Examining the Impact of Monitoring and Enforcement on Stationary Source Emissions

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Monitoring and enforcement are an important part of any environmental regulatory regime, and the costs of such regulatory actions should be justified by improvements in environmental performance. However, the literature has not studied the impact of monitoring and enforcement actions on emissions of criteria pollutants, which are commonly found air pollutants that affect human health and the environment. This article, the first to examine the impact of monitoring and enforcement on emissions of criteria pollutants, finds that penalties significantly reduce criteria pollutant emissions at stationary sources. In particular, penalties in the top quartile of positive penalties significantly reduce emissions compared to no penalties, while penalties in the third or second quartile have no significant impact, suggesting that the deterrent impact of penalties might arise out of a small proportion of the largest penalties.

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Introduction

Public monitoring and enforcement are an important part of any regulatory regime. This is especially true for environmental regulations as environmental harms can be complex and widespread and private parties are often ill equipped to perform monitoring and enforcement. At the same time, monitoring and enforcement actions are costly, and, in order to justify their cost, they should produce environmental benefit. This article investigates how monitoring and enforcement actions affect stationary source emissions, focusing on emissions of nitrogen oxides (NO_x), an important air pollutant that has not been studied. I find that penalties decrease emissions. In particular, assessing a penalty in the top quartile of positive penalties results in a 11.4% decrease in NO_x emissions compared to the omitted category of receiving no penalties. Being assessed a penalty in third or second quartile does not have any significant impact on emissions, implying that the deterrent impact of penalties arises out of a small proportion of the most severe penalties.

The U.S. Environmental Protection Agency (EPA) establishes federal air quality standards for commonly found pollutants that harm health and the environment, also known as criteria pollutants. As criteria pollutants are ubiquitous, it is crucial to establish the impact that monitoring and enforcement have on emissions. Because NO_x is a precursor to ozone and fine particles, two criteria pollutants that cause the most significant human health effects, it is an important pollutant on which regulators focus. Unfortunately, due to the limited availability of data, the literature has not investigated the impact of monitoring and enforcement on emissions of criteria pollutants.

In this article, I use a dataset of stationary source emissions in California to examine the impact of monitoring and enforcement on NO_x emissions. I find that penalties produce significant reductions in NO_x emissions. In particular, after receiving a penalty in the top quartile of penalties assessed that year, facilities significantly reduced emissions. Penalties in the third and second quartile had no significant impact, suggesting that only relatively large penalties have deterrent value.

This article extends the literature by examining NO_x, an important criteria pollutant that has not been studied because of the lack of data. Articles that studied the effect of regulatory actions on air pollution have focused on compliance and not emissions (e.g., Gray and Deily 1996; Nadeau 1997; Deily and Gray 2007); those that studied emissions examined toxic chemicals covered by the Toxics Release Inventory (TRI) (Hanna and Oliva 2010). However, the TRI does not cover NO_x and other criteria pollutants, so researchers have not examined emissions of criteria pollutants. This article is the first to study the impact of monitoring and enforcement on emissions of criteria pollutants. Furthermore, limiting the sample to one jurisdiction, California, reduces the heterogeneity in regulatory policy and allows me to better understand state and local regulatory policy. This is especially important because state and local regulators play a major role in the implementation of the Clean Air Act (CAA).

Regulatory Background

The CAA is a comprehensive national air pollution control program that regulates nationwide air quality. Under § 109 of the CAA, the EPA establishes the National Ambient Air Quality Standards (NAAQS) for six commonly found pollutants that harm health and the environment. These pollutants, also called criteria pollutants, are ozone, particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead. The EPA has identified ozone and fine particles as the criteria pollutants that cause the most significant human health effects (EPA

2011a), and NO_x is a precursor of both pollutants. Ozone is not emitted directly, but is created by chemical reactions between NO_x and volatile organic compounds. There are two types of particulate matter: particulate matter with a diameter of 10 micrometers or less (PM_{10}) and particulate matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$); $PM_{2.5}$, also known as fine particles, may be emitted directly but is mostly formed by reactions between other air pollutants such as sulfur dioxide and NO_x.

Although the NAAQS are federal standards, states have primary responsibility for achieving and maintaining these standards. In California, stationary source monitoring and enforcement are handled primarily by thirty-five local air districts, not by the EPA.[1] Monitoring and enforcement practices depend on the type of source: major sources are sources that emit (or have the potential to emit) more than 100 tons per year of any pollutant and synthetic minor sources are sources that emit (or have the potential to emit) above 80% of the major source threshold (EPA 2001). Minor sources are sources whose potential uncontrolled emissions are below 100 tons per year. In my analysis, I focus on inspections, enforcement actions, and penalties. There are two types of inspections, full compliance evaluations (FCEs) and partial compliance evaluations (PCEs), and three types of enforcement actions, notices of violation (NOVs), administrative orders, and consent decrees. Administrative orders and consent decrees are usually accompanied by penalties.

An FCE is a comprehensive evaluation of the facility, addressing all regulated pollutants and emission units, and a PCE focuses on a subset of pollutants, requirements, or emission units and can be used to address particular areas of concern at a facility (EPA 2001). Air districts typically perform an FCE at least once every two years for major sources and once every five

[1] Local air districts are responsible for almost 99% of the regulatory actions in my data, so my discussion focuses on air district policy and practice, not EPA policy and practice. I base this description of air district policy on discussions with staff at the four largest air districts, which constitute 80% of my sample.

years for synthetic minor sources. The time required to perform an FCE varies. For smaller facilities, the inspection can be performed in a day. For larger, more complex facilities, such as refineries, inspectors might be at the facility three to four days of the week for up to a year. Districts typically perform other smaller inspections, PCEs, when there are complaints, ongoing violations, or reports of equipment breakdown. All districts report FCEs to the EPA's data system, but only two districts report some or all of their PCEs.[2] For districts that do not report PCEs, I enter zero PCEs.

