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

A User's Guide

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

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1. Purpose and Scope

Significant reductions in non-compliance and emissions are obtainable with traditional monitoring and enforcement. The regulation literature indicates that inspections and enforcement actions produce improved future environmental performance at the evaluated or sanctioned facility. In other words, regulatory activity generates substantial specific deterrence. The literature also shows that inspections and enforcement actions produce significant spillover effects on non-sanctioned facilities. Regulatory activity generates substantial general deterrence.

This report provides a technical user's guide to the quantitative measurement of the specific and general deterrence effects of environmental monitoring and enforcement. First, we present an overview of "big-picture" issues confronted when considering the database analysis of the deterrence effects of environmental monitoring and enforcement. Second, we discuss necessary data extraction and data preparation steps. We discuss the basic sequencing to ensure that the dataset itself is complete, reliable, and suitable for analysis. Third, we provide a detailed guide to the quantitative statistical analysis. We discuss the basic sequencing and steps necessary to implement the metrics and techniques designed in Task 3 and implemented in Task 4. Metrics are as technically rigorous as possible yet cost-effective for use by non-statisticians.

The user's guide is intended to complement the contractors' October 23-24, 2008 training visit. During that visit, contractors began training OECA and other interested Agency personnel to perform their own quantitative database analyses for the measurement of specific and general deterrence. The goal of this user's guide is to facilitate the capacity building necessary for the Agency to improve its external reporting and internal management with respect to the deterrent impacts of inspections and enforcement.

As requested in the Statement of Work, this user's guide is very limited in scope. It is most effectively considered 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 encouraged to familiarize themselves with the associated "Monitoring, Enforcement, and Environmental Compliance: State-of-Science White Paper"[1], "Monitoring, Enforcement, and Environmental Compliance: Metrics and Model Calibration."[2], and "Monitoring, Enforcement, and Environmental Compliance: A Multiple Sector Analysis."[3] The white

[1] White Paper: J. Shimshack, "Monitoring, Enforcement, and Environmental Compliance: Understanding Specific and General Deterrence, State-of-Science White Paper." Paper Prepared for the Environmental Protection Agency's Office of Research and Development and Office of Enforcement and Compliance Assurance. Oct. 2007.

[2] Models and Metrics paper: J. Shimshack, "Monitoring, Enforcement, and Environmental Compliance: Metrics and Model Calibration." Paper Prepared for the Environmental Protection Agency's Office of Research and Development and Office of Enforcement and Compliance Assurance. July 2008.

[3] Multiple Sector Analysis paper: J. Shimshack, "Monitoring, Enforcement, and Environmental Compliance: A Multiple Sector Analysis." Paper Prepared for the Environmental Protection Agency's

paper reviews the recent policy-relevant environmental compliance literature. The metrics and models paper presents and calibrates simplified frameworks for database analysis of specific and general deterrence of environmental monitoring and enforcement. The multiple sector analysis paper uses developed simplified metrics to measure the specific and general deterrence effects of environmental monitoring and enforcement in the petroleum, paper, steel, inorganic chemicals, organic chemicals, and alumina/aluminum smelting industries. Many of the theoretical foundations, statistical concepts, and practical considerations essential to fully understanding this user guide's metrics and methods are discussed in detail in these previous papers and will not be repeated here.

This document's target audience is policy personnel who will themselves critically examine and potentially replicate quantitative database analyses for practical evaluation purposes. The report's goal is instructional, and this report has not been formally peer reviewed. Policy discussions are relegated to the extensive work summarized in the white paper, the metrics and models paper, and the multiple sector analysis study.

2. Quantitative Database Analysis: Why measure deterrence?

Deterrence measurement, along with other factors, may enhance internal diagnostics and management. Measurement results may be utilized to make justifiable quantitative assessments of deterrence in specific sector and media combinations. Measurement results may also be utilized to make justifiable quantitative assessments of deterrence across a wide range of sector/media combinations. The collective results may help Agency personnel identify the *regulatory instruments* within a sector that may induce particularly significant changes in environmental performance. Results may also help Agency personnel identify the *sectors* where regulatory monitoring and enforcement induce particularly significant changes in environmental performance.

