the 0/1 compliance indicator may signify if a plant is determined to be in significant non-compliance with its conventional water pollution obligations in a given month. An example of the continuous pollution variable is the percent of permitted TSS contaminants discharged by a given plant in a given month. The key explanatory variable for specific deterrence models is lagged EPA/state enforcement activities directed at that facility. For example, the key specific deterrence explanatory variable may be the number of inspections directed at the given facility over the past year. The key explanatory variable for general deterrence models is lagged EPA/state enforcement activities directed at other facilities in the same state and sector. For example, the key general deterrence explanatory variable may be the presence of a fine directed at another facility in the same state and sector in the past year. Other explanatory variables are included in the simplified models to capture confounding factors.

For the more mathematically and statistically inclined reader, the basic regression model is $y_{it} = \alpha_i + \gamma_t + D_{it}\delta + \mathbf{X}_{it}\boldsymbol{\beta} + \varepsilon_{it}$, where i indexes the unit of observation (a facility) and t indexes time (months or years). y_{it} represents facility i's compliance status or scaled pollution discharges in period t. α_i is typically a facility-specific indicator that represents unobserved time invariant facility characteristics like size, capacity, industrial sub-category, and profitability. The basic idea here is that different facilities have different regression intercepts. γ_t is a year-specific indicator that represents unobserved time effects common to all facilities like technological change, sector maturation, and economic fluctuations over time. D_{it} is the key explanatory variable and represents the presence or count of lagged EPA/state enforcement or monitoring activities. 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. X_{it} represents other control variables, including seasonality indicators to control for within-year variation and state-specific indicators to control for average differences in regulatory activity across states.[2] ε_{it} is the usual regression error term.

The basic intuition of the empirical models is quasi-experimental. Essentially, the simplified 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, in the specific deterrence models, we might compare facility/time combinations with an inspection in the past year with facility/time combinations without an inspection in the past year. The difference between these two average levels represents the average deterrence effect of an inspection in the recent past. For some of the models, the actual statistical identification of deterrence effects is more subtle, but the basic intuition still holds.[3,4]

[2] As a technical note, in models that actually contain facility specific fixed effects, these state level fixed effects are omitted since they are redundant.

[3] Note that this intuition implies that any concerns about regression to the mean are minimized. The regression to the mean concern is that periods that triggered regulator actions may reflect abnormally high pollution levels and therefore post-action periods may *inherently* display lower pollution levels than pre-action periods. However, note that the relevant comparison is not pre-action vs. post-action performance. The relevant comparison is performance (or changes in performance) for those observations with actions vs. performance (or changes in performance) for those observations without actions, and so the comparison is relative to *all* non-sanction periods (not just the pre-action period).

[4] Also note that this intuition implies that historically-derived baseline data is not necessary to achieve useful results. Results still show the impact of inspections or enforcement activity on pollution and

Both specific and general deterrence analyses should be typically examined on a sector-by-sector basis. Since a key component of the statistical identification and statistical intuition in the specific deterrence models is a behavioral comparison of facility/time pairs with an inspection or enforcement action to facility/time pairs without an inspection or an enforcement action, specific deterrence models should typically be considered one sector at a time. This restriction ensures that comparison facilities share roughly similar characteristics. Similarly, a key component of the statistical identification in the general deterrence models is a behavioral comparison of facility/time pairs with enforcement actions on neighboring facilities to facility/time pairs without an enforcement action on neighboring facilities. So, general deterrence models should also typically be considered one sector at a time.

When the dependent variable is continuous, like emissions or discharges, ordinary linear regression models are most appropriate. The values of the explanatory variables for a given observation predict a corresponding average or expected emissions level. For example, all else equal, we would expect a facility's average emissions to be lower following an enforcement action. When the dependent variable is discrete, however, like a 0/1 compliance status or non-compliance status indicator, non-linear models are more appropriate than linear regression models. When the dependent variable is limited to take on a value of 0 or 1, ordinary linear regressions are known as linear probability models. The values of the explanatory variables for a given observation predict a corresponding average or expected probability of compliance. For example, all else equal, we would expect a facility's probability of compliance to be higher following an enforcement action. Linear probability models exhibit at least two well-known weaknesses. First, predicted values from a linear regression may lie outside of the 0/1 range. For example, the predicted probability of compliance from a linear probability model may be negative or greater than 1. Second, linear probability models force the impact of an explanatory variable to be the same for all values of the dependent variable. For example, the change in the predicted probability of compliance due to an enforcement action is the same for a facility with a low probability of compliance and a facility with a high probability of compliance. Non-linear models, like the logit model, overcome these difficulties and are therefore used here when the dependent variable is discrete.

Three regression approaches

This brief sub-section is for the more technically inclined reader, and can be skipped if preferred. Here, we discuss the three regression approaches proposed in the next two sections. Each regression approach maps to the basic empirical model discussed above, and all are discussed in the related white paper, easily implemented with common statistical packages, and are referenced in most basic statistics/econometrics textbooks. The key difference between the three models is their approach to addressing the facility-specific regression parameter α_i. Recall that the key function of this facility-specific

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compliance for a given period of time ("aggregate BOD and TSS discharges within a state fall approximately 7 percent in the year following a sanction within that state.") without reference to a historical period.

regression parameter is to capture the "individuality" of each facility without actually requiring data on all of the differences between facilities. In other words, α_i exploits the panel nature of the data to account for facility-specific confounding factors (like size, age, industrial sub-category, and profitability) without actually requiring data on these confounders.