There are three types of enforcement actions: NOVs, administrative orders, and consent decrees (EPA 2011b, 2012). The enforcement process begins with the discovery of a violation; inspectors can discover a violation through self-reporting, record review, or inspection. Upon discovering a violation, inspectors typically issue an NOV. A facility with multiple violations might receive one NOV for all the violations or one NOV for each violation; there is no fixed practice regarding the number of NOVs. The time between detecting a violation and issuing an NOV can vary. An NOV can be issued the same day, but it may take several weeks for more involved violations, such as violations that require review of the facility's records. District regulators place an emphasis on correcting violations; once detected, violations are usually remedied quickly, sometimes the same day. NOVs usually expose the facility to penalties.

After receiving an NOV, facilities typically resolve the matter administratively, and the district assesses a penalty and issues an administrative order. An administrative order might deal with multiple violations. The time between an NOV and an administrative order varies, but it is usually less than 270 days.

[2] The San Joaquin Valley Air Pollution Control District reports some of its PCEs, and the South Coast Air Quality Management District reports all of its PCEs.

In California, NOVs typically expose the facility to penalties and almost all NOVs end up as administrative orders.[3] An NOV notes a violation that is later addressed by an administrative order, which typically assesses a penalty.[4] However, because an administrative order can address multiple violations, there might not be a one-to-one relationship. Additionally, most violations are corrected early in the process, before the penalty is assessed. Facilities rarely, if ever, refuse to correct a violation. Figure 1 shows the timeline of a typical violation.

[Insert figure 1 here.]

Some cases might go through the judicial process instead of the administrative process, which can take three to five years and usually ends in a consent decree. However, this is rare; almost all cases go through the administrative process.[5] Districts also vary in their reporting practices; all districts report violations that are considered high-priority violations,[6] but some districts report some or all violations that are not considered high-priority violations.[7]

Literature Review and Contributions

Water pollution studies generally investigated the relationship between regulatory action and effluent and compliance. Magat and Viscusi (1990) and Laplante and Rilstone (1996) found that inspections improved compliance with water pollution regulations and decreased water

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[3] This is different from other jurisdictions where only some of the NOVs expose the facility to penalties.

[4] Administrative orders may include other requirements. For instance, an administrative order could include a shutdown order, which requires the facility to stop operating the particular piece of equipment, or it could include a variance, which relaxes the facility's permit restrictions. Obviously, the shutdown order is far more costly than the variance, and this aspect of the enforcement process is important. However, I do not have any of these details about the administrative orders.

[5] Only 3.1% of the enforcement actions in my data are consent decrees.

[6] High-priority violations are violations that the EPA believes should receive the "highest scrutiny and oversight" (EPA 1998, p. 3). These include more serious permit, emissions, and testing violations, and chronic violations. All districts report high-priority violations; the San Joaquin Valley Air Pollution Control District reports some of its violations that are not considered high-priority violations, and the South Coast Air Quality Management District reports all of its violations regardless of whether they are considered high-priority violations.

[7] Regulatory authorities also have other types of enforcement actions at their disposal, such as notices to comply. However, as these are not reported to the EPA database, I do not discuss them.

pollution effluent at pulp and paper plants. Shimshack and Ward (2005) found a similar result; additionally, they found that the presence and magnitude of fines on pulp and paper plants had a general deterrence impact (but no specific deterrence impact). Similarly, Earnhart (2004a, b) studied municipal wastewater plants in Kansas and found that actual inspections and enforcement actions reduced effluent but predicted inspections and enforcement actions had no significant impact.

Articles that investigated air pollution have studied the impact of monitoring and enforcement on whether a facility complies with its permit limits, the duration a facility remains noncompliant, and emissions. Gray and Deily (1996) studied Clean Air Act (CAA) compliance at steel-making plants and found that inspections and enforcement actions increased compliance. In a later paper (Deily and Gray 2007), their investigation of the joint effect of environmental regulations and health and safety regulations yielded similar results. Lastly, Hanna and Oliva (2010) studied emissions of toxic chemicals at manufacturing plants and found that CAA inspections decreased emissions. They also found that facilities in low-fine industries tended to reduce emission after an inspection, but facilities in high-fine industries did not; they argued that industries with high abatement costs preferred fines to abatement, thus producing this counterintuitive result.

This article contributes to the literature by investigating the impact of monitoring and enforcement on emissions of NO_x. Previous studies have examined the impact of monitoring and enforcement on compliance with air pollution regulations and toxic emissions, but not the impact on emissions of criteria pollutants, which are important pollutants in the Clean Air Act. This article fills that gap in the literature.

Additionally, this article takes a closer look at the impact of penalties. Previous literature focused primarily on inspections and enforcement actions, and there is little evidence that penalties produce any specific deterrence impacts. In this article, I find that penalties are effective. In particular, receiving a penalty in the top quartile of penalties produces a significant decrease in emissions.

Data Description

I obtain emissions data from the California Air Resources Board's (CARB) emissions inventory and monitoring and enforcement data from the EPA's Air Facility System (AFS) database. While I do not restrict my sample to specific industries like other articles do, potentially introducing heterogeneity among the sources, by studying only California, I limit heterogeneity in monitoring and enforcement policy. This also allows me to get a better understanding of state and local regulatory policy.