In the longer run, deterrence measurement may also help OECA and related offices make justifiable statements to external stakeholders about the impacts of monitoring and enforcement on measured environmental outcomes. Current performance metrics, like the number of inspections conducted in a given year, the number of administrative penalties levied in a given year, and the number of Department of Justice referrals in a given year are imperfect measures, since more monitoring and enforcement may occur in periods where environmental performance is poor. Other performance metrics, like clean-up dollars or pollution reductions committed under consent decrees and court settlements may also be incomplete. These latter metrics typically fail to capture deterrence – the impact of monitoring and enforcement on future environmental behavior. Further, by focusing only on the monitored or sanctioned firm, these metrics fail to capture the spillover effects of monitoring and enforcement on the behavior of facilities beyond the inspected or sanctioned firm (general deterrence).

3. Conducting Quantitative Database Analysis: Selecting Data and Metrics

The analysis of general and specific deterrence needs to identify two key types of data: measures of environmental performance and measures of regulatory activity. Performance measures in the past have included compliance with air pollution regulations, discharges of water pollutants, and compliance with water pollution regulations. See the Task 4 Multiple Sector Analysis report for a more detailed discussion. Measures of regulatory activity have included inspections, other regulatory actions, and penalties.

A. Environmental Performance Measure Selection

Performance measures must include significant compliance or pollution variation over time and across facilities. These measures also need to be assessed often enough to provide a reasonably large set of observations for each facility in the analysis. Many of the statistical techniques, including the preferred "fixed-effect" models outlined in Task 3 and 4 reports, rely on variation within each facility over time. Performance measures must also be assessed consistently over time, which may become an issue for analyses that spanning many years.

Analyses of air pollution performance have often focused on compliance status, which is recorded in EPA Air Facility System (AFS) data on a monthly frequency. Measures of air pollution emissions tend to be available through the National Emissions Inventory only at three-year intervals (except for very large facilities which report data from continuous emissions monitors), which makes them less likely candidates for a deterrence analysis of the sort described here. For water pollution performance, the monthly Discharge Monitoring Report (DMR) data provide information on discharges of water pollutants and their limits. Discharges are often expressed as a fraction of the facility's discharge limit as defined in its discharge permit or as a 0-1 measure for violations of the limit. If regular reporting of the DMR data by facilities is an important goal, a 0-1 measure for failing to file a report could also be used as a performance measure. Other regulatory areas may offer different types of variables.

B. Regulatory Activity Measure Selection

For deterrence analyses, the standard measures of regulatory activity are facility inspections, facility enforcement actions, and facility monetary penalties. Past research has often found that the presence of regulatory activity is a better predictor of deterrence than the total amount of activity (that is, being inspected ten times in one year does not produce ten times the deterrence effect of one inspection). Therefore, the specific deterrence activity measure is often an indicator (0-1) variable representing whether or not the facility has experienced any of the selected activity within the past year or two years. The general deterrence activity measure is often an indicator (0-1) variable representing whether or not other facilities in the same state and sector have experienced any of the selected activity within the past year or two years.

Multiple regulator activity measures are also possible. For example, specific deterrence measures might include both recent inspections at the facility and recent penalties at the facility. Similarly, in principle, general deterrence measures might include recent inspections in the facility's state and sector as well as recent penalties in the facility's state and sector. In practice, however, inspections are so common for analyzed sectors that there is limited information in the general deterrence analysis of inspections.

