Enforcement of Vintage Differentiated Regulations: The Case of New Source Review

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Abstract

This paper analyzes the effects of the New Source Review (NSR) environmental regulations on coal-fired electric power plants. Regulations that grew out of the Clean Air Act of 1970 required new electric generating plants to install costly pollution control equipment but exempted existing plants. Existing plants lost their exemptions if they made "major modifications." We examine whether this caused firms to invest less in grandfathered plants, possibly leading to lower efficiency and higher emissions. We find evidence that heightened NSR enforcement reduced capital expenditures at vulnerable plants. However, we find no discernable effect on other inputs or emissions.

JEL Classification: L51, L94, Q58, and Q52 *Keywords:* New Source Review, Environmental Regulations, Productivity, and Electricity

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1 Introduction

Many regulations in the United States apply different standards to new and old units, whether the units are cars subject to fuel-efficiency standards, buildings subject to building codes, or electric power plants subject to environmental regulations. This asymmetric regulatory treatment is known as vintage differentiated regulation (VDR). There are several rationales for using a VDR. From an efficiency perspective, it is often prohibitively expensive to retrofit existing units with the new technology, either because the retrofits themselves are expensive or because the transaction costs involved in running a recall program are prohibitive. From a political perspective, if owners of existing units are exempt from the new regulation, their incentives to oppose it are limited. Policymakers envision that over time, new units will replace old ones, so that in the long run, the universe of units will reflect the new standard.

Previous theoretical and empirical work has shown that vintage differentiated regulations can lead to several types of distortions in the short run (see Stavins (2006) for an overview of the literature). First, if the regulations increase the cost of building the new unit, old units will be kept in service far longer than they would have absent the VDR. For example, previous work has found some evidence that the Corporate Average Fuel Economy standards for new vehicles increased sales of used vehicles (Goldberg, 1998). Related to this, in contexts where consumers face a choice between using a new or an old unit, they may favor the old unit if the new regulation imposes an additional variable cost.

Another distortion can arise in contexts where regulators attempt to impose the new standards on old units. Often this is accomplished by enforcing the new standards when the old units engage in what the regulator considers to be significant retrofitting. Regulators target retrofitting both to mitigate the incentive to keep old units in service to avoid building new units compliant with the stricter standard and because the costs of complying with new standards may be lower when coupled with other changes. If units subject to this oversight take costly steps to avoid meeting the new standards, this can lead to distortions. For example, in many states, new residential buildings are required to meet certain safety or energy-efficiency standards. To avoid triggering those standards when they remodel, existing homeowners may hire unlicensed contractors or design their remodeling plans to preserve enough of the existing structure to avoid invoking the new standards, actions they might not have taken in the absence of the VDR. More significantly, the threat of meeting new standards may lead homeowners to defer or avoid any remodeling, even though the contemplated changes may have made the home *somewhat* more safe or energy efficient.

This paper considers evidence that this second type of distortion impacted electric power plants subject to environmental regulation. Specifically, we consider the effects of the New Source Review (NSR) program, which grew out of the Clean Air Act of 1970. Under the Clean Air Act, new fossil-fuel-fired power plants have been required to install various forms of pollution-control equipment. In an attempt to counteract the incentive to defer retirements of grandfathered plants, the regulations require that existing plants install pollution-control equipment if they perform a major overhaul. However, exactly what qualifies as a major, lifetime-extending modification has been the subject of extensive debate. Sparring over the application of the retrofitting rules culminated in several lawsuits filed by the Department of Justice on behalf of the EPA beginning in late 1999. The lawsuits alleged that a number of utilities had performed modifications to their coal-fired power plants without seeking the proper permits or installing required mitigation technologies. The utilities countered with claims that, enforced in the way the lawsuits suggested it should be, NSR could become "the greatest current barrier to increased efficiency at existing units" (National Coal Council, 2001). In a 2002 report, the EPA largely accepted these arguments, finding that "NSR discourages some types of energy efficiency improvements" (EPA, 2002). This paper provides the first empirical evidence to address these claims.

The stakes in this debate are substantial. Power produced at coal-fired plants, a prime target of NSR enforcement, provides roughly half of the electricity consumed in the US. These power plants used over 30 billion dollars in fossil fuels during 2004, so even a small fractional impact on fuel efficiency could lead to large absolute increases in costs. Coal-fired power plants are also major polluters, emitting nearly 30 percent of the carbon dioxide, the major contributor to climate change, and 67 percent of the sulfur dioxide, the major contributor to acid rain, in the US. Policies that impact their emissions can have significant effects on environmental quality. NSR has also been one of the most contentious pieces of environmental regulation, and legal wrangling over how to determine whether plants have engaged in routine maintenance have been taken all the way up to the Supreme Court (Environmental Defense v. Duke Energy 549 U. S. ____ (2007)). The lawsuits have resulted in substantial payouts by the utilities. For instance, American Electric Power settled its NSR enforcement case in 2007 by agreeing to pay over $4.5 billion in fines and for new pollution control equipment (see Cusick, 2007).