The fixed effect empirical model holds the slope coefficient (representing the impact of an additional regulatory action on future pollution or compliance) constant for all facilities, but allows each facility to have its own regression intercept α_i. This approach accounts for the "individuality" of each facility and implicitly controls for all facility-specific confounding factors that are approximately constant across time, like size, profitability, and industrial sub-category. Intuitively, the identification of the fixed effects model can be interpreted as a difference-in-differences estimator. Here, the specific deterrence impact of a marginal (additional) regulator action on compliance or pollution is the difference between (a) the difference between post-action pollution or compliance and the average pollution or compliance levels for all facilities that had received an action in the recent past and (b) the difference between the same time periods and the average pollution or compliance levels for all facilities that did not receive an regulatory action in the recent past. The general deterrence impact of a marginal (additional) regulator action is similar, except that the regulator action is on other facilities in the same state and sector, rather than on plant i itself.

Random effect models also attempt to capture the "individuality" of facilities while holding the slope coefficient (representing the impact of an additional regulatory action on future pollution or compliance) constant. However, the modeling approach for α_i differs from the fixed effect approach. Instead of allowing each facility its own intercept as in the fixed effects model, the random effects model assumes a statistical distribution for these parameters around a common mean value. Intuitively, the identification of the random effects model can be interpreted like an ordinary least squares regression. Here, the specific deterrence impact of a marginal (additional) regulator action on compliance or pollution is the pollution or compliance difference between 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, after controlling for confounding factors. The general deterrence impact of a marginal (additional) regulator action is the pollution or compliance difference between observations in which there was an agency action in the recent past directed towards others in the same state and sector to observations in which there was no agency action in the recent past directed towards others in the same state and sector.

Finally, the *conditional* random effects model also attempts to capture the "individuality" of facilities while holding the key slope coefficient constant. The intuition is identical to that of fixed effects, and the aim is still to control for missing variables potentially correlated with the key explanatory variables. Conditional random effects are persistent effects at the plant-level, like fixed effects, but they condition on the sample average of a few observed variables rather than all variables (as in fixed effects). Since the intuition is identical, and fixed effects are more comprehensive, one might wonder why conditional random effect regression specifications are ever preferred to fixed effect regression specifications. For reasons beyond the scope of this report, fixed effects lead to biased (wrong, on average) estimates for the non-linear models necessary when the dependent variable is discrete like a 0/1 compliance indicator.

Correlation vs. Causality

The first lesson of basic statistics is that correlation is not causality. However, the simplified, cost-effective regression models developed in this report *do* attempt to isolate causality and *do* intend to attribute deterrence directly to average regulatory actions. First, the panel data techniques discussed in the preceding sub-section are explicitly designed to minimize bias from omitted variables (important confounding factors not explicitly included in the data and models). Second, and more importantly, the models account for reverse causality. The concern here is that correlations between monitoring and enforcement activities and compliance and emissions may reflect the causal effect of compliance or emissions on monitoring and enforcement due to regulator targeting. However, this reverse causality is minimized in two ways. First, all monitoring and enforcement variables in the analysis are lagged. While it is possible that contemporaneous pollution or compliance may induce regulator actions, it is unlikely that current pollution or compliance induced regulator actions *in the past.* Only past pollution or compliance is likely to have induced past regulator actions. Second, two of the panel data techniques (fixed effects and conditional random effects) discussed in the preceding sub-section provide unbiased (accurate, on average) estimates of deterrence impacts in the presence of correlations between the facility specific control and the standard error term. In other words, these models isolate the direction of causality, even if enforcement or inspection targeting is based upon a plant's overall environmental performance.[5]

3. Simplified Methods for Measuring Specific Deterrence

The state-of-science white paper prepared for Task 1 of this ORD/OECA deterrence research project reveals that significant reductions in non-compliance and emissions are obtainable with traditional monitoring and enforcement. *The environmental regulation literature indicates that inspections and enforcement actions consistently produce improved future environmental performance at the evaluated or sanctioned facility*. Results hold both historically and currently.

Consequently, the Task 1 state-of-science white paper recommended that OECA should consider closely replicating statistical database analyses for measuring the specific deterrence effects of monitoring and enforcement. This section presents simplified, cost-effective quantitative methods for this purpose. In this context, specific deterrence refers to the effects of regulatory actions on the evaluated or sanctioned firm itself.

[5] A complete proof of this statement is beyond the scope of this report, but the well known econometric advantage of fixed effect and conditional random effect models over other techniques is unbiased estimates in the presence of such a correlation. See any introductory econometrics textbook for a more complete discussion.

- **Metrics:** (1) the response of a plant's compliance status to lagged EPA/state enforcement and monitoring activities directed at that facility, (2) the response of a plant's pollution emissions to lagged EPA/state enforcement and monitoring activities directed at that facility. Metrics should be explored on a sector-by-sector basis.

- **Peer-Reviewed Foundation:** Gray and Deily (1996), Gray and Shadbegian (2005), Gray and Shadbegian (2007), and Deily and Gray (2007).

- **Potential Data Requirements:** (1) compliance status (a discrete 0/1 indicator variable) or specific pollutant emissions (a continuous variable) for plant i in time period t,[6] (2) a year indicator for time t, (3) a season indicator for time t if the data are monthly or quarterly, (4) a state indicator for plant i, (5) inspections at plant i over the past year, (6) inspections at plant i 1-2 years ago, (7) inspections at plant i 2-3 years ago, (8) enforcement actions at plant i over the past year, (9) enforcement actions at plant i 1-2 years ago, and (10) enforcement actions at plant i 2-3 years ago.