CARB's emissions inventory contains information about facilities regulated by California, including the facility's name, address, city, and county and the air district responsible for its regulation, as well as the amount of emissions the facility produced in that year. Every year, each facility's emissions are estimated by the air district based on information submitted by the facility, such as fuel usage, and other information about the facility, such as equipment and abatement technology. Air districts compile this information for all facilities that emit over ten tons of pollutants per year.

Emissions data are available between 1995 and 2010. I limit the period of study to 2002-2010 because compliance monitoring policy and data reporting practices changed significantly in

2001.[8] I also dropped the facilities that produced no NO_x over the entire period and facilities that participated in the Regional Clean Air Incentives Market, a sulfur oxides and NO_x emissions trading scheme in the South Coast Air Quality Management District.

[Insert figure 2 here.]

The trend of mean NO_x emissions is presented in figure 2. Mean NO_x emissions decrease steadily over time, from 72.1 tons in 2003 to 39.9 tons in 2010. The corresponding numbers are shown in table 1. Overall, mean NO_x emissions 54.6 tons per facility-year. As the distribution of NO_x values is very right-skewed, I use the natural log of emissions (plus one) as the dependent variable. The mean of the natural log is 1.8 and the standard deviation is 9.6.

[Insert table 1 here.]

The number of observations also increases over the years, from 742 facilities in 2003 to 1,023 facilities in 2010. There are 1,149 facilities, which should produce 9,129 observations over eight years; my dataset has fewer than that, with 7,209 observations. Some of this growth in the number of observations is likely due to record-keeping getting better over time. Additionally, the number of facilities grows over time as the EPA discards all facilities that shut down from the dataset and adds new facilities that begin operation. As a result, my dataset excludes facilities that existed in 2003 but shut down before 2010, but includes facilities that did not exist in 2003 but began operation before 2010.[9] Thus, the number of facilities in my dataset increases over time. If facility closure is unrelated to regulatory actions, then this will not bias my coefficients. However, if regulatory actions result in facility closure, then such actions in effect reduce

[8] The EPA adopted a new Compliance Monitoring Strategy in October of 2001 (EPA 2001). This introduced new types of regulatory actions and changed the recommended inspection frequency.

[9] I determine the facility's start date using the earliest entry of compliance data or any regulatory action at the facility.

emissions to zero and excluding those facilities from my regressions will underestimate the effect of regulatory actions.

Several other reasons could cause the missing values, and each reason implies a different method of overcoming the problem. First, the facility might have failed to submit information due to reasons unrelated to emissions or regulatory actions. In this case, missing values will not bias the results. Second, the facility might have shut down temporarily due to factors such as a short-term decline in demand; in this case, these missing values should be treated as zero tons of emissions. Air districts usually fill in zero if this is the case, but it is still possible that such observations slip through as missing values. In this case, my coefficients will likely underestimate the impact of regulatory actions.

Third, the facility might have failed to submit emissions information due to reasons related to emissions or monitoring and enforcement actions, which would bias my results. For example, facilities might choose not to submit information if emissions are unusually high or a high number of regulatory actions at the facility might burden the facility's environmental staff with other responsibilities, causing them to fail to submit the information. Regulators indicated that they did not think that facilities were trying to hide high emissions levels by not submitting the required information. Because I am unable to discern the reason for the missing values, I treat the missing values as randomly missing values. Thus, I do not perform any corrections to compensate for missing values.

The AFS is the EPA's database for CAA-regulated sources. The database contains details of each polluting facility, such as its address, program identification number, and permit type.[10]

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[10] Note that the data only show whether the facility received an enforcement action; they do not specify which pollutant the enforcement action concerns. Thus, I cannot tell if the facility violated a NOx emissions limit or some other permit condition. Additionally, while some of the water pollution literature used information on individual effluent pipes within the facility, my data treat the facility as the unit of observation, and I do not have information

Additionally, it has details of regulatory actions since 2002: the date and type of regulatory action as well as the penalty. I classify all state and federal FCEs and PCEs as inspections and all state and federal NOVs as NOVs. Other enforcement actions consist of administrative orders and consent decrees and are usually accompanied by penalties. I classify these based on whether they were accompanied by a penalty. For enforcement actions that are accompanied by a penalty, I calculate the total penalty for the year. For enforcement actions that are not accompanied by a penalty, I calculate the total number of enforcement actions that are not accompanied by a penalty for the year. For convenience, I refer to these enforcement actions that are not accompanied by penalties as "enforcement actions without penalties." Thus, if a facility received four enforcement actions in a year and two were accompanied by a thousand-dollar penalty each and two were not accompanied by any penalty, the facility would be coded as having two enforcement actions without penalties and two thousand dollars in penalties. Table 2 shows a summary of the number of inspections, NOVs, enforcement actions, and total penalty per facility-year in 2010 dollars.

[Insert table 2 here.]

There is a mean of 2.12 inspections per facility-year, and 73.2% of the facilities-years receive at least one inspection. The mean number of NOVs is 0.42 and 15.0% of the facility-years receive at least one NOV. The mean penalty per facility-year is $8,759. However, only 14.1% of the facility-years have any penalties. Conditional upon a penalty, the mean is $61,923. As the distribution of penalties is very right-skewed, my regressions use the natural logarithm of penalties. I add one to all penalties before taking the natural logarithm as there are many zero values. The mean of the logarithm of penalties is 1.20.

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on individual smokestacks within a facility. Lastly, while one firm may own many facilities, the data are at the facility level, so I study the facility as the unit of observation, not the firm.

[Insert table 3 here.]

Table 3 shows the correlations between current- and previous-year regulatory actions. Part A of the table shows the correlations between the number of actions and logarithm of the penalty, while part B shows the correlations between the dummy variables for whether the facility received the specific regulatory action or penalty. The number of inspections is weakly correlated with other regulatory actions and their lagged values, probably because most inspections are performed at a predetermined frequency. It is also worth noting that NOVs are highly correlated with both enforcement actions without penalties and with penalties because most NOVs expose the facility to an enforcement actions and penalties.