C. Industry Selection

The statistical analysis facilitated by this user's guide should typically be applied to one industry or sector at a time. Even if the eventual intent is to calculate deterrence effects for many industries, the actual analysis will be done separately for each industry. This is done because the quantitative database analysis measures the average impact of regulatory activity on environmental performance. This measure is most meaningful when the relationship between regulatory activity and environmental performance is roughly similar in magnitude across facilities. Further, some specific deterrence metrics facilitated by this user's guide rely on behavioral comparisons of facility/time pairs with an inspection or enforcement action to facility/time pairs without an inspection or an enforcement action. Restricting attention to a single sector ensures that comparison facilities share roughly similar characteristics. Similarly, some general deterrence metrics facilitated by this user's guide rely on behavioral comparisons of facility/time pairs with enforcement actions on neighboring facilities to facility/time pairs without enforcement actions on neighboring facilities. Examining one sector at a time again ensures that comparison observations share roughly similar characteristics.

The industry involved should typically be defined at the 4-digit NAICS level, the 6-digit NAICS level if there are sufficient numbers of facilities for the analysis, or the 4-digit SIC code level if reliable NAICS data are unavailable. The key selection criteria are data availability, model suitability, and aggregate environmental impact.

All else equal, more facilities and broader industry definitions increase the statistical precision of the results, and so "industries" with larger numbers of facilities are desirable. There is no correct size for data analysis, however. A key trade-off exists between broadening the industry definition to expand the number of facilities and maintaining a reasonable degree of similarity within the sample. An analysis of water pollution from facilities in the paper industry might choose to concentrate on pulp and paper mills (SIC 2611 and 2621) while excluding paperboard mills (SIC 2631) since these latter facilities differ significantly from pulp and paper mills. Other facility characteristics besides industry may also be important. For example, major facilities and minor facilities may face different sets of regulatory constraints, and data may be more regularly collected for major facilities. In such a case, limiting the sample to major facilities may be helpful. When the unit of observation is infrequent like annual data, as many as 100 facilities may be necessary for statistical precision. When the unit of observation is frequent like monthly data, as few as 20 facilities may result in statistically precise deterrence estimates.

Large industrial sources have the most complete air and water data and the most significant environmental impacts. They may also have received more regulatory attention over time and are more likely to have homogeneous regulatory constraints. They are natural candidates for initial assessment. Several large industrial sources have also been core programs in the completed Sector Facility Indexing Project.

D. Time Period Selection

The time period covered by the analysis is most often limited by data availability. For example, air pollution compliance status is generally unavailable prior to the mid-1990s, so such analyses wouldn't begin before 1996. Similarly, permit compliance system water data is unreliable before the late 1980s and toxic releases inventory data does not begin until 1987. In most cases, longer time periods are preferred to shorter time periods. It is usually desirable to have at least 8+ years of data if the analysis is based on annual data observations. With monthly observations, 5+ years of data may be sufficient.

Some caveats exist to the "longer is better" premise. Substantial changes in the definitions of the measures of regulatory activity or environmental performance over time could make it desirable to limit the sample to a time period with stable performance and activity definitions. Similarly, substantial changes in expected deterrence impacts due to major changes in enforcement strategy or industrial composition could make it desirable to limit the sample to a time period with stable regulatory strategies or industrial compositions. In nearly all cases, datasets that include more recent data are more preferred, since results reveal more about deterrence impacts of current policy implementations.

4. Quantitative Database Analysis: Generic Data Preparation Steps and Sequencing

Once the scope of the analysis has been identified, the data need to be prepared for the analysis. The first step is to identify the set of facilities to be used in the analysis. The second step is data extraction. The relevant data can be extracted directly from Agency databases or simply requested from the Agency's database administrators. Finally, the data should be prepared for the analysis, including any data cleaning that is desired.

A. Sample Selection

1. Select an industry and identify the relevant 4-digit NAICS code(s) or SIC code(s). For example, the pulp and paper industry would be described by NIACS 3221 or primary SIC codes 2611 and 2621.

2. Select a time period for analysis. The time period for inspection and enforcement data should begin a full two years prior to the desired time period for compliance and discharge data to accommodate time lags.

3. Select the relevant environmental performance measure. One possibility is air pollution compliance status, defined on an annual basis. Another possibility is total suspended solids discharges relative to permitted total suspended solids levels, defined on a monthly basis. Many possibilities exist.