- **Potential Statistical Methodologies for the Continuous Emissions Metric:** (1) linear regression with plant-specific fixed effects, (2) linear regression with plant-specific random effects, and (3) linear regression with plant-specific conditional random effects. The continuous nature of the emissions metric suggests linear regressions are appropriate. All methods are discussed in Section 2 and the technical appendix of the Task 1 white paper. All are easily implemented (pre-programmed) with modern statistical software. All models include state-specific indicator variables and year-specific indicator variables.[7]

- **Potential Statistical Methodologies for the Compliance Status Metric:** (1) logit regression with plant-specific fixed effects, (2) logit regression with plant-specific random effects, and (3) logit regression with plant-specific conditional random effects. The discrete nature of the 0/1 compliance status metric suggests non-linear logit regressions are more appropriate than linear regression models. All methods are discussed in Section 2 and the technical appendix of the Task 1 white paper. All are easily implemented (pre-programmed) with modern statistical software. All models include state-specific indicator variables and year-specific indicator variables.

- **Key Simplification and Justification 1:** Detailed variables representing plant and community characteristics assembled from non-EPA datasets are omitted. State indicator variables, year indicator variables, and panel data statistical

[6] In principle, compliance status may refer to any desired compliance indicator, including agency determined Significant Non-compliance status or High-Priority Violation status. In the Gray and co-author papers that serve as the foundation of the later specific deterrence benchmarking analyses, compliance status is EPA-determined as reported in the Compliance Data System and the more recent Integrated Data for Enforcement Analysis Database.

[7] Technically, models with plant-specific fixed effects will not also include state-specific indicators, since these variables are redundant.

techniques account for these omitted factors in our simplified models. State indicator variables capture community and regulatory differences across states. Year indicator variables capture common technological change, sector maturation, and economic fluctuations over time. Panel data statistical techniques capture systematic plant characteristics like age, capacity, industrial sub-category, and profitability. The key assumption underlying the statistical validity of the "no outside data" simplification is that technical change is relatively modest, regulations are fairly static, and managerial attitudes are not evolving rapidly for most facilities over the sample period. My subjective assessment is that broad conclusions are likely applicable on the scale of a decade or so for many industries, but unlikely applicable for multiple decade periods.

- **Key Simplification and Justification 2:** Sophisticated econometric prediction techniques meant to minimize the possibility of "reverse causality" are replaced with an analysis that includes panel-data statistical techniques and lagged monitoring and enforcement variables. The statistical techniques and lagged explanatory variable specifications used here still attempt to isolate causality and minimize statistical bias. The reverse causality concern is that plants with higher emissions or frequent non-compliance are often targeted for inspections and enforcement actions, and therefore regression models may show a positive correlation between enforcement and emissions/non-compliance. If present this reverse causality erroneously suggests that inspections and sanctions may increase emissions. Panel data statistical techniques (fixed effects, random effects, conditional random effects), however, at least partially remove cross-plant differences in overall enforcement. Further, lagged monitoring and enforcement variables should only reflect factors operating in the past, so these variables should not depend (theoretically) on the current level of environmental performance.

4. Simplified Methods for Measuring General Deterrence

The state-of-science white paper prepared for Task 1 of this ORD/OECA deterrence research project reveals that monitoring and enforcement spills over to deter violations at facilities beyond the sanctioned entity. Environmental facilities learn from the experiences of their neighbors, and this learning impacts compliance behavior. *The environmental regulation literature indicates that inspections and enforcement actions consistently produce significant spillover effects on non-sanctioned facilities.* Focusing on deterrence effects at the sanctioned facility alone may seriously underestimate the efficacy of fines and other sanctions.

The Task 1 state-of-science white paper therefore recommended that OECA should consider closely replicating statistical database analyses for measuring the general deterrence effects of monitoring and enforcement. This section presents simplified, cost-effective quantitative methods for this purpose. In this context, general deterrence refers to the effects of regulatory actions aimed at one facility on the environmental performance of other similar facilities.

- **Metrics:** (1) the response of a plant's compliance status to lagged EPA/state enforcement and monitoring activities directed at other facilities in the same state and sector, (2) the response of a plant's pollution emissions to lagged EPA/state enforcement and monitoring activities directed at other facilities in the same state and sector.[8] Metrics should be explored on a sector-by-sector basis.

- **Peer-Reviewed Foundation:** Shimshack and Ward (2005) and Shimshack and Ward (2008).

- **Potential Data Requirements:** (1) compliance status (a discrete 0/1 indicator variable) or specific pollutant emissions (a continuous variable) for plant i in time period t,[9] (2) a year indicator for time t, (3) a season indicator for time t if the data are monthly or quarterly, (4) a state indicator for plant i, (5) inspections at other similar plants over the past year, (6) inspections at other similar plants 1-2 years ago, (7) inspections at other similar plants 2-3 years ago, (8) enforcement actions at other similar plants over the past year, (9) enforcement actions at other similar plants 1-2 years ago, and (10) enforcement actions at other similar plants 2-3 years ago.

- **Potential Statistical Methodologies for the Continuous Emissions Metric:** (1) linear regression with plant-specific fixed effects, (2) linear regression with plant-specific random effects, and (3) linear regression with plant-specific conditional random effects. The continuous nature of the emissions metric suggests linear regressions are appropriate. All methods are discussed in Section 2 and the technical appendix of the Task 1 white paper. All are easily implemented (pre-programmed) with modern statistical software. All models include state-specific indicator variables and year-specific indicator variables.[10]

- **Potential Statistical Methodologies for the Compliance Status Metric:** (1) logit regression with plant-specific fixed effects, (2) logit regression with plant-

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[8] Although sector emissions or compliance should be considered on a sector-by-sector basis, it is not strictly necessary to restrict attention to enforcement and monitoring activities directed at other facilities in the same state and sector. However, Gray and Shadbegian [2005] found that plants seem inclined to respond to general deterrence created by the experiences of facilities in the same state, but not neighboring states. In principle, one might examine the response of pulp and paper compliance to enforcement actions levied in the chemical sector, since these actions may also signal the regulator's reputation for toughness. However, restricting attention to enforcement and monitoring activities directed at other facilities in the same sector seems like the appropriate starting point for analysis.