I merge AFS inspection and enforcement information with CARB emissions information based on facility name and address. I manage to match about three-fifths of the AFS facilities to their emissions.

I also control for air quality, including variables for NAAQS attainment status, and demographic factors, including variables for per capita income, unemployment, and percent white at the county-year level. Being in a nonattainment area might increase regulatory activity at a facility but might also cause the facility to face other pressure from the community to control emissions. Thus, I include NAAQS attainment status, from the EPA's Green Book, to avoid omitted variables bias. I control for attainment status for ozone, PM_{10}, $PM_{2.5}$, and carbon monoxide.[11] I do not control for attainment status for nitrogen oxides, sulfur dioxide, and lead because all areas are in attainment of those standards. I get information about per capita income from the Bureau of Economic Analysis and unemployment rate from the Bureau of Labor Statistics and include them in my regressions to control for the price of the facility's output and

[11] Nonattainment classification for $PM_{2.5}$ started only in 2005. All areas were classified as in attainment prior to 2005. In my regressions, year dummy variables account for this.

cost of its inputs. I also obtain information about the percentage of white people in the county from the Census; counties with a large minority population might have less political power and less regulatory pressure to lower emissions, and omitting this might cause omitted variables bias.

[Insert table 4 here.]

Table 4 presents a brief description and summary statistics for each variable. As the table shows, many facilities are situated in nonattainment counties. Fifty-two percent of the facility-years are in PM_{10} nonattainment counties while 62.9% of the facilities-years are in $PM_{2.5}$ nonattainment counties. Ninety percent of the facility-years are in ozone nonattainment counties, while 9.8% of the facility-years are in carbon monoxide nonattainment counties. The average unemployment rate is 8.5%, average income is $39,581, and average percentage of the population that is white is 77.8%.

Econometric Methods

When investigating the impact of monitoring and enforcement on pollution, researchers have to overcome reverse causality. For instance, high emissions may attract regulatory action, leading to the mistaken conclusion that regulatory action causes high emissions. Researchers have developed several methods of overcoming reverse causality: including a wide range of control variables; limiting the analysis to facilities in one industry; and adjustments to the regulatory action explanatory variable.

Most studies combat this problem by including a wide range of control variables, such as the facilities' output and production process (e.g., Magat and Viscusi 1990). For example, if a facility's output increases, this increase might increase emissions but also draw regulators' attention. Including an extensive set of controls can alleviate such problems. I do not have detailed facility information, but I use facility fixed effects to control for heterogeneity across facilities and industry-year fixed effects, based on two-digit Standard Industrial Classification codes, to control for unobserved shocks to the industry. I also control for income, unemployment rate, percent white, and NAAQS attainment status on the county-year level.

Researchers most commonly compensate for reverse causality by regressing compliance or pollution releases in the current time period against monitoring and enforcement actions in previous time periods. Lagged variables avoid reverse causality because current noncompliance or pollution releases cannot cause inspections or enforcement actions in a preceding time period. For example, Magat and Viscusi (1990) found that previous-quarter inspections increased compliance and decreased effluent at pulp and paper plants.

Other studies addressed the reverse causality problem by using the predicted probabilities of an inspection or enforcement action as explanatory variables, in addition to using lagged regulatory variables. For instance, Laplante and Rilstone (1996) found that predicted inspections produced larger reductions than actual inspections, and Nadeau (1997) found that predicted monitoring and enforcement actions, when predictions were based on the noncompliant sample, significantly reduced the duration a facility remained noncompliant. However, most authors (e.g., Earnhart 2004a, b; Gray and Deily 1996; Hanna and Oliva 2010) found that predicted inspections and enforcement actions have no significant impact on pollution outcomes.

Lastly, researchers used instrumental variables to compensate for reverse causality. In their study of pulp and paper mills, Shimshack and Ward (2005) used the rate of inspection at other regulated plants in the same jurisdiction as an instrument for inspections at the facility. They reasoned that, as pulp and paper plants formed a very small portion of the regulator's responsibilities, inspections at other regulated plants were unrelated to any idiosyncratic plantspecific effects. Thus, they argued, the variable reflected an overall rate of inspection and met the exclusion restriction. Current inspections, for which the authors used instrumental variables, had no significant impact. On the other hand, Earnhart (2004b), in his study of municipal wastewater treatment plants, used enforcement at all regulated plants in the jurisdiction as an explanatory variable (not an instrumental variable) and found that the general enforcement rate reduced effluent.

In this article, I use facility fixed effects, which examines the changes in NO_x at the same facility across time. This can reduce problems presented by differences in facilities across industries. I use industry-year fixed effects to control for unobserved shocks to the industry. For instance, an increase in the price of petroleum could result in an increase in emissions and inspections at refineries, resulting in a positive relationship between emissions and inspections; industry-year fixed effects should control for this. Lastly, I use lagged regulatory variables to control for reverse causality. Lagged regulatory variables can also mitigate mean-reversion issues. Unusually high emissions draw increase regulatory action; lower emissions in the next period due to mean reversion might be mistakenly attributed to the increased regulatory action. However, I use lagged explanatory variables: emissions in 2005 are regressed against inspections in 2004. As the inspections precede emissions, I avoid the mean reversion problem.