The onset of carbon dioxide (CO2) regulations may produce an important new chapter in the debate over the enforcement of NSR. Since a 2007 Supreme Court ruling determined that the EPA was responsible for regulating CO2 under the Clean Air Act, the agency has been developing a new set of performance standards. A preliminary proposal issued by the EPA in September of 2009 (EPA, 2009) would create CO2 performance requirements for both new facilities and those undertaking "major modifications." The substantial additional compliance costs will likely exacerbate the tensions over NSR, which were previously dominated by concerns over the costs of complying with SO2 regulations.

We consider evidence that coal units concerned about triggering NSR changed their operations in the late 1990s and early 2000s when the threat of NSR enforcement became acute. We argue that plants that had already installed the most expensive type of pollution-control equipment, scrubbers, provide a useful control group, so we use a difference-in-difference approach to compare input use at plants with and without scrubbers. We see some evidence that plants without scrubbers reduced their capital expenditures more than the control plants, but little evidence that they changed their operations and maintenance expenditures. Also, we see no evidence that fuel efficiency degraded or that emissions increased at the plants without scrubbers compared to the control plants.

This paper proceeds as follows. The next section presents an overview of the NSR program and reviews some of the existing literature that speaks to the effects that it has had. Section 3 outlines our empirical approach to testing for an effect of NSR on unit operations and Section 4 discusses the empirical results from applying those tests. Section 5 concludes.

2 The New Source Review Program

The 1970 amendments to the Clean Air Act (CAA) established the New Source Performance Standards (NSPS), requirements for the installation of pollution control equipment on major stationary sources of emissions, including electricity generation units. In recognition of cost concerns and political realities, these standards were applied only to new facilities.[1] Existing facilities were not required to retrofit. Proponents of the new emissions standards, ignoring the incentive effects of the regulation, envisioned that a natural cycle of replacement of existing power plants would lead to universal adoption of the new standards. During the 1970s, however, less progress than was expected was made toward achieving the ambient air-quality goals established in the 1970 amendments.

Partially in reaction to frustrations over this lack of progress, the NSR program was created as part of the 1977 amendments to the Clean Air Act. Importantly for our focus on coal-fired electricity generation plants, the 1977 amendments further strengthened source-specific emission regulations on new facilities, particularly those for emissions of SO2. In addition to limiting the maximum emission of SO2, the 1977 amendments required specific levels of post-combustion removal of the pollutant. The requirement for removal effectively mandated the use of flue gas desulfurization (FGD), also known as "scrubbers." These new source-specific regulations significantly increased the mitigation costs for new facilities and further widened the gap in compliance costs between existing and new (post-1978) facilities.

The NSR program was designed to review any proposed new source as well as major modifications to existing sources. By including major modifications, regulators intended to counteract the incentives provided by the 1970 and 1977 amendments to extend the lifetime of existing

[1] See Ellerman and Joskow (2000).

facilities in order to avoid building a replacement that would require more costly mitigation technology. In order to police attempts to artificially extend the lifetime of plants, however, the EPA was in the position of trying to differentiate between "routine maintenance" and "major modifications." Almost from the inception of the NSR program, there has been controversy over which activities constituted a major modification to an existing facility and what criteria should be used to identify these activities.

The first major NSR enforcement case involving electricity generation was the Wisconsin Electric (WEPCo) case in 1990. WEPCo's proposal to substantially overhaul several coal units was deemed by EPA in 1988 to be non-routine, lifetime-extending and likely to lead to increased emissions in the future, implying that the plant should install pollution control equipment compatible with NSPS. A superior court upheld this interpretation in 1990. The case also led to an adoption in 1992 of a standard, known as the "WEPCo Rule," that implied that efficiency-improving investments would not trigger NSPS even if they resulted in increased emissions, as long as those increases were a consequence of the improved efficiency of the plant or, in the case of electric utilities, a result of demand growth.

Throughout the 1990s the industry, EPA, and other agencies struggled to further clarify the distinctions between a lifetime extending, major modification that would subject a plant to NSPS and routine maintenance activities that would not. In the meantime, in 1997, the EPA's enforcement division began investigations of coal-fired electricity plants to determine whether they had complied with NSR provisions in the past. Finally, in November 1999, the Department of Justice, acting for the enforcement division of the EPA, filed suits against seven utility companies as well as the federally-owned Tennessee Valley Authority alleging NSR violations at many power plants.

The violations cited in the lawsuits involved actions going back 15 to 20 years. The EPA claimed that major, life-extending modifications had taken place in these plants without proper permitting under the NSR program. The agency sought the installation of pollution control equipment compliant with NSPS or the immediate shutdown of the plants, as well as up to

$27,500 per violation-day in civil penalties.

The defendants and other firms in the industry claimed to be stunned at what they viewed as a radical redefinition of the boundary between routine maintenance and life-extending major modification. They expressed dismay that actions that could potentially trigger new source review might include "like kind replacement of component parts with new equipment that has greater reliability"(Utility Air Regulatory Group, 2001). Such activities might include "[r]epair or replacements of steam tubes, and [r]eplacement of turbine blades," activities which utilities believed to be completely routine. For its part, the EPA claimed that it was not reinterpreting the rule and that such projects were non-routine, increased generation capacity, and extended the lifetime of the plant, so the rule governing major modifications applied.[2]

At its heart, the struggle during this period highlighted the differences between those who were frustrated at the lack of proliferation of mitigation technologies mandated 20 years earlier and those who felt existing plants should never have to install such equipment. The original Clean Air Act of 1970 was intended to avoid the incremental costs of retrofitting these technologies in favor of applying them to new facilities. But in order for the technologies to proliferate, new facilities had to replace the old ones. However, aggressively policing the incentives to artificially extend the life of existing plants threatened to severely impact the efficiency of those existing plants.