[9] In principle, compliance status may refer to any desired compliance indicator, including Agency determined Significant Non-compliance status or High-Priority Violation status. In the Shimshack and Ward papers that serve as the foundation of the later general deterrence benchmarking analyses, compliance status is determined by examining actual discharges relative to permitted standards. While any exceedance of permitted levels is considered non-compliance, a large number of violations correspond to significant non-compliance (greater than 40 percent above permitted limits for conventional water pollutants).

[10] Technically, models with plant-specific fixed effects will not also include state-specific indicators, since these variables are redundant.

specific random effects, and (3) logit regression with plant-specific conditional random effects. The discrete nature of the 0/1 compliance status metric suggests non-linear logit regressions are more appropriate than linear regression models. All methods are discussed in Section 2 and the technical appendix of the Task 1 white paper. All are easily implemented (pre-programmed) with modern statistical software. All models include year-specific indicator variables and period-specific indicator variables.

- **Key Simplification and Justification 1:** Detailed variables representing plant and community characteristics assembled from non-EPA datasets are omitted. State indicator variables, time indicator variables, and panel data statistical techniques account for these omitted factors in our simplified models. State indicator variables capture community and regulatory differences across states. Year indicator variables capture common technological change, sector maturation, and economic fluctuations over time. Panel data statistical techniques (fixed effects, random effects, conditional random effects) capture systematic plant characteristics like age, capacity, industrial sub-category, and profitability. The key assumption underlying this simplification is that technical change is relatively modest, regulations are fairly static, and managerial attitudes are not evolving rapidly for most facilities over the sample period.

- **Key Simplification and Justification 2:** Concerns about reverse causality are substantially less significant for the measurement of general deterrence than for the measurement of specific deterrence. In short, monitoring and enforcement targeting at any given plant has less to do with emissions or non-compliance at other facilities than emissions or non-compliance at the plant in question. Lags do not typically need to be as far in the past and reverse causality is not typically crucial. Therefore, only minor additional simplifications are required for measuring general deterrence with cost effective methods. These simplifications include ignoring statistical techniques designed to improve the statistical precision of the estimation. The magnitudes of the deterrence estimates are unaffected by these more minor statistical considerations.

5. Benchmarking the Simplified Methods

In this section, we first benchmark the simplified models for measuring specific deterrence presented in Section 3. We then benchmark the simplified models for measuring general deterrence in Section 4. In each case, we use a dataset that has been extensively analyzed in the existing peer-reviewed literature. The goal is to evaluate the simplified deterrence models and compare key results to those published using the same datasets with more expensively implemented statistical methods.

Benchmarking Specific Deterrence Methods

Our benchmark dataset for the specific deterrence measurement methods is a steel industry dataset of 41 mills for the period 1980-1989. The steel industry is characterized by large industrial sources with relatively similar production processes and pollution treatment technologies across facilities. Sources, however, may be geographically diverse. Deterrence effects from this dataset were examined in Gray and Deily (1996) and Deily and Gray (2007). The key data source was the EPA's Compliance Data System (CDS), which has since been updated and incorporated into the Integrated Data for Enforcement Analysis (IDEA) system. Air compliance status outcomes, and not air emissions, are investigated.

Results from applying the simplified models for measuring specific deterrence to the steel mill dataset are presented in Table 1A and Table 1B. Table 1A presents regression specifications with key explanatory variables defined as 'inspection lagged 1-2 years ago.' Table 1B presents regression specifications with key explanatory variables defined as 'inspection lagged 1-3 years ago.' Nearly all of the models show a statistically significant specific deterrence effect. The estimated impact of lagged inspections on the compliance status dependent variable is always positive and typically strongly significant for both lag specification types. The magnitudes are also quite large. For example, in Table 1A, all three simplified models indicate that a plant with at least one inspection 1-2 years ago was 17-19 percent (.17-.19) more likely to be in compliance than a plant with no inspections 1-2 years ago. Specific deterrence effects of lagged inspections on air compliance in Table 1B are relatively similar in practice. Here, we find that plants with at least one inspection 1-3 years ago were approximately 27 percent (.27) more likely to be in compliance than plants with no inspections 1-3 years ago.

The 0.487 fixed effects estimate in Table 1B suggests that plants with at least one inspection 1-3 years ago were approximately 49 percent (.49) more likely to be in compliance than average, after controlling for changes in plants with no inspections 1-3 years ago. This latter fixed effect result is considerably larger than other estimated inspection impacts (~27 percent) and may represent an outlier. Statistical estimates can vary with the regression approach, and the presence of an anomalously large or small impact suggests that multiple regressions approaches may be useful to understand the sensitivity of empirical results to the chosen statistical technique. When results are particularly sensitive to the regression approach, conclusions should be based on the most consistent or conservative estimate. In other words, conservative, or at least average, deterrence magnitude estimates should typically be selected when estimates vary across specifications.

Most importantly, results presented in Tables 1A and 1B are reasonably similar to those found in the peer-reviewed studies Gray and Deily (1996) and Deily and Gray (2007). Since published deterrence effects for this steel dataset were derived with different models than those reported here, small adjustments are necessary to make results comparable. Gray and Deily's (1996) key explanatory variable was an indicator measuring the existence of an inspection in two earlier years, so the results in Table 1B are most closely comparable to that study's results. Gray and Deily (1996) found an unadjusted logit coefficient of 1.13. The equivalent unadjusted coefficient for the closely related inspection variable in columns 2 and 3 of Table 1B is approximately 1.47. Given the slight differences in variable definition across studies, deterrence effects here are relatively similar to those reported in the literature. Deily and Gray (2007) found that the deterrence effect of any enforcement action on the probability of compliance was approximately 32 percent. As noted above, results in Table 1B for inspections reveal deterrence effects of inspections on the probability of compliance of approximately 27 percent. Deterrence effects seem statistically and practically similar to published deterrence effects.