Regression Analysis

In order to analyze the impact of monitoring and enforcement on emissions, I use a fixed effects regression model with lagged regulatory actions. The econometric model is represented by

$$100 * \ln(1 + y_{icnt}) = RegulatoryAction'_{i,t-1}\beta + X'_{ct}\gamma + a_i + \delta_{nt} + \varepsilon_{icnt}. \tag{1}$$

Emissions for facility i of county c in industry n on year t are represented by y_{icnt}. I used the natural log tons of NO_x released in that; I multiplied the number by a hundred for ease of interpretation. Time-invariant facility characteristics, such as technology, industry, or location of the facility, are captured by a_i. Industry-year dummy variables are represented by δ_{nt}, which captures industry-specific shocks over time. Other time-varying characteristics of county c are captured by X_{ct}; this controls for demographic characteristics (income, unemployment rate, and percent white) and NAAQS attainment status (for particulate matter, ozone, and carbon monoxide) of the county in which the facility is located.

The variable $RegulatoryAction_{i,t-1}$ represents regulatory actions in the previous year, such as inspections and enforcement actions taken or penalties assessed. I use two different measures of the explanatory variable: in one set of regressions, I use the number of regulatory actions, such as the number of inspections or number of enforcement actions, taken in any given year. This has the advantage of providing a more complete picture: if a facility is subject to more inspections, then it should show a larger effect on emissions than a facility that is subject to fewer inspections.

In my second set of regressions, I use dummy variables to indicate whether the facility has received a particular regulatory action. This would make sense if the presence of regulatory action, not the number of regulatory actions, is what drives any changes in emissions.[12] The

[12] Additionally, in my data, the number of regulatory actions might be driven primarily by the size of the facility, not the degree of regulatory scrutiny the facility is facing. Because I do not limit my data to facilities in specific industries, there is great variation in the size of the facilities and therefore great variation in the number of regulatory actions. For example, a large facility can receive multiple enforcement actions for multiple smokestacks but a small facility with only one smokestack is unlikely to receive multiple actions. Thus, the number of regulatory actions is perhaps more representative of the size of the facility than the degree of regulatory scrutiny the facility is facing; this would make dummy variables more appropriate. Furthermore, dummy variables can minimize problems in my data. For instance, the data show that many large facilities received multiple FCEs per year. This is likely a reporting error

literature has taken both approaches, so I run the regression using both the number of actions and dummy variables. I expect the coefficients of regulatory variables to be negative.

[Insert table 5 here.]

In regression (1) of table 5, I present the effect of previous-year regulatory actions on emissions. Enforcement actions and penalties are effective. As the dependent variable is in logs and the explanatory variable is in levels, the coefficient can be interpreted as a percentage change. An increase in the number of enforcement actions without penalties by one reduces emissions by 3.98%. At the mean emissions of 54.6 tons, this is a reduction of 2.2 tons. This shows that enforcement actions that are not accompanied by penalties can be effective at reducing emissions. Penalties also have a negative and significant impact on emissions. As both the dependent variable and penalties are logs, the coefficient of penalties can be interpreted as the elasticity of emissions with respect to penalty. The elasticity is -0.005; an increase in penalty by 1% results in a decrease in emissions by 0.005%. Though statistically significant, this effect is small. This is possibly due to nonlinearities in the impact of penalties, which I explore later in the paper.

Surprisingly, NOVs have no significant impact on emissions. This is perhaps because the enforcement actions are highly correlated. NOVs are later accompanied by other enforcement actions and possibly penalties; it is possible that they alone have no significant impact as other enforcement actions and penalties capture the deterrent effect of the enforcement action.

In the regression, inspections do not affect emissions. This is probably because there is not much variation within the facility. Most air districts perform inspections at the same frequency through the study period, once every two years for major sources and once every five

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as inspectors state that it is highly unlikely that they could complete multiple FCEs on a large facility in a year because such FCEs are time consuming.

years for synthetic minor sources, so there is not much within-facility variation. Furthermore, the inspection rate is high, with 73.2% of facility-years receiving at least one inspection, and a marginal increase in inspections might have no impact. Thus, these two factors might be responsible for the lack of significance of the coefficient of inspections.[13]

In regressions (2) and (3), I run the same regression with different samples. Regression (2) displays the regression results when I use only facilities that are considered major sources and regression (3) displays the regression results for facilities that are in the manufacturing industry (Standard Industrial Classification code 20-39). The results are similar, but the statistical significance of penalties is smaller, likely due to the reduced sample size.

[Insert table 6 here.]

In table 6, I present the effect of the presence of regulatory actions (whether the facility was subject to an inspection, an NOV, an enforcement action without penalties, and a penalty) on emissions. For manufacturing facilities in regression (3), receiving at least one enforcement action without a penalty reduces emissions by 13.6%.[14] For the other samples in regressions (1) and (2), although the coefficients are generally the same direction, the significance is changes. NOVs are effective in this regression but enforcement actions and penalties are not. This shows that, overall, the enforcement process, consisting of NOVs, enforcement actions without penalties, and penalties, is effective but suggests that the results might not be robust. This is likely due to how closely related NOVs, enforcement actions, and penalties are.

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[13] It is worth noting that other studies have found that inspections improved compliance and decreased pollution releases. For example, Hanna and Oliva (2010) found that inspections significantly reduced toxic emissions, but they had dropped facilities that face yearly inspections from their sample. Other studies (e.g., Gray and Deily 1996) also found that inspections improved compliance. My sample is more recent and focuses on California, which has an aggressive inspection regime; thus, it likely has less variation in inspection rates, causing the insignificant coefficients.

[14] As the dependent variable is in logs and the explanatory variable is a dummy variable, a coefficient of β implies proportion change of $e^{\beta} - 1$.