The lawsuits and the more aggressive enforcement stance underlying them spawned a huge outcry within the electricity industry. A utility group argued that "the NSR interpretations currently being advanced by EPA Enforcement would create an entirely unworkable system where every capital project would be deemed non-routine" (UARG, 2001). Thus, utilities have to either "take limits that ensure that units cannot operate at higher levels after the project than before, or to delay needed repair and replacement projects and subsequent operations pending receipt of NSR permits and the subsequent retrofit of emissions control equipment." The National Coal Council stated that the NSR policies "strongly discourages utilities from undertaking [efficiency

[2] A background paper by EPA, EPA (2002), describes the history and controversy surrounding NSR enforcement.

improving] projects, due to the significant permitting delay and expense involved, along with the expensive retrofit of pollution controls that are intended for new facilities" (NCC, 2000).

A proposal by Detroit Edison to reconfigure two of its steam turbines produced a case that utilities felt typified the perverse incentives created by the EPA enforcement initiatives. In 2000, Detroit Edison proposed that, in the process of a periodic overhaul of its turbines, it replace older failing turbine blades with a newer "dense pack" turbine blade configuration that would improve both the fuel efficiency and reliability of the generating units. An EPA regional administrator ruled that such a project would constitute a major modification and should go through NSR. Rather than installing new pollution-control equipment, Detroit Edison eventually agreed to limit the output of the plant to operating levels experienced before the overhaul. Critics of the decision argued that such policies limited both the efficiency and reliability benefits of these kinds of projects and created a disincentive for utilities to undertake them.

The scale of the lawsuits and the broader implications of the EPA enforcement initiatives made NSR policy a major focus of lobbying efforts and policy debate during the early years of George W. Bush's presidency. In 2001, the EPA initiated another review of its NSR policies that culminated a year later in the June 2002 New Source Review Report to the President. In this report the EPA established a finding that "NSR discourages some types of energy efficiency improvements when the benefits to the company of performing such improvements is outweighed by the costs to retrofit pollution controls or to take measures necessary to avoid a significant net emissions increase" (EPA, 2002). In August 2003, the EPA issued the Equipment Replacement Provision (ERP). It stated that any repair, replacement, and maintenance activities would be considered routine maintenance, and therefore not subject to NSR, so long as those activities did not exceed 20% of the capital costs of the plant in one year. By establishing an extremely high threshold for routine maintenance, the ERP effectively eliminated the risk that an existing power plant would be forced to retrofit emissions controls under the NSR provisions.

2.1 Existing Empirical Evidence on NSR

Early empirical work on NSR focused on its impact on the retirement of old plants and entry of newer, cleaner ones. Maloney and Brady (1988) found that electric power plants were kept in service longer during the 1970s in states with more stringent environmental regulations. Nelson, Tietenberg, and Donihue (1993) estimate a similar model using utility-level data and also show that tighter regulation increased the age of capital, but they emphasize that the aging capital stock did not significantly impact overall emissions.

Several recent papers analyze various dimensions of NSR. Heutel (2008) builds a structual model to revisit the question of the extent to which NSR and NSPS delayed power plant retirements. Lange and Linn (2008) present results from an event study of the 2000 election and show that stock prices for electric utilities with a large fraction of coal-fired power plants increased more than the stock prices of other utilities when the Supreme Court decision established George W. Bush's presidency, a result which they attribute to anticipated weakening of the NSR process. Keohane, Mansur and Voynov (2009) consider whether the threat of the NSR lawsuits caused coal plants to reduce SO2 emissions in the year before the first round of lawsuits were announced, hypothesizing that utilities would reduce emissions in an attempt to avert a lawsuit. While they are studying the effect of NSR on generating plant level variables over a similar time period to ours, the two papers differ in several ways. First, Keohane, Mansur and Voynov focus exclusively on emissions, while we analyze the substitution in plant inputs that could be caused by NSR enforcement. They also focus on behavior in the year following October 1998, when they hypothesize that efforts to avert a lawsuit would be highest, and identify an effect based on the estimated probability of being sued.

There has been little empirical work addressing the incentive effects of the regulatory policing of plant retrofit activities, which is our focus. Yet, many of the policy decisions by the EPA with respect to NSR have been driven by the belief that the enforcement of NSR has negatively impacted productivity. One exception is List, Millimet, and McHone (2004) who use the variation in county attainment status to examine modification decisions at manufacturing plants in New York State from 1980-1990. Under the argument that the costs of complying with the NSPS are higher in nonattainment areas, the disincentive to invest in a plant, for fear of triggering NSR, should be strongest there.[3] They find some evidence that plants were less likely to undertake modifications if they were located in non-attainment areas, although they did not find an effect on the retirement of existing plants. Facing data limitations, List, Millimet and McHone are only able to look at modification decisions and not the resulting effects on efficiency or emissions, as we are able to do in this paper. Also, while they measure the impact on a count variable indicating the number of modifications, we are able to measure capital expenditures. Finally, we focus on the coal-fired power plants, and, as we documented in the introduction, these are significant sources of pollution and were the only targets of the NSR lawsuits.