It would be desirable to benchmark the specific deterrence models for continuous emissions as well as discrete compliance status indicators. However, this is not possible since the Gray and co-author papers in the scientific literature that examine the deterrence effect of monitoring and enforcement on the emissions of sanctioned or inspected facilities use confidential data from non-EPA databases. However, there is no reason to suspect, *a priori*, that the proposed models for these investigations are not properly calibrated since the basic statistical approach is similar in both the discrete and continuous cases. For example, the explanatory variables in each case are identical. Further, as will be discussed in the next section, the general deterrence benchmarking yields similar results when applied to both discrete compliance status indicators and continuous pollution discharge measures.

Benchmarking General Deterrence Methods

Our benchmark dataset for the general deterrence measurement methods is a pulp and paper industry dataset of 251 major mills for the period 1990-2004. Like the steel industry, the pulp and paper industry is characterized by large industrial sources with relatively similar production processes and pollution treatment technologies across facilities. Sources, however, may be geographically diverse. Deterrence effects from this dataset were examined in Shimshack and Ward (2005) and Shimshack and Ward (2008). The key data source was the EPA's Permit Compliance System, and both water non-compliance status and continuous water pollution discharges are examined.

Results from applying the simplified models for measuring general deterrence to *discharges* from the pulp and paper dataset are presented in Tables 2A and 2B. All of the models show a statistically significant general deterrence effect of lagged enforcement actions. The estimated impact of a fine on another plant in the state on the ratio of actual to permitted discharges (the dependent variable) is negative and strongly significant for both biochemical oxygen demand (BOD) and suspended solids (TSS). The magnitudes are extremely consistent across models and practically meaningful. For the BOD discharges examined in Table 2A, the average discharge ratio declines approximately 0.022 in the year following a fine.[11] Given the overall mean discharge ratio, this

[11] Here, we explore the impact of a regulatory action in the past 1-12 months. We choose this time frame to most closely replicate the analyses in the relevant published studies. Further, Shimshack and Ward [2008] found that facilities regularly updated their beliefs about regulatory stringency. At least for the studied pulp and paper sector, the regulator reputation effect underlying general deterrence begins to decay within one year after a fine for a water pollution violation. Within 2 years of a fine, general deterrence has decayed by more than 50 percent. The implication is that regulators must maintain a monitoring and enforcement presence to induce consistent environmental performance over time. However, the general deterrence decay does not render any given study for any given period obsolete. The key consideration is whether the

translates (on average) into an approximately 6% reduction in aggregate BOD discharges. For the TSS total discharges examined in 2B, the average discharge ratio declines approximately 0.018 in the year following a fine. Given the overall mean discharge ratio, this translates (on average) into an approximately 6% reduction in the aggregate TSS discharges.

Most importantly, results presented in Tables 2A and 2B are extremely similar to those found in the peer-reviewed study Shimshack and Ward (2008). Specifications for the key dependent and the key explanatory variables are identical here and in that study, so results are comparable. Shimshack and Ward (2008) found a general deterrence coefficient for BOD of -0.023. The simplified models presented here yield general deterrence coefficients for BOD of approximately -0.022. After modest rounding, *all* models translate (on average) into an approximately 6% reduction in BOD aggregate discharges. Similarly, Shimshack and Ward (2008) found a general deterrence coefficient for TSS of -0.024. The simplified models presented here yield general deterrence coefficients for TSS of approximately -0.018. Published results translate (on average) into an approximately 8% reduction in TSS aggregate discharges, while the simplified model results translate (on average) into an approximately 6% reduction in TSS aggregate discharges.

Results from applying the simplified models for measuring general deterrence to *the BOD non-compliance status* in the pulp and paper dataset are presented in Table 3A. All of the BOD models show a significant general deterrence effect of lagged enforcement actions. The coefficients on 'fines 1-12 months ago on another plant in the state' are negative and strongly statistically significant. Most importantly, the results are all nearly identical to those presented in Shimshack and Ward (2005). Specifications for the key dependent and the key explanatory variables are extremely similar here and in that study, so results are comparable. The relevant coefficient in Shimshack and Ward (2005) was -0.509. Here, coefficients vary between -0.487 and -0.514. *All* models translate (on average) into an approximately 60-65 percent reduction in the statewide probability of a BOD violation in the year following a fine.

Results from applying the simplified models for measuring general deterrence to *the TSS non-compliance status* in the pulp and paper dataset are presented in Table 3B. None of the TSS models show a general deterrence effect of lagged enforcement actions. The coefficients on 'fines 1-12 months ago on another plant in the state' are never close to being statistically meaningful. These results, however, are entirely consistent with the combined analyses of Shimshack and Ward (2005) and Shimshack and Ward (2008) published in the literature. Those studies, and especially the later paper, indicated that TSS compliance is typically indirectly determined by BOD compliance. Thus, the finding of no direct deterrence impact of fines on TSS discharges is consistent with peer-reviewed research.

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underlying decision-making process has importantly changed, on average, for the regulated facilities. See the associated white paper for a more detailed discussion.

6. Major Findings and Recommendations

Can OECA identify simplified quantitative database analyses capable of capturing the specific and general deterrence effects of environmental monitoring and enforcement in a scientifically rigorous yet efficient manner?

- Major Finding 1: Simplified, cost-effective quantitative database methods exist to measure the specific and general deterrence of environmental monitoring and enforcement.

  Sections 3 and 4 present such simplified metrics and statistical methods. They are grounded in peer-reviewed research and technically rigorous, yet can be cost-effectively implemented in-house by OECA personnel with modest database and statistical training.

- Major Finding 2: When benchmarked against data analyzed in the pre-existing literature, the simplified metrics and methods typically produce deterrence effects approximately equal to those in the literature.