In order to better understand the effect of penalties, I divide them into quartiles. For each facility that received a penalty, I coded the penalty based on which quartile the penalty was in compared to all positive penalties in the same year. I created dummy variables for each quartile; the omitted category is no penalty. The regressions results are shown in table 7.

[Insert table 7 here.]

The impact of the number of enforcement actions without penalty is approximately the similar to the analogous result in table 5. However, the impact of the penalty depends on which quartile the penalty is in. In regression (1), receiving a penalty in the top quartile reduces facility emissions by 10.8% (compared to the omitted category of receiving no penalty). Receiving a penalty in the second and third quartile does not significantly affect emissions. This implies that facilities pay attention to large penalties and adjust their behavior accordingly, but generally do not react to smaller penalties. Notably, although the maximum penalty in any one year can be several million dollars, the seventy-fifth percentile is typically less than $15,000. This amount is likely to be considered a small sum for facilities. Instead, it is likely that a penalty in the top quartile signals to the facility that regulators are watching the facility and willing to impose more stringent enforcement in the future, thus producing the deterrent effect.

Additionally, receiving a penalty in the bottom quartile reduces emissions by 12.6% compared to the omitted category of receiving no penalty. This is unexpected because receiving larger penalties in the second and third quartile has no impact. This result is somewhat similar to the result that receiving an enforcement action that is not accompanied by a penalty reduces emissions by 4.0%. This is perhaps because violations that receive small or no penalties are violations that are easier to remedy. Facilities remedy the problem, thus resulting in a decrease in emissions. Regressions (2) and (3) for the samples of major polluters and manufacturing facilities show similar results: receiving a penalty in the top quartile of the penalty distribution significantly reduces emissions, as does receiving a penalty in the bottom quartile of the distribution and receiving an enforcement action without penalties.

[Insert table 8 here.]

In table 8, I show that the results of the penalties are robust to using dummy variables to represent the presence of regulatory actions. The results are similar to those shown in table 7: penalties in the bottom and top quartile are effective at reducing emissions. Compared with the regressions in table 6, which uses dummy variables to represent regulatory actions and finds that penalties did not have any significant impact, this specification finds that penalties in the top quartile are effective. It is possible that assigning one dummy variable to whether the facility received a penalty (in table 6) muted the otherwise strong effect of penalties in the top and bottom quartiles.

Conclusion

This article is one of the few studies to directly examine air pollution emissions, and the first to examine the effect of monitoring and enforcement on NO_x and criteria pollutant emissions. Furthermore, by limiting my study to one jurisdiction, I am able to better understand the monitoring and enforcement policies of the regulator; this is important because state and local regulators play a big role in the CAA.

Penalties have a relatively robust impact. A facility that is assessed a penalty in the top quartile reduces its emissions by 10.8%. This result suggests that the deterrent impact might arise out of a small proportion of the highest penalties. Previous research has focused on whether a penalty was present and the magnitude of the penalty; this finding that the impact of the penalty depends on the size of the penalty relative to other penalties is worth further study.

Additionally, this result has two interpretations. First, it is possible that facilities only pay attention and react to penalties above a certain absolute value. Across the years, the 75th percentile of positive penalties were relatively similar; thus, the top quartile could be an approximate threshold after which the facility attempts to improve its pollution outcomes.

Second, it is also possible that regulators possess limited enforcement resources and can aggressively pursue a limited number of facilities for future violations. The regulators use the size of the penalty to signal to specific facilities that it might become a target of aggressive enforcement in the future by assessing a penalty in the top quartile of the penalties it issues. This signal thus convinces the facility to reduce its pollution.

The two interpretations have different implications. The first interpretation implies that, in order to improve environmental performance, regulators merely need to assess higher penalties. The second interpretation implies that, in order to improve environmental performance, the regulator needs to increase its enforcement resources so that it can credibly threaten to pursue more violators.

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Tables

Table 1. Mean Facility NO_x Emissions in Tons

Year	Obs.	Mean	(Std. dev.)
2003	742	72.054	(333.402)
2004	788	66.210	(303.945)
2005	857	62.814	(299.672)
2006	924	57.854	(285.877)
2007	937	54.388	(283.152)
2008	935	50.373	(256.146)
2009	1,003	41.621	(190.046)
2010	1,023	39.873	(180.273)
Overall	7,209	54.588	(267.016)
Overall (log)	7,209	1.822	(8.569)

Source: Author's calculations and California Air Resources Board Emissions Inventory, 2003-2010.

Table 2. Means for Inspections, Enforcement Actions, and Penalty Amount per Facility-Year

	Mean	(Std. dev.)	Proportion positive
Inspections	2.122	(3.178)	0.732
Notices of violation	0.418	(2.180)	0.150
Enforcement without penalty	0.071	(0.995)	0.028
Penalty in thousands	8.759	(156.908)	0.141
Penalty in thousands (given penalty > 0)	61.923	(413.439)	
Penalty (log)	1.197	(3.022)	0.141

Source: Author's calculations and EPA Air Facility System, 2002-2010.

Table 3. Correlations Between Current- and Previous-Year Regulatory Actions at a Facility

	Inspections	Notices of violation	Enforcement without penalty	Penalty (log or presence)
A. Number of regulatory actions				
Current year actions:				
Inspections	1.000			
Notices of violation	0.180	1.000		
Enforcement without penalty	0.125	0.569	1.000	
Penalty (log)	0.254	0.392	0.129	1.000
Previous year actions:				
Inspections	0.738	0.202	0.208	0.236
Notices of violation	0.148	0.602	0.523	0.312
Enforcement without penalty	0.045	0.241	0.461	0.079
Penalty (log)	0.203	0.265	0.133	0.267
B. Dummy variable for regulatory actions				
Current year actions:				
Inspections	1.000			
Notices of violation	0.124	1.000		
Enforcement without penalty	0.034	0.292	1.000	
Positive penalty	0.108	0.648	0.187	1.000
Previous year actions				
Inspections	0.362	0.133	0.027	0.141
Notices of violation	0.130	0.251	0.215	0.462
Enforcement without penalty	0.036	0.084	0.171	0.076
Positive penalty	0.126	0.234	0.131	0.242

Source: Author’s calculations and EPA Air Facility System, 2002-2010.