3 Empirical Approach

As is true of most capital equipment, power plant performance can degrade over time. Firms can undertake a number of different capital projects to recover lost efficiency. We assume that all the power plant owners are optimizing their choice of inputs against a set of incentives provided by the market and regulatory environment in which they operate.[4] These firms decide how much capital to invest (*i.e.,* how many projects to undertake) by comparing the cost of new capital versus the expected savings and benefits from lower input costs (primarily through lower fuel use and greater reliability).[5] Rigorous NSR enforcement increases the effective cost of capital, since firms must not only pay for the specific project, but also risk having to pay for new pollution control equipment. This means that under an extremely rigorous NSR enforcement regime,

[3]We also explored distinctions between plants in attainment and nonattainment areas but found no effect. Note that the attainment-nonattainment distinction may be less relevant for coal power plants since all new plants must install the same SO2 emissions control equipment, regardless of location.

[4]We also assume that these incentives do not change during the period of heightened NSR enforcement, with the exception of the effect of NSR enforcement itself.

[5]As all of the firms in our data set were subject to some form of cost-plus regulation over the time period we study, it is reasonable to question whether they would minimize costs. For this reason, part of our null hypothesis is that the NSR enforcement did not affect utilities' incentives because their costs were regulated. We note that this view is inconsistent with the vociferous objections the utilities raised to NSR enforcement, some of which we have quoted above.

firms will see fewer capital projects that have the required pay-back in terms of fuel and other savings. This will cause plants to spend less on capital, but perhaps more on other inputs to the production process such as fuel or nonfuel materials.

To assess the impact of NSR enforcement activities, we characterize units as either being concerned about triggering NSR or not concerned. We then use a difference-in-difference approach to compare input use across the two types of units around the various NSR enforcement events to evaluate whether fear of increased NSR enforcement impacted the mix of inputs. The units that were not concerned serve as controls for other changes in coal-fired power plant operations. In the following subsection, we detail a model that summarizes our research design, discuss our identification strategy, summarize our data and discuss evidence bearing on the validity of our identifying assumptions.

3.1 Research Design

Electric generating plants have been used to estimate production functions in a number of previous papers (see, *e.g.,* Nerlove, 1963; Christensen and Greene, 1976; Kleit and Terrel, 2001; Knittel, 2002). All of these papers specify output as a function of inputs that capture the important input categories. Here, to motivate our empirical specifications, we posit a Cobb-Douglas production function:

$$Q_{it} = F_{it}^{\gamma_i^F} OM_{it}^{\gamma_i^{OM}} K_{it}^{\gamma_i^K} \tag{1}$$

where F describes fuel, OM captures non-fuel operating and maintenance expenses, including labor, and K represents capital. While several of the papers mentioned above focused on productivity and jointly estimate the set of inputs used to produce Q_{it}, we follow the approach of Fabrizio, et al. (2007) and use factor-demand equations for the specific inputs of interest. A cost-minimizing firm faced with input costs S_t, W_t, and R_t for fuel, O&M, and capital respectively would select optimal inputs by

$$\min_{F_{it}, OM_{it}, K_{it}} S_t \cdot F_{it} + W_t \cdot OM_{it} + R_t \cdot K_{it}$$

$$\text{s.t. } Q_{it} \leq F_{it}^{\gamma_i^F} OM_{it}^{\gamma_i^{OM}} K_{it}^{\gamma_i^K}$$

yielding the following factor demand equations

$$F_{it} = (\lambda_{it} \gamma_i^F Q_{it})/S_t, \tag{2}$$

$$OM_{it} = (\lambda_{it} \gamma_i^{OM} Q_{it})/W_t, \tag{3}$$

$$K_{it} = (\lambda_{it} \gamma_i^K Q_{it})/R_t \tag{4}$$

where λ_{it} is the Lagrangian on the production constraint.

We adopt the factor-demand approach because our focus is on dissecting the use of individual inputs. The argument that NSR enforcement has impacted power plant operations suggests that by reducing their capital expenditures, utilities have compromised their units' fuel efficiencies or increased their operations and maintenance costs and so are spending more on other inputs for a given level of output. Put another way, we are interested in whether NSR introduced a new bias against capital, and what the implications of that change in relative input costs were to input usage.[6] We are particularly interested in assessing whether NSR enforcement caused the plants to reduce fuel efficiency (e.g. substitute fuel for capital), since fuel use is highly correlated with pollution output. We cannot exclude the possibility that any new bias provided by NSR enforcement partially offset existing biases, perhaps even improving overall productive efficiency. However, even in that case there is still a perverse environmental impact in that fuel consumption

[6]Existing biases may have favored capital due to the Averch-Johnson effect, for instance.

and emissions would have increased as a result of more stringent environmental regulation. To investigate the impact on emissions directly, we also estimate versions of our specification that use emission rates as the dependent variable.