B. Data Acquisition

4. Identify database facility indicators for all major facilities in the desired industry over the relevant sample period. For example, one might select AFS (Air Facility System) identifiers for all major pulp and paper facilities operating between 1995 and 2003. Similarly, one might select NPDES (National Pollution Discharge Elimination System) identifiers in the PCS (Permit Compliance System) for all major pulp and paper facilities operating between 1996 and 2006.

5. Extract the environmental performance data for the facilities identified in step 4. For example, one might select AFS compliance status data for all major pulp and paper facilities operating between 1997 and 2003. Alternatively, one might select the PCS total suspended solids (parameter code '00530') discharge monitoring report data and discharge limit data for all major pulp and paper facilities operating between 1998 and 2006.

6. Extract the monitoring and enforcement action data for the facilities identified in step 4. For example, one might select AFS inspections and enforcement action data for all major pulp and paper facilities operating between 1995 and 2003. Alternatively, one might select PCS administrative penalties, other disciplinary actions, and inspections data for all major pulp and paper facilities operating between 1996 and 2006. Note that data extraction for monitoring and enforcement requires sample years that precede the compliance/discharges data to account for temporal lags.

C. Data Cleaning

7. Prepare compliance status or discharges/limit data obtained in steps 4 - 6.

   For example, AFS violation status for pulp and paper mills may be coded as 0/1 indicator variables. If violation status is in "CM234589" the violation indicator is set to 0, if status is in "7W61B" the violation indicator is set to 1, and set to missing otherwise. This violation variable is then added up for each facility/year. A final compliance indicator is set to 0 if no months are found in violation and at least one month is found in compliance, set to 1 if any months are found in violation, and set to missing if there were no months of recorded compliance or non-compliance.

   In a water pollution database analysis, PCS discharge data may be merged with PCS discharge limit data for a given contaminant on identifiers NPDES, discharge number, limit type, modification number, season number, pipe set qualifier, and

report designator. Discharge quantity averages, maximums, and limits are set to 0 if no discharge indicators are present and set to 0 (or missing) if limits are optional or supplemental. Discharge ratios are calculated by dividing quantities or maximum discharges by corresponding limits. The highest non-missing discharge ratio across outfalls for each facility/month is selected. Compliance status can by coded as 0 if the discharge ratio exceeds one (or any preferred threshold), 1 if the discharge ratio is below one (or the alternate threshold), and missing otherwise.

8. Prepare monitoring and enforcement action data obtained in steps 4 - 6.

   For example, AFS action descriptions may be translated into usable action variables. Actions formally described as "inspections" are denoted inspections and actions formally described as "enforcement" are denoted enforcement. Inspection data is then combined into annual inspection totals for each facility. Enforcement actions data is then combined into annual enforcement action totals for each facility. Inspection indicator variables are constructed such that they are set to 0 if the facility had no inspections for the year, 1 if the facility had one or more inspections for the year, and missing otherwise. Enforcement indicator variables are constructed such that they are set to 0 if the facility had no enforcement actions for the year, 1 if the facility had one or more enforcement actions for the year, and missing otherwise.

   In a water pollution database context, PCS inspection indicator variables may be constructed such that they are set to 0 if the facility had no inspections for the month, 1 if the facility had one or more inspections for the month, and missing otherwise. Penalty indicator variables are constructed such that they are set to 0 if the facility had no administrative penalties for the month, 1 if the facility had one or more penalties for the month, and missing otherwise. Disciplinary action indicator variables are constructed such that they are set to 0 if the facility had no non-penalty enforcement actions for the month, 1 if the facility had one or more non-penalty enforcement actions for the month, and missing otherwise.

9. Combine all compliance, inspection, and enforcement actions into one dataset for analysis. For each facility/period combination, a compliance status indicator represents if the facility was in compliance for the period and (if possible) a pollution measure variable reflects the ratio of discharges to permitted levels for the period. For each facility/period combination, an inspection indicator will indicate the presence or absence of inspections at this facility this period, an enforcement action indicator will indicate the presence or absence of enforcement actions at this facility this period, and (if possible) a penalty indicator will indicate the presence or absence of penalties at this facility this period.