  Specific deterrence results for our models applied to air compliance status in a 1980-1989 steel industry dataset are typically quite similar to the results found in the peer-reviewed studies Gray and Deily (1996) and Deily and Gray (2007). General deterrence results for our models applied to water discharges in a 1990-2004 pulp and paper industry dataset are nearly identical to the results found in the peer-reviewed study Shimshack and Ward (2008). General deterrence results for our models applied to water non-compliance status in a 1990-2004 pulp and paper industry dataset are very similar to the collective results in the peer-reviewed studies Shimshack and Ward (2005) and Shimshack and Ward (2008).

How can OECA use the methods and results to measure and/or manage elements of compliance assurance and enforcement programs?

- Recommendation 1: In the short-run, OECA and its contractors should apply the simplified models developed in Sections 3 and 4 and benchmarked in Section 5 to approximately 4 additional sector / pollution media combinations (as outlined in Task 4 of the Statement of Work).

  On average, the easily implemented models seem to reveal similar deterrence effects as their more sophisticated and costly counterparts in the academic literature. Further, applying these models to new sectors, contaminants, and time periods could importantly contribute to the state of knowledge on deterrence. While the model benchmarking for conventional air and water pollutants in the steel and pulp and paper sectors is illustrative, it is quite possible that other sectors and contaminants exhibit different patterns of deterrence. Such deterrence effect heterogeneity would not be surprising, since various sectors, contaminants, and time periods are characterized by significant difference in production processes, treatment technologies, environmental impact, and regulator attention.

Sectors for future consideration should be selected on the basis of data availability, environmental impact, and agency priorities. The external validity of the simplified models is also strongest for sectors with salient characteristics similar to the pulp and paper and iron and steel sectors used to calibrate the presented models. The common characteristics of these industries are large industrial sources, relatively similar production processes, relatively similar pollution treatment technologies, and geographic diversity. Several core program sectors in the completed Sector Facility Indexing Project are particularly good candidates for replication, since they have significant environmental impacts, significant data availability, and relatively large and homogeneous industrial facilities.

- Recommendation 2: In the longer run, OECA should consider applying the simplified deterrence measurement models to datasets created from the extensive data available to the EPA (facilitated by Task 5 of the Statement of Work).

  Extensive Permit Compliance System water pollution discharges and violations data, Continuous Emissions Monitoring System air pollution discharges and violations data, Toxic Releases Inventory toxics data, RCRA Biennial Reporting System hazardous waste violations data, and Compliance Data System/IDEA air pollution violations data are available for analysis across a wide range of industries and time periods. In many cases, near-censuses of major facilities can be obtained.

- Recommendation 3: As work continues in the Compliance and Deterrence Research project, particular care should be paid to the issue of reverse causality in the estimation of specific deterrence effects. Future work should allow for alterative lag specifications and additional conditional random effects corrections.

  Lagged monitoring and enforcement variables serve two important purposes. First, lags reduce statistical simultaneity (endogeneity) and help isolate the direction of causality. If contemporaneous monitoring and enforcement variables are included in the analysis, statistically detected correlations between these factors and compliance or emissions may reflect the causal effect of compliance or emissions on monitoring and enforcement due to regulator targeting. This reverse causality is mitigated using lags. Second, lags allow time for firms to alter their environmental behavior in response to regulatory actions. Alternative lagged specifications for the key explanatory variables should be considered for all future explorations, since firm response times and regulator targeting regimes may differ across sectors. Alternative lag specifications, like inspections 1 year ago, or 2 years ago, or 3 years ago should be considered for different sector analyses. In other words, future research in the compliance and deterrence project should not necessarily be bound to the exact lag variable specifications included in this report. Recall that the precise variable specifications included in this report are dictated by the papers being replicated for calibration, but slight modifications may be helpful for future research on other sectors (since they may have different targeting regimes and different enforcement response times).

The panel data techniques presented here, including fixed effects and conditional random effect specifications, also help minimize the important reverse causality concern in the measurement of specific deterrence. Intuitively, these techniques partially remove statistical bias associated with enforcement or inspection targeting based upon the plant's overall environmental performance. For presented conditional random effect specifications, however, the relevant metrics in this report include only one conditional random effect (the average number of regulatory actions directed at the facility). Alternative conditional random effect techniques might include additional statistical corrections, including the average emissions of the facility or the average compliance level of the facility. In other words, future research in the compliance and deterrence project should not necessarily be bound to the exact conditional random effect specifications included in this report. Recall that the precise conditional random effect specifications included in this report are dictated by the papers being replicated for calibration, but slight modifications may be helpful for future research on other sectors (since they may have different targeting regimes).

Fortunately, the reverse causality concern is less significant for the measurement of general deterrence.

- Recommendation 4: If robust and theoretically consistent results emerge from future applications of the simplified models, deterrence estimates should help inform OECA and Agency management decisions, along with other relevant considerations.

  In the short run, metrics and deterrence measurement results may be utilized to make justifiable quantitative assessments of deterrence in specific sectors for internal diagnostics. In the longer run, metrics and deterrence measurement results may be utilized to make justifiable quantitative assessments of deterrence across a wide range of regulated sectors. Such assessments, along with other factors, may assist internal management. Additionally, these assessments may eventually help OECA and related offices make justifiable statements to external stakeholders about the impacts of monitoring and enforcement on measured environmental outcomes. These statements will be directly or indirectly drawn from peer-reviewed research, and they will be based upon technically rigorous quantitative methods of known value to OECA, the EPA, EPA stakeholders, and other interested parties.