We develop our first empirical specification by taking the logs of both sides of (4).

$$\ln(K_{it}) = \ln(Q_{it}) + \ln(\lambda_{it}) - \ln(R_t) + \ln(\gamma_i^K). \tag{5}$$

Similar transformations can be applied to (2) and (3). Note that λ_{it} is defined simultaneously by equations (2)-(4). Our hypothesis is that heightened enforcement of NSR increased the cost of capital for firms, to $R_t * NSR_1$ where $NSR_1 > 1$, causing a potential shift away from capital toward one of the other inputs.[7] Intuitively, an increase in one of the factor prices causes an increase in the shadow value of the production constraint, to $\lambda_{it} * NSR_2$ where $NSR_2 > 1$. It is now more expensive to produce at the same level, and therefore the value of relaxing the production constraint has increased. We would therefore expect λ_{it} to increase with an increase in a factor price.

$$\ln(K_{it}) = \ln(Q_{it}) + \ln(\lambda_{it}) + \ln(NSR_2) - \ln(R_t) - \ln(NSR_1) + \ln(\gamma_i^K) \tag{6}$$

For any given level of Q_{it}, the direct effect (NSR_1)dominates, leading to a reduction in capital expenditures and increase in other inputs.[8] Conversely, for the other inputs, an increase in the implied cost of capital would have only an indirect effect through λ_{it}. From equation (2) this would in turn increase utilization of fuel, as fuel price S_t has remained unchanged.

[7]Modeling NSR as an increase in the price of capital reflects the assumption that the likelihood of triggering the regulation was increasing in the amount of the capital expenditure. This is consistent with the distinction the regulation drew between "routine maintenance" and "major modifications."

[8]Combining equations (4) and (2) one can see that $\frac{K_{it}}{F_{it}} = \frac{\frac{\gamma^K}{R_{it}}}{\frac{\gamma^F}{F_{it}}}$. For a given output level Q, an increase in capital costs R_{it} therefore implies both a reduction in K and increase in F as the ratio K/F must decline and Q is unchanged.

$$\ln(F_{it}) = \ln(Q_{it}) + \ln(\lambda_{it}) + \ln(NSR_2) - \ln(S_t) + \ln(\gamma_i^F). \tag{7}$$

Our base specifications use equations (6) and (7).

$$\begin{aligned} \ln(I_{it}) \quad = \quad & \beta_1 \ln(Q_{it}) + \beta_2 Vulnerable * NSR\ Enforcement\ Period_{it} \\ & + \beta_3 Vulnerable * Post\ NSR\ Enforcement\ Period_{it} + \beta_4 X_{it} + \kappa_t + \mu_i + \varepsilon_{it} \end{aligned} \tag{8}$$

for unit or plant i in period t where I indexes the input category, Q is output of the plant, $Vulnerable{*}NSR\ Enforcement\ Period$ is a dummy variable equal to one during the enforcement period for $Vulnerable$ units (we define both the enforcement period and the set of $Vulnerable$ units in the next subsection), X_{it} is a set of control variables. The unit-fixed effects (μ_i) reflect the unit-specific production characteristics captured by the γ_i. Note that we do not directly observe input prices or the λ_{it}. The unit- and time-specific fixed effects capture most of the variation in these factors.

We hypothesize that β_2 (e.g. $ln(NSR_2) - ln(NSR_1)$) will be negative for $I = capital$ if the heightened enforcement of NSR caused utilities to cut back on investing in their vulnerable plants. We conjecture β_2 will be positive for $I = fuel$ if degradations in the capital caused fuel efficiency to go down, in effect creating a substitution of fuel for capital. The expected sign for β_2 for $I = maintenance\ expenditures$ is less clear. To the extent our variable measures expenditures that reflect truly routine maintenance, they may be positively affected if they substitute for capital. On the other hand, the category may include expenditures that firms perceive to be subject to regulatory scrutiny. $Vulnerable * Post\ NSR\ Enforcement\ Period$ is a dummy variable equal to one after the enforcement period (*i.e.,* in 2003 and 2004). We include it to assess whether utilities increased capital use at $Vulnerable$ plants to make-up for any reductions made during the enforcement period. We discuss the assumptions necessary to identify β_2 in the following subsections.

3.2 Identification Strategy

An important step to our empirical approach is identifying the units that were most concerned about NSR. Our fundamental identifying assumption is that firms were less concerned about heightened enforcement at plants where they had already installed state-of-the-art pollution mitigation technologies. This is due less to the fact that such plants were unlikely to be the subject of an enforcement action, and more to the fact that the likely result of any enforcement would be a requirement to install equipment that they already had. Since these plants had already borne the main costs that would arise from enforcement, they had relatively little cost exposure to an NSR enforcement action.