10. If desired, generate general deterrence variables. General deterrence enforcement action indicators are set to 0 if there were no enforcement actions levied against other facilities in the same state and sector this period and set to 1 if there were enforcement actions levied against other facilities in the same state and sector this

period. General deterrence penalty indicators are set to 0 if there were no penalties levied against other facilities in the same state and sector this period and set to 1 if there were penalties levied against other facilities in the same state and sector this period. Recall that inspections are typically so frequent that there is little meaningful variation in general deterrence inspection variables, so the general deterrence of inspections is often not measured.

11. Lag inspection, enforcement action, and/or penalty indicators for the specific facility for the measurement of specific deterrence. Lag inspection, enforcement action, and/or penalty indicators for other plants in the same state and sector for the measurement of general deterrence.

12. If desired, generate other control variables. Generate seasonality indicator variables, generate year indicators, and generate specific indicators.

5. Quantitative Database Analysis: A Data Preparation Example

Here, we illustrate a particular example of data preparation by summarizing Wayne Gray's October 24, 2008 (10am-1pm) presentation to OECA personnel. This session was not designed as a complete training course in programming using SAS,[4] but as an introduction to the types of decisions involved in this sort of database preparation. The session also demonstrated how an existing set of SAS programs could be used to carry out the sample database preparation, and how SAS programs could be modified for analysis of other industries.

We began with a brief discussion of the different types of files used by SAS. SAS datasets are saved with file type ".sas7bdat". The information in these datasets would be extracted from various EPA datasets and converted to SAS format datasets using any of a variety of available programs (such as Stat-Transfer). The example datasets used here were based on EPA data extracts created by Wayne Gray and Jay Shimshack.

SAS Program files have file type ".sas". These SAS programs can be edited using a text editor such as Notepad (right-click on the file and then "Open With" Notepad) and can then be executed using the "Batch Submit" command (right-click on the file and then "Batch Submit"). Running SAS in batch mode generates two additional files: the ".log" file shows the results of each individual SAS command in the program, while the ".lst" file shows the output from SAS statistical commands.

We began by examining the five datasets to be used in the analysis:

NPDES_MAJORS = one record for each NPDES facility (select by SIC/NAICS)
APO9 - Administrative penalty records for NPDES facilities
INSPECTIONS9 - Inspection records for NPDES facilities

[4] One accessible and up-to-date introduction to SAS programs is The Little SAS Book: A Primer, Fourth Edition by Lora Delwiche and Susan Slaughter (Perfect Paperback - Aug 25, 2008).

PCS_TSS - Monthly Discharge Monitoring Reports for Total Suspended Solids
PCS_TSS_QLIM - quantity limits associated with NPDES permits

The SAS datasets were opened, running the SAS System software interactively, to see what variables were contained in each dataset. A listing of all variables in these datasets is contained in Appendix A.

We then reviewed the three SAS program files that converted these datasets to a format usable for statistical analysis. The first program, setup1.sas, identifies the facilities in the NPDES_MAJORS dataset that are in the desired industry (NAICS code 3241, petroleum refineries), gathers all the inspections and enforcement actions for those facilities, and gets total counts of inspections and enforcement actions by month for each facility. This will provide the measures of regulatory activity faced by these facilities. The second program, setup2.sas, gets the monthly discharge data for total suspended solids from these facilities and links it to the quantity limits for the facilities' NPDES permits. This will provide the measures of environmental performance for these facilities. The third program, setup3.sas, aggregates the regulatory activity by state, providing measures for the general deterrence analysis, and combines the regulatory data with the discharge data to create the dataset that could be used for statistical analysis.

For each of these programs, we first reviewed the program file (using Notepad), including a discussion of the general outline of the program's logic, and particular statements needed to achieve different parts of the program. We then ran the program using SAS (in "batch submit" mode), and examined the program log file (using Notepad) to see the results of the individual commands in the programs, such as the number of records in various intermediate datasets and the final datasets created by each program. The SAS program log files are included later in this report, as Appendix B. Bolded lines summarize what the program does at each major step.