  Many justifiable quantitative assessments of deterrence may emerge from the results of this on-going compliance and deterrence research project. Hypothetical possibilities include: (a) "Among large steel mills, an additional inspection increases criteria air pollution compliance by 10% at the evaluated facility for the year following the evaluation." Note that this is a specific deterrence statement for a single sector, with attribution in an average sense. (b) "Among large pulp and paper mills, an additional fine reduces aggregate BOD water pollution discharges within a state (across all facilities) by 7 percent in the year following a penalty in that state." Note that this is a general deterrence statement for a single sector, with attribution in an average sense. (c) "Among large refining facilities, an additional non-pecuniary enforcement action (like warning letters, telephone calls, and notices of non-compliance) has no statistically detected impact on criteria air pollution emissions." Note that this is a specific deterrence statement for a single sector, with attribution in an average sense. (d) "Across a wide range of air polluting industries characterized by large and relatively homogeneous facilities, an additional inspection reduces SO_2 emissions by 3 percent at the evaluated facility for the year following the evaluation, an additional non-monetary sanction reduces SO_2 emissions by 1 percent at the sanctioned facility for the year following the sanction, and an additional financial administrative penalty reduces SO_2 emissions by 10 percent at the fined facility for the year following the sanction. Monetary fines also induce general deterrence, and an additional fine reduces SO_2 emissions at other facilities in the same state and sector as the fined facility by 3 percent in the year following the fine. Non-monetary sanctions induce no general deterrence." Note that this statement combines both specific and general deterrence impacts for a number of industries, with attribution in an average sense (across facilities in multiple industries).

The type of assessments in the previous paragraph may eventually help internal management, along with other relevant factors. Such assessments may help Agency personnel identify sectors where monitoring and enforcement actions may induce particularly significant changes in environmental performance. Further, such assessments may help Agency personnel identify the regulatory instruments (inspections, non-monetary sanctions, fines) within a sector that may induce particularly significant changes in environmental performance. When combined with rough regulatory action cost estimates and other appropriate considerations, these assessments may help augment internal decisions like inspection and enforcement targeting considerations within and between sectors.

In the longer run, the type of assessments discussed above may also help OECA and related offices make justifiable statements to external stakeholders about the impacts of monitoring and enforcement on measured environmental outcomes. Many current methods for evaluating the effectiveness of environmental regulatory activities are incomplete. Outcome measures like pounds of pollution directly reduced through consent decree agreements and court settlements do not typically capture deterrence, and especially general deterrence. For example, if a specific facility agrees to reduce pollution by some number of tons in response to a regulator action, this reduction is important but may considerably understate it's the action's overall impact since it fails to capture the impacts of this signal of regulatory ‘toughness’ on the behavior of other facilities in the same state and sector.

References

*M. Deily and W. Gray, Agency Structure and Firm Culture: OSHA, EPA, and the Steel Industry, *J. Law, Economics, and Organ.* 23, 685-709 (2007)

*W. Gray and M. Deily, Compliance and Enforcement: Air Pollution Regulation in the U.S. Steel Industry, *J. Environ. Econ. Manage*. 31, 96-111 (1996).

*W. Gray and R. Shadbegian, When and Why do Plants Comply? Paper Mills in the 1980s, *Law and Policy,* 27, 238-261 (2005).

*W. Gray and R. Shadbegian, The Environmental Performance of Polluting Plants: A Spatial Analysis, *J. Regional Science*, 47, 63-84 (2007).

*J. Shimshack, Monitoring, Enforcement, and Environmental Compliance: Understanding Specific and General Deterrence, *State-of-Science White Paper Prepared for the Environmental Protection Agency’s Office of Research and Development and Office of Enforcement and Compliance Assurance*. Oct. 2007. See http://www.epa.gov/compliance/resources/reports/compliance/research/index.html .

*J. Shimshack and M.B. Ward, Regulator Reputation, Enforcement, and Environmental Compliance, *J. Environ. Econ. Manage*. 50, 519-540 (2005).

*J. Shimshack and M.B. Ward, Enforcement and Over-Compliance, *J. Environ. Econ. Manage*. 55, 90-105 (2008).

Table 1A. Benchmarking Simplified Methods for Measuring Specific Deterrence: A Quantitative Analysis of Air Pollution Compliance in the Steel Industry

Variable Description	Logit with Fixed Effects	Logit with Random Effects	Logit with Conditional Random Effects
Inspections 1-2 years ago on this plant	0.185 (1.07)	0.174* (1.74)	0.176* (1.75)
Year Indicator Variables	Yes	Yes	Yes
State Indicator Variables	No	Yes	Yes
Facility-Specific Fixed Effects	Yes	No	No

NOTES: Observations are by plant and year. The dependent variable is the 0/1 compliance status with air pollution regulations. Non-compliance ("0") occurs if the facility for one or more quarters during the year. The key explanatory variable is a 0/1 inspection indicator variable. This variable equals 1 if this facility received an inspection 1-2 years ago. For comparability with the existing literature, reported coefficients on the key explanatory variables are *marginal effects* (not coefficients). A superscript * indicates statistical significance at the 10% significance level. ** indicates statistical significance at the 5% significance level. *** indicates statistical significance at the 1% significance level.

Table 1B. Benchmarking Simplified Methods for Measuring Specific Deterrence: A Quantitative Analysis of Air Pollution Compliance in the Steel Industry

Variable Description	Logit with Fixed Effects	Logit with Random Effects	Logit with Conditional Random Effects
Inspections 1-3 years ago on this plant	0.487** (2.02)	0.272*** (2.56)	0.274*** (2.58)
Year Indicator Variables	Yes	Yes	Yes
State Indicator Variables	No	Yes	Yes
Facility-Specific Fixed Effects	Yes	No	No

NOTES: Observations are by plant and year. The dependent variable is the 0/1 compliance status with air pollution regulations. Non-compliance ("0") occurs if the facility for one or more quarters during the year. The key explanatory variable is a 0/1 inspection indicator variable. This variable equals 1 if this facility received an inspection 1-2 years ago and/or 2-3 years ago. For comparability with the existing literature, reported coefficients on the key explanatory variables are *marginal effects* (not coefficients). A superscript * indicates statistical significance at the 10% significance level. ** indicates statistical significance at the 5% significance level. *** indicates statistical significance at the 1% significance level.