We take a number of factors into consideration in making this assumption, starting with the basic rules governing new sources. Environmental regulations (see 40CFR52) specified that new coal units, or existing coal units that triggered the new source requirements, were required to achieve the lowest achievable emissions rate (LAER) if they were located in a non-attainment area and were required to use the best available control technology (BACT) if they were in a non-attainment area. The LAER and BACT standards varied by pollutant and over time. New coal units, as well as existing units that triggered the NSPS, were required to mitigate multiple pollutants, including nitrogen oxides (NOx), sulfur dioxide (SO2) and particulates.

Retrofitting a plant with a scrubber to remove SO2 was far more costly than retrofitting a plant with a control device for NOx or particulates. Industry estimates suggest that installing and operating a scrubber was over six times more expensive than the comparable costs for the most expensive type of pollution control equipment required to remove NOx, and particulate controls are less than one-tenth the cost of NOx controls (see ICF, 2001). Confirming this, of the 20 plants in our data set that we know installed scrubbers during our time period and for which we know the year of installation, the median increase in the total capital of the plant in the year the scrubber was installed was 17 percent and the mean increase was nearly 40 percent. By contrast, of the four plants that we know installed selective catalytic reduction equipment, the most expensive and effective NOx removal technology, the mean increase in the total capital of the plant in the year the equipment was installed was two percent. Further, while the standard for NOx removal varied between attainment and non-attainment areas and over time (partially explaining why so few plants in our data installed selective catalytic reduction equipment), the nationwide control technology required for SO2 has been scrubbers since at least 1984.[9] For these reasons, we characterize plants that had scrubbers installed (*i.e.,* were *Scrubbed*) by 1998 as not concerned about NSR since they had already installed the most expensive pollution control device that would be required if they were to trigger a new source review.[10]

The outcomes of the lawsuits brought beginning in November 1999 support the assumption that plants with scrubbers were less concerned about NSR. In *all* of the cases involving coal-fired plants that have settled to date, the companies have agreed to install scrubbers, suggesting that the lawsuits foced the companies to do what they should have done had they gone through the NSR process at the time they made the capital investments.[11] Further, company expenditures on pollution control equipment were by far the largest monetary component of the settlements.

Our base specifications use the time between 1998-2002 as the period of heightened NSR enforcement. We start the enforcement period in 1998 (implying that the utilities were sensitive to the heightened risk of NSR enforcement action throughout most of 1998) as it is roughly halfway between two dates that could plausibly be linked to a signal of heightened enforcement.[12] We end the enforcement period in 2002, since by the end of that year, the Bush Administration had signaled its willingness to relax the enforcement of NSR, culminating, as we describe above, in the Equipment Replacement Provision issued in August 2003 which articulated very generous

[9] The nationwide standard has not been uniformly applied and several of the units built since 1984 were built without scrubbers. All those units were subject to the 1999 lawsuits.

[10] Six plants installed scrubbers in 1998 or later, several in response to the NSR lawsuits. We treat these plants as part of the treatment group and include a dummy variable to measure the effect the installation of the scrubber had on the plants' operations.

[11] See US EPA Compliance and Enforcement, Case Settlements (http://cfpb.epa.gov/compliance/cases/#572) for a summary of the disposition of the NSR cases.

[12] In testimony to the Senate in 2004, Bruce Buckheit, formerly the EPA Enforcement Chief, stated that in February 1997, the Air Enforcement Division, "began investigations of coal fired utility boilers to determine compliance with NSR provisions" (Buckheit, 2004). It is unclear how long it took the utilities to become aware that the EPA could be interpreting past investment decisions as potentially requiring an NSR process. In October 1998, an article in the trade press announced that the EPA requested information from boiler manufacturers on known changes to boilers they had sold to utilities (*Electricity Daily*, 1998).

definitions of what constituted routine maintenance. We explore the sensitivity of our results to the specific delineation of the enforcement time period.

Our main estimating equation is thus equation (8) where we define $Vulnerable$ units as $NotScrubbed$:

$$\ln(I_{it}) = \beta_1 \ln(Q_{it}) + \beta_2 Not\ Scrubbed_* NSR\ Enforcement\ Period_{it} \tag{9}$$
$$+\beta_3 Not\ Scrubbed * Post\ NSR\ Enforcement\ Period_{it} + \beta_4 X_{it} + \kappa_t + \mu_i + \varepsilon_{it}$$

3.3 Data

We use data on nearly 900 coal generating units housed at over 300 plants.[13] We use both detailed hourly data on fuel use spanning the nine years from 1996 to 2004, and annual data on all inputs from 1988 to 2004. We draw on data filed with various regulatory agencies by investor- and municipally-owned utilities. The sources are described more fully in the data appendix. Our panel is not balanced because non-utility owners are not required to report these data and some of the plants in our sample were divested to non-utility owners. (We discuss the potential bias this may create below.)

For inputs, we analyze fuel use as well as expenditures on capital and operations and maintenance (O&M). O&M expenditures include both labor and materials.[14] For consistency with the industry standard for describing fuel use, we divide $Fuel$ by Q and use the $HeatRate$–the inverse of fuel efficiency. For capital and O&M, we consider expenditures and not quantities. Because these categories comprise many different physical inputs, we cannot properly define a variable that measures the physical inputs given the data we have. Last, note that we do not include the prices of the inputs, but to the extent that these are constant within a time period across units, the time effects (κ_t) pick up price trends. Also, in some specifications, we allowed κ_t to vary by age, size, region or other covariates which could be correlated with input prices.