At various stages of the session we discussed ways in which the programs could be adjusted to modify the analysis. The simplest variation would be to select another industry, which would involve changing the commands in setup1.sas and setup2.sas which select the facilities for the analysis from the NPDES_MAJORS dataset. In this case "if naics=3241;" could become "if naics=3251;" (or even "if sic=2611 or sic=2621;" which would select facilities in either of two SIC industries).

Another variation would involve adding alternative regulatory measures to the dataset, such as the specific deterrence effect of compliance assistance activity at a set of facilities, or the general deterrence effect of criminal sanctions directed at any facility in the same state (or EPA region), including all facilities, not just those in this particular industry (the analysis shown here limits the general deterrence effect to enforcement activity at other plants in the same industry and same state).

We also noted that there were other alternatives available to the SAS examples which we demonstrated. More of the data preparation could be done by EPA dataset programmers, linking together the data from different files using SQL commands within

the EPA databases, rather than extracting the basic data from the EPA datasets and using SAS to combine the various data into an analysis dataset.

An important point of the training session is that there are several points in the analysis where important decisions are being made. On the data side, the analyst must decide which industries, which years, which measures of environmental performance, and which measures of regulatory activity will be considered. The sample programs discussed reflected one particular set of answers to these questions about the structure of the data and the analysis, but OECA should consult with Agency program and database experts in order to provide the most internally useful analysis.

6. Statistical Analysis

Once the data is prepared, it will contain a measure of performance and a measure of regulatory activity. Our example activity measures included inspections and enforcement actions for air pollution and inspections and penalties (including a measure of penalties at other plants in the same state) for water pollution. Some analyses (specifically for water pollution) employed more than one activity measure. We also need to control for changes over time with 0/1 year indicator variables, and for seasonal changes when the analysis is conducted with facility-month observations.

Before analysis, the dataset must be exported into a form that can be readily read into a statistical package. Our preferred statistical package is STATA, but other programs are possible. The simplest way to transfer data into a program like STATA is with a program called "Stat/Transfer." It is available inexpensively. Alternatively, one can output the data from SAS or other database preparation software into readable "ASCII" form and then import it into the statistical package. Once the dataset is assembled, processed, cleaned, and imported into a statistical package, the actual analysis is straight-forward. An annotated sample STATA program is summarized in Appendix C.

Recall that the Task 3 and 4 reports described three different, but related, regression approaches for measuring specific and general deterrence: fixed effects regression, random effects regression, and conditional random effects regression. The overall empirical strategy for all three approaches is to link inspections and enforcement actions to subsequent compliance and pollution behavior. Each of the three regression approaches are discussed in detail in the related white paper and Task 3 and 4 reports, 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 facility-specific controls. The key function of these facility-specific controls is to capture the "individuality" of each facility without actually requiring data on all of the differences between facilities; the different techniques provide three different ways of capturing this "individuality."

A. Implementation Example 1: Fixed-effect regressions
Discharges Dependent Variable

When the dependent variable is continuous like discharges as a percent of permitted levels, we use the fixed effects regression command to regress the dependent discharges variable on lagged regulatory activity and other explanatory variables like n-1 year indicators and n-1 season indicators (if data are observed monthly). Fixed effects are at the plant-level. In STATA, the fixed effects command for a continuous discharges dependent variable might look like:

---

xi: xtreg *discharges otherfine1 otherfine2 ownfine1 ownfine2 owninsp1 owninsp2 i.year i.season*, fe

where:

xtreg ….., fe is the STATA command for fixed effects regression.
xi: …. i. is the STATA command for including all variables with names that begin with the word that follows "i."