Table 2A. Benchmarking Simplified Methods for Measuring General Deterrence: A Quantitative Analysis of BOD Water Pollution Discharges in the Pulp and Paper Industry

Variable Description	Linear Regression with Fixed Effects	Linear Regression with Random Effects	Linear Regression with Conditional Random Effects
Fines 1-12 months ago on	-0.022***	-0.023***	-0.022***
another plant in same state	(-4.22)	(-4.23)	(-4.20)
Fines 1-12 months ago on	-0.003	-.001	-0.003
this plant	(-0.22)	(-0.05)	(-0.22)
Season Indicator Variables	Yes	Yes	Yes
Year Indicator Variables	Yes	Yes	Yes
State Indicator Variables	No	Yes	Yes
Facility-Specific Fixed Effects	Yes	No	No

NOTES: Observations are by plant and month. The dependent variable is continuous BOD water pollution discharges as a percent of permitted levels. The key explanatory variables is a 0/1 fine indicator variable. This variable equals 1 if another facility in this industry in the same state received a fine in the last year. For comparability with the existing literature, reported coefficients on the key explanatory variables are coefficients (equal to marginal effects in these linear regressions). A superscript * indicates statistical significance at the 10% significance level. ** indicates statistical significance at the 5% significance level. *** indicates statistical significance at the 1% significance level.

Table 2B. Benchmarking Simplified Methods for Measuring General Deterrence: A Quantitative Analysis of TSS Water Pollution Discharges in the Pulp and Paper Industry

Variable Description	Linear Regression with Fixed Effects	Linear Regression with Random Effects	Linear Regression with Conditional Random Effects
Fines 1-12 months ago on	-0.018***	-0.018***	-0.018***
another plant in same state	(-3.64)	(-3.75)	(-3.67)
Fines 1-12 months ago on	-0.012	-0.007	-0.012
This plant	(-0.95)	(-0.52)	(-0.95)
Season Indicator Variables	Yes	Yes	Yes
Year Indicator Variables	Yes	Yes	Yes
State Indicator Variables	No	Yes	Yes
Facility-Specific Fixed Effects	Yes	No	No

NOTES: Observations are by plant and month. The dependent variable is continuous TSS water pollution discharges as a percent of permitted levels. The key explanatory variables is a 0/1 fine indicator variable. This variable equals 1 if another facility in this industry in the same state received a fine in the last year. For comparability with the existing literature, reported coefficients on the key explanatory variables are coefficients (equal to marginal effects in these linear regressions). A superscript * indicates statistical significance at the 10% significance level. ** indicates statistical significance at the 5% significance level. *** indicates statistical significance at the 1% significance level. ** indicates statistical significance at the 5% significance level. *** indicates statistical significance at the 1% significance level.

Table 3A. Benchmarking Simplified Methods for Measuring General Deterrence: A Quantitative Analysis of BOD Water Pollution Non-Compliance in the Pulp and Paper Industry

Variable Description	Logit with Fixed Effects	Logit with Random Effects	Logit with Conditional Random Effects
Fines 1-12 months ago on another plant in same state	-0.487** (-2.20)	-0.514*** (-2.34)	-0.490** (-2.22)
Fines 1-12 months ago on this plant	-0.494 (-1.37)	-.246 (-0.69)	-0.490 (-1.35)
Season Indicator Variables	Yes	Yes	Yes
Year Indicator Variables	Yes	Yes	Yes
State Indicator Variables	No	Yes	Yes
Facility-Specific Fixed Effects	Yes	No	No

NOTES: Observations are by plant and month. The dependent variable is the 0/1 non-compliance status with BOD limits this month. Non-compliance ("1") occurs if the facility exceeds its BOD average quantity limit this period. The key explanatory variables is a 0/1 fine indicator variable. This variable equals 1 if another facility in this industry in the same state received a fine in the last year. For comparability with the existing literature, reported coefficients on the key explanatory variables are coefficients (not marginal effects). A superscript * indicates statistical significance at the 10% significance level. ** indicates statistical significance at the 5% significance level. *** indicates statistical significance at the 1% significance level.

Table 3B. Benchmarking Simplified Methods for Measuring General Deterrence: A Quantitative Analysis of TSS Water Pollution Non-Compliance in the Pulp and Paper Industry

Variable Description	Logit with Fixed Effects	Logit with Random Effects	Logit with Conditional Random Effects
Fines 1-12 months ago on another plant in same state	0.232 (0.88)	0.140 (0.54)	0.213 (0.81)
Fines 1-12 months ago on this plant	-0.319 (-0.70)	0.027 (0.06)	-0.305 (-0.67)
Season Indicator Variables	Yes	Yes	Yes
Year Indicator Variables	Yes	Yes	Yes
State Indicator Variables	No	Yes	Yes
Facility-Specific Fixed Effects	Yes	No	No

NOTES: Observations are by plant and month. The dependent variable is the 0/1 non-compliance status with TSS limits this month. Non-compliance ("1") occurs if the facility exceeds its TSS average quantity limit this period. The key explanatory variables is a 0/1 fine indicator variable. This variable equals 1 if another facility in this industry in the same state received a fine in the last year. For comparability with the existing literature, reported coefficients on the key explanatory variables are coefficients (not marginal effects). A superscript * indicates statistical significance at the 10% significance level. ** indicates statistical significance at the 5% significance level. *** indicates statistical significance at the 1% significance level.