[13] Electric power plants in our data comprise multiple generating units, ranging from one to ten.

[14] We also have data on the number of employees at the plants. Estimates using employees as the input showed no statistically significant effect of $Not\ Scrubbed * NSR\ Enforcement\ Period$.

The set of controls, the granularity with which we observe input use (*i.e.,* what t measures), and the unit of observation (*i.e.,* whether i indexes a plant or a unit) all vary by input. A number of the items that comprise O&M and capital expenditures are not attributable to a particular unit. This is true for most of the employees and often times multiple units will share facilities such as the fuel handling system or a cooling tower. For these reasons, our data on capital and O&M are reported at the plant level and not the unit level. Because fuel use is directly tied to a unit, we can estimate the fuel equations at the unit level.

Because some input data are only available at the plant level, we must aggregate unit characteristics to form our control and treatment group identifiers. Specifically, some plants have some units that are scrubbed and others that are not. We define a plant as *Scrubbed* if the capacity weighted average of the scrubbed units at the plant is greater than .5.[15] In other words, a plant is treated as more concerned about NSR enforcement if less than half its units have scrubbers.

Data on the dependent variables are summarized in the top panels of Tables 1a and 1b. Table 1a separately summarizes characteristics at *Scrubbed* and *Not Scrubbed* plants, while Table 1b compares characteristics at the unit level. In both tables, the time-varying variables are measured in 1996, before the NSR enforcement period began.

Considering first the top of Table 1a, we analyze capital costs using the "total cost of plant" variable, which measures the aggregate depreciated value of land, buildings, and machinery for each plant, and we analyze total operating and maintenance expenses, which comprise the bulk of non-fuel operating expenditures at power plants. The O&M and capital costs are nearly twice as high at *Scrubbed* plants. In part this reflects the costs of the scrubbers themselves, but it is primarily driven by the fact that *Not Scrubbed* plants are bigger and older (see the bottom of Table 1a). Capital costs reflect the book value, and so the older *Not Scrubbed* plants have depreciated more of the total costs.

Dependent variables at the unit level are summarized in Table 1b. The *Scrubbed* and

[15]The distribution is skewed towards either 1 (all scrubbed) or 0 (no units scrubbed). Out of 329 plants in our sample in 1996, less than 1/3 (93) have any units with scrubbers. Of those, 68 plants are fully scrubbed, and 9 more have a capacity weighted average between .5 and 1.

$Not\ Scrubbed$ units have almost identical $HeatRates$, although this represents the offsetting effects of two factors. Newer and bigger units tend to have lower heat rates (are more fuel efficient), but the scrubbers themselves reduce fuel efficiency. In cross-unit specifications of ln($HeatRate$) on a third-order polynomial in age and a third-order polynomial in size plus the $Scrubbed$ dummy, the coefficient on the $Scrubbed$ is .023 (se = .008) (recall that higher heat rates mean lower fuel efficiency). The unit-level emissions rates are significantly lower at scrubbed units, which is unsurprising in the case of SO2, the pollutant removed by a scrubber. In the case of NOx, the lower emission rate reflects the fact that the newer, larger scrubbed units also have more advanced NOx pollution controls installed.

The summary statistics on both the unit- and plant-specific characteristics at the bottoms of Tables 1a and 1b confirm that units with scrubbers are considerably younger and bigger than units without scrubbers. This makes sense since installing a scrubber requires a large fixed cost, so older units have fewer useful years over which to spread the costs. Also, the scrubber fixed costs do not scale with plant size, so the smaller plants must spread the fixed cost over less output. Tables 1a and 1b both also suggest that the scrubbed plants have higher capacity factors. This result is robust to controlling for age and size with third-order polynomials. These differences highlight the importance of controlling for unit- and plant-specific differences between the two sets of plants. The following section details the steps we take to do this.

Scrubbed plants were less likely to be divested, and since divestitures cause plants to exit our dataset, we discuss the potential biases this may create below. Finally, the bottom row of Table 1b summarizes the variable measuring the average hourly temperature across units. This is a significant exogenous determinant of $HeatRates$ so we include it as a control. Temperatures are statistically indistinguishable between $Scrubbed$ and $Not\ Scrubbed$ units.

3.4 Identification Assumptions

This section considers the assumptions necessary to interpret β_2, the coefficient on $Not\ Scrubbed*$ $NSR\ Enforcement\ Period$ in equation (9), as an NSR effect. We discuss and address issues related to the comparability of our treatment and control groups, including the existence of pre-existing time trends, and potential endogeneity concerns.

Potential Pre-existing Time Trends

By including plant- or unit-fixed-effects in equation (9), we are controlling for the time-invariant differences between *Not Scrubbed* and *Scrubbed* plants. This does not address the concern, however, that trends in input use varied across these different plant types. Specifically, the *Scrubbed* plants help identify the year effects, κ_t, which control nonparametrically for time trends in input use. β_2, therefore, captures systematic shocks to the factor demands of the *Not Scrubbed* (treatment) plants that are contemporaneous with the heightened NSR enforcement. The crucial assumption is that the *Scrubbed* plants serve as good controls for all other industry-wide trends in factor demands.

If they were ideal controls, *Scrubbed* units would be identical to *Not Scrubbed* units on all dimensions except the fact that they had pollution control equipment installed. As the bottom panels of Tables 1a and 1b demonstrate, this is hardly the case: the average *Scrubbed* plant is almost 13 years younger and ten percent larger than the average *Not Scrubbed* plant. While the means of the *Size* and *Age* variables differ, the distributions overlap substantially, as demonstrated in Figures 1 and 2. In most of the specifications reported below, we control for age- and size-specific trends by dividing the distributions into two age and two size subgroups. Figures 1 and 2 suggest that there is enough overlap in the distributions to identify a *Not Scrubbed* effect within subgroups. The regressions reported below are also robust to using different cut-offs to define the two age and size bins, as well as to the inclusion of finer cuts in the distributions (we have tried up to five categories of both the age and size distribution).

To assess the extent to which time trends in input use differed between *Not Scrubbed* and

Scrubbed plants in the pre-period, we estimated the following variant of equation (9):

$$\begin{aligned} \ln(I_{it}) &= \beta_1 \ln(Q_{it}) + \beta_2 Scrubber\ Added\ After\ 1997_{it} \\ &\quad + Not\ Scrubbed_i * \kappa_t + Scrubbed_i * \kappa_t \\ &\quad + Large_i * \kappa_t + Young_i * \kappa_t + \mu_i + \varepsilon_{it} \end{aligned} \tag{10}$$

where $Not\ Scrubbed_i$,$Scrubbed_i$, $Large_i$ and $Young_i$ are indicator variables for plants with those fixed characteristics.[16] Large plants are defined to be greater than 800 MWs in size, of which there are 36 *Scrubbed* plants and 105 *Not Scrubbed*. A t-test on the difference in means amongst the *Large* plants fails to reject the null of equal means (t=0.85), although amongst the *Small* plants, where there are 41 *Scrubbed* and 147 *Not Scrubbed*, the t-test suggests that the *Scrubbed* plants are significantly larger. *Young* plants are defined to be less than 30 years old, of which there are 55 *Scrubbed* plants and 60 *Not Scrubbed* plants. The *Scrubbed* plants are significantly younger (t=2.63) in the *Young* category, although they are indistinguishable from the *Not Scrubbed* plants in the *Old* category, where there are 22 *Scrubbed* plants and 192 *Not Scrubbed* (t=1.15).

Figures 3a-c and 4a-c plot $Not\ Scrubbed_i * \kappa_t$ and $Scrubbed_i * \kappa_t$ (1997 is the omitted year). Consider first Figure 3a, based on specifications with $\ln(TotalCapital)$ as the dependent variable where we do not estimate $Large_i * \kappa_t$ or $Young_i * \kappa_t$, the year-effects by size and age group. In the years before 1998, the beginning of the treatment period, the trends in input use are not the same: *Scrubbed* plants' capital costs grow more slowly than *Not Scrubbed* plants. This causes two problems. First, this suggests that the two groups of plants trend at different rates, which could suggest that the *Scrubbed* plants may not be good controls during the treatment period, if the difference in trends continues. Second, even if the *Scrubbed* and *Not Scrubbed* plants followed similar trends during the treatment phase (absent an NSR effect), the pre-period mean will be

[16] Note that this equation replicates equation (9), our main estimating equation, but captures the treatment effects through the *NotScrubbed* year effects.

lower for the *Not Scrubbed* plants, which will cause the difference-in-difference methodology to estimate a larger change for these plants.

Figure 3b plots $Not\ Scrubbed_i * \kappa_t$ and $Scrubbed_i * \kappa_t$ from specifications that included the age- and size-specific year effects, $Large_i * \kappa_t$ and $Young_i * \kappa_t$. In this specification, *Scrubbed* plants' capital costs appear to grow more quickly than *Not Scrubbed*.

As we document above, installing scrubbers entails a large capital expenditure. If some of the *Scrubbed* plants in Figure 3b installed their equipment during the pre-period, this could explain why their capital costs were growing faster than *Not Scrubbed* plants. Figure 3c plots coefficient estimates from the same specification depicted in Figure 3b, but estimated on the subset of plants that either had no scrubber or for which we could confirm that the scrubber was installed before the data set begins (before 1988). We have scrubber installation dates for only approximately 80 percent of our plants, so the restriction may exclude plants with scrubbers built before the period covered by our data.[17] Imposing this requirement leaves us with 42 scrubbed plants in 1996, the base year summarized in Table 1a.[18]

In Figure 3c, the *Scrubbed* and *Not Scrubbed* plants appear to follow very similar trends in capital costs during the pre-period. The year effects during the treatment period suggest that there was an NSR effect and that *Scrubbed* plants reduced capital spending relative to *Not Scrubbed* plants. The next section reports regression estimates to test this hypothesis directly. Based on the pre-period trends, we will focus on results that include age- and size-specific year effects and that exclude plants at which scrubbers were installed after 1988.

Figures 4