discharges is the discharges as a percent of permitted levels dependent variable

otherfine1 is the lagged general deterrence action variable that indicates the presence of 1 or more fines on other plants in the same state and sector in the past year

otherfine2 is the lagged general deterrence action variable that indicates the presence of 1 or more fines on other plants in the same state and sector 1-2 years ago

ownfine1 is the lagged specific deterrence action variable that indicates the presence of 1 or more fines on this plant in the past year

ownfine2 is the lagged specific deterrence action variable that indicates the presence of 1 or more fines on this plant 1-2 years ago

ownfine1 is the lagged specific deterrence action variable that indicates the presence of 1 or more fines on this plant in the past year

ownfine2 is the lagged specific deterrence action variable that indicates the presence of 1 or more fines on this plant 1-2 years ago

year represents year indicator variables with names that begin with "year"
season represents season indicator variables with names that begin with "season"

When running regressions for specific deterrence only, omit the "*other*" explanatory variables (in this example, omit *otherfine1* and *otherfine2*). When examining only specific deterrence of inspections, omit the "*fine*" explanatory variables (in this example, omit *otherfine1, otherfine2, ownfine1,* and *ownfine2*). When examining annual data, omit the "*season*" explanatory variables (in this example, omit *i.season*). For example, a STATA command for fixed-effects examination of specific deterrence for inspections only with annual data and a continuous discharges dependent variable might look like:

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xi: xtreg *discharges owninsp1 owninsp2 i.year*, fe

Sample STATA code is provided in Appendix C.

B. Implementation Example 2: Random-effect regressions
Discharges Dependent Variable

An alternative approach to the fixed effects regression approach is the random effects regression approach. When the dependent variable is continuous like discharges as a percent of permitted levels, we use the random effects regression command to regress the dependent discharges variable on lagged regulatory activity and other explanatory variables like n-1 year indicators and n-1 season indicators (if data are observed monthly). When using the random effects model, we also include state-level indicators. In STATA, the random effects command for a continuous discharges dependent variable might look like the sample code below. Note the ',re' (random effects) instead of ',fe' (fixed effects) at the end of the command line.

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xi: xtreg *discharges otherfine1 otherfine2 ownfine1 ownfine2 owninsp1 owninsp2 i.year i.season i.state*, re

where:

xtreg ….., re is the STATA command for random effects regression.
xi: …. i. is the STATA command for including all variables with names that begin with the word that follows "i."

state represents state indicator variables with names that begin with "state"

Other variables are described above.

Just like fixed effects, when running random effects regressions for specific deterrence only, omit the "*other*" explanatory variables (in this example, omit *otherfine1* and *otherfine2*). When examining only specific deterrence of inspections, omit the "*fine*" explanatory variables (in this example, omit *otherfine1, otherfine2, ownfine1,* and *ownfine2*). When examining annual data, omit the "*season*" explanatory variables (in this example, omit *i.season*). For example, a STATA command for random-effects examination of specific deterrence for inspections only with annual data and a continuous discharges dependent variable might look like:

---

xi: xtreg *discharges owninsp1 owninsp2 i.year i.state*, re

Sample STATA code is provided in Appendix C.

D. Interpreting Regression Results

Coefficient estimates represent the impact of increasing the independent variable by 1 unit on the dependent variable. Coefficient estimates are listed under the column "coef." in STATA output. For example, consider the regression of TSS (total suspended solids) discharges as a percent of permitted levels on lagged enforcement at each facility (specific deterrence variables) and lagged enforcement at other facilities in the same state and sector (general deterrence variables). Suppose the coefficient on the variable indicating the presence of a fine on other facilities in the state and sector over the past year was -.049. This implies that TSS discharges at non-sanctioned facilities are 4.9 percentage points (.049) lower than expected in the year following a fine in the same state and sector.