Table 4. Description and Mean (by Facility-Year) of Variables

Variable	Description	Mean	(Std. dev.)	Proportion positive
Dependent variable				
NO_x	Natural log of NO_x emissions plus one. Source: CARB.	1.822	(8.569)	
Explanatory variables				
Inspections	Number of full and partial compliance evaluations performed. Source: EPA.	2.122	(3.178)	0.732
Notices of violation	Number of notices of violation issued. Source: EPA.	0.418	(2.180)	0.150
Enforcement without penalty	Number of administrative orders and consent decrees issued that were not accompanied by a penalty. Source: EPA.	0.071	(0.995)	0.028
Penalty (log)	Natural log of total penalty the facility received in the year plus one. Source: EPA.	1.197	(3.022)	0.141
PM_{10} nonattainment	Indicator for county nonattainment of PM_{10} NAAQS. Source: EPA.	0.522	(0.500)	
$PM_{2.5}$ nonattainment	Indicator for county nonattainment of $PM_{2.5}$ NAAQS. Source: EPA.	0.629	(0.483)	
Ozone nonattainment	Indicator for county nonattainment of ozone NAAQS. Source: EPA.	0.901	(0.298)	
Carbon monoxide nonattainment	Indicator for county nonattainment of carbon monoxide NAAQS. Source: EPA.	0.098	(0.298)	
Unemployment rate	Percentage unemployment rate in the county. Source: BLS.	8.516	(4.036)	
Income	Per capita income in the county, in thousands of dollars. Source: BEA.	39.581	(11.229)	
Percent white	Percent white population in the county. Source: Census.	77.806	(9.279)	

Source: Author’s calculations, California Air Resources Board (CARB) emissions inventory, EPA Air Facility System, Bureau of Labor Statistics (BLS), Bureau of Economic Analysis (BEA), and U.S. Census.

Table 5. Fixed Effects Regressions of the Impact of the Number of Regulatory Actions in the Previous Year on NO_x Emissions

Sample[a]	All (1)	Major (2)	Manufacturing (3)
Number of inspections in the previous year	-1.065	-1.281	-1.715
	(0.744)	(0.810)	(1.542)
Number of notices of violation in the previous year	-0.115	-0.120	-0.107
	(0.516)	(0.571)	(0.431)
Number of enforcement actions without penalty in the previous year	-3.981**	-3.992**	-3.585**
	(1.011)	(1.131)	(1.131)
Total penalty (log) in the previous year	-0.498*	-0.520^{+}	-0.475^{+}
	(0.250)	(0.273)	(0.269)
PM_{10} nonattainment	-3.873	-11.197	12.893
	(6.792)	(9.339)	(11.116)
$PM_{2.5}$ nonattainment	-4.465	-6.521	-1.763
	(4.285)	(5.416)	(6.459)
Ozone nonattainment	-3.819	-0.244	-1.764
	(7.594)	(10.765)	(10.363)
Carbon monoxide nonattainment	-12.970**	-16.777**	-8.030
	(4.772)	(5.775)	(7.019)
Unemployment rate	-6.469**	-6.226*	-7.097*
	(2.034)	(2.418)	(3.299)
Income (/$1000)	0.979	0.620	0.529
	(0.900)	(1.243)	(0.997)
Percent white	-9.552**	-9.260*	-6.469
	(3.104)	(4.225)	(4.916)
Observations	7,206	4,960	3,026
Facilities	1,147	756	475
Adjusted R-squared	0.097	0.110	0.133
Within R-squared	0.145	0.168	0.171

** $p < 0.01$, * $p < 0.05$, $^{+}$ $p < 0.1$; cluster-robust standard errors in parentheses; industry-year dummy variables included but not shown.

[a] Column titles (“all,” “major,” and “manufacturing”) refer to the sample used in the regression.

Table 6. Fixed Effects Regressions of the Impact of the Presence of Regulatory Actions in the Previous Year on NO_x Emissions

Sample[a]	All (1)	Major (2)	Manufacturing (3)
Presence of any inspections in the previous year	-1.381	-0.139	-0.833
	(1.898)	(2.701)	(2.573)
Presence of any notices of violation in the previous year	-4.789^{+}	-5.784^{+}	-0.487
	(2.761)	(3.108)	(4.180)
Presence of any enforcement actions without penalty in the previous year	-8.297	-6.744	-14.651^{+}
	(6.050)	(6.675)	(8.597)
Presence of a penalty in the previous year	-2.599	-2.250	-4.020
	(2.264)	(2.594)	(2.885)
PM_{10} nonattainment	-3.999	-10.496	12.458
	(6.897)	(9.609)	(11.410)
$PM_{2.5}$ nonattainment	-5.039	-7.407	-2.193
	(4.289)	(5.430)	(6.472)
Ozone nonattainment	-3.561	-0.691	-1.560
	(7.519)	(10.562)	(10.172)
Carbon monoxide nonattainment	-13.975**	-18.166**	-9.328
	(4.810)	(5.905)	(6.940)
Unemployment rate	-6.556**	-6.296**	-7.149*
	(2.030)	(2.413)	(3.271)
Income (/$1000)	1.122	0.867	0.745
	(0.902)	(1.239)	(0.963)
Percent white	-9.491**	-9.141*	-6.274
	(3.107)	(4.237)	(4.985)
Observations	7,206	4,960	3,026
Facilities	1,147	756	475
Adjusted R-squared	0.093	0.103	0.121
Within R-squared	0.141	0.162	0.160

** $p < 0.01$, * $p < 0.05$, $^{+}$ $p < 0.1$; cluster-robust standard errors in parentheses; industry-year dummy variables included but not shown.

[a] Column titles ("all," "major," and "manufacturing") refer to the sample used in the regression.

Table 7. Fixed Effects Regressions of the Impact of the Number of Regulatory Actions and Penalty Quartiles in the Previous Year on NO_x Emissions

Sample[a]	All (1)	Major (2)	Manufacturing (3)
Number of inspections in the previous year	-1.020 (0.742)	-1.215 (0.807)	-1.576 (1.516)
Number of notices of violation in the previous year	-0.022 (0.476)	0.054 (0.527)	0.153 (0.395)
Number of enforcement actions without penalty in the previous year	-4.027** (0.966)	-4.075** (1.067)	-3.773** (0.994)
Total previous-year penalty in the bottom quartile	-13.478** (4.335)	-12.855** (4.904)	-14.507* (6.933)
Total previous-year penalty in the second quartile	2.299 (3.300)	1.653 (3.667)	-0.276 (4.493)
Total previous-year penalty in the third quartile	-1.411 (4.799)	-1.004 (4.958)	8.962 (5.919)
Total previous-year penalty in the top quartile	-11.390* (5.787)	-15.109* (6.500)	-19.476* (7.572)
PM_{10} nonattainment	-3.959 (6.763)	-11.549 (9.302)	13.166 (10.919)
$PM_{2.5}$ nonattainment	-4.658 (4.279)	-6.802 (5.408)	-2.586 (6.427)
Ozone nonattainment	-4.474 (7.554)	-0.780 (10.662)	-2.393 (10.216)
Carbon monoxide nonattainment	-12.846** (4.752)	-16.544** (5.754)	-8.238 (6.964)
Unemployment rate	-6.418** (2.019)	-6.145* (2.399)	-7.024* (3.241)
Income (/$1000)	0.910 (0.905)	0.542 (1.250)	0.356 (0.999)
Percent white	-9.496** (3.079)	-9.219* (4.197)	-6.325 (4.790)
Observations	7,206	4,960	3,026
Facilities	1,147	756	475
Adjusted R-squared	0.100	0.112	0.141
Within R-squared	0.148	0.171	0.180

** $p < 0.01$, * $p < 0.05$, + $p < 0.1$; cluster-robust standard errors in parentheses; industry-year dummy variables included but not shown.

[a] Column titles ("all," "major," and "manufacturing") refer to the sample used in the regression.

Table 8. Fixed Effects Regressions of the Impact of the Presence of Regulatory Actions in the Previous Year on NO_x Emissions

Sample[a]	All (1)	Major (2)	Manufacturing (3)
Presence of any inspections in the previous year	-1.446	-0.223	-0.768
	(1.901)	(2.721)	(2.574)
Presence of any notices of violation in the previous year	-4.255	-4.840	-0.005
	(2.637)	(2.967)	(3.934)
Presence of any enforcement actions without penalty in the previous year	-7.930	-6.040	-14.855^{+}
	(6.056)	(6.710)	(8.484)
Total previous-year penalty in the bottom quartile	-11.752**	-10.862*	-14.531*
	(4.151)	(4.785)	(6.676)
Total previous-year penalty in the second quartile	4.132	3.670	-0.543
	(3.529)	(3.983)	(4.759)
Total previous-year penalty in the third quartile	-0.110	0.531	8.550
	(4.633)	(4.894)	(6.078)
Total previous-year penalty in the top quartile	-9.937	-13.532*	-20.704*
	(6.057)	(6.786)	(8.472)
PM_{10} nonattainment	-4.027	-10.811	12.757
	(6.868)	(9.566)	(11.209)
$PM_{2.5}$ nonattainment	-5.232	-7.706	-3.077
	(4.285)	(5.426)	(6.444)
Ozone nonattainment	-4.119	-1.231	-2.277
	(7.503)	(10.536)	(10.063)
Carbon monoxide nonattainment	-13.856**	-17.948**	-9.474
	(4.791)	(5.884)	(6.898)
Unemployment rate	-6.486**	-6.196**	-7.063*
	(2.016)	(2.396)	(3.219)
Income (/$1000)	1.066	0.797	0.575
	(0.906)	(1.244)	(0.956)
Percent white	-9.481**	-9.153*	-6.156
	(3.084)	(4.211)	(4.854)
Observations	7,206	4,960	3,026
Facilities	1,147	756	475
Adjusted R-squared	0.095	0.106	0.130
Within R-squared	0.144	0.165	0.169

** $p < 0.01$, * $p < 0.05$, $^{+}$ $p < 0.1$; cluster-robust standard errors in parentheses; industry-year dummy variables included but not shown.

[a] Column titles ("all," "major," and "manufacturing") refer to the sample used in the regression.

Figures

Figure 1. Timeline of a Typical Violation

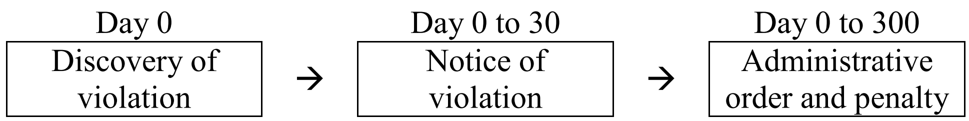

Figure 2. Mean NO_x Emissions Over Time