Statistical significance is measured for hypothesis tests with null hypotheses of no impact of enforcement/inspections on discharges. Specific levels of statistical significance can be inferred by examining t-statistics (denoted by "t" column in STATA output) or p-values (denoted by "P>|t|" column in STATA output). As a rule of thumb, if the t-statistic is greater than 2 in absolute value, the result is statistically significant at the 5% level of significance. The p-value provides more detailed information. If the p-value is less than 0.10, the result for the corresponding independent variable is statistically significant at 10%. If the p-value is less than 0.05, the result for the corresponding independent variable is statistically significant at 5%. If the p-value is less than 0.01, the result for the corresponding independent variable is statistically significant at 1%. For example, suppose the t-statistic on the variable indicating the presence of a fine on other facilities in the state and sector over the past year was -3.24. Since this t-statistic is greater than 2 in absolute value, the relationship described by the coefficient (TSS discharges at non-sanctioned facilities are 4.9 percentage points lower than expected in the year following a fine in the same state and sector) is statistically significant at the 5% level. Similarly, suppose the p-value on the variable indicating the presence of a fine on other facilities in the state and sector over the past year was 0.001. Since this p-value is

less than 0.01, the relationship described by the coefficient is statistically significant at the 1% level (and therefore also the less restrictive 5% and 10% levels).

Results can be easily contextualized for the continuous discharges dependent variable as well. In the example discussed in the preceding paragraphs, we found a statistically significant relationship between lagged penalties at other facilities and pollution discharges (as a percent of allowable levels). The specific numerical relationship indicated that TSS discharges at non-sanctioned facilities are 4.9 percentage points lower than expected in the year following a fine in the same state and sector. We can put the results in an approximate context by dividing by average TSS discharges in the sector over the sample period. In this example, the average TSS discharges for the sector were 24.6 percentage points (average discharges were 26.4 percent of allowable levels). Therefore, our statistically significant impact of a 4.9 percentage point fall in TSS discharges implies an approximately 4.9/24.6 = ~20 percent fall in TSS discharges relative to expected levels in the year following a fine the sector. Contextualizing numerical results is more difficult when the dependent variable is a discrete compliance status indicator, but the intuition is similar. Moreover, interpreting signs and statistical significance follows identically.

The statistical analysis for all three regression approaches was discussed in detail during Jay Shimshack's Oct 24, 2008 (1-3pm) presentation to OECA personnel. While the session was not designed as a complete training course in statistical programming using STATA, the session provided an introduction to quantitatively analyzing deterrence with statistical software. The session also provided a detailed overview of interpreting results of deterrence research.

The analysis training session also examined an executable STATA file in detail, so OECA personnel might understand the slight modifications necessary for automated analysis and replication on other datasets. The simplest variations involved analyzing other enforcement actions beyond penalties. In this case, the file only needs to be modified by replacing the fine variables ("otherfinedyr1 otherfinedyr2 ownfinedyr1 ownfinedyr2") in the command line with non-fine enforcement action (nfea) variables ("othernfeadyr1 othernfeadyr2 nfeadyr1 nfeadyr2") in the command line. Other variations included dropping seasonality controls (omit 'i.season" from the regression command line) and dropping state indicator control variables (omit 'i.state" from the regression command line). A final variation of potential interest was the analysis of fine magnitudes instead of the presence or absence of fines (replace "otherfinedyr1 otherfinedyr2 ownfinedyr1 ownfinedyr2" with ("otherfineyr1 otherfineyr2 ownfineyr1 ownfineyr2").

7. Conclusion

This report provides a technical user's guide to the quantitative measurement of the specific and general deterrence effects of environmental monitoring and enforcement. We discussed the use of deterrence analysis, the big-picture issues in quantitative deterrence analysis, the necessary steps for data extraction and preparation, and the

necessary steps for generating and interpreting statistical results. We also referenced the more detailed discussions of these issues provided in the Oct 23-24, 2008 training sessions.

Appendix A – Sample SAS Datasets

Appendices and sample program files are available from the authors. Please contact Wayne Gray (wgray@clarku.edu) or Jay Shimshack (jshimsha@tulane.edu).

Appendix B – Sample SAS Program Log Files

Appendices and sample program files are available from the authors. Please contact Wayne Gray (wgray@clarku.edu) or Jay Shimshack (jshimsha@tulane.edu).

Appendix C – Sample STATA Analysis Code

Appendices and sample program files are available from the authors. Please contact Wayne Gray (wgray@clarku.edu) or Jay Shimshack (jshimsha@tulane.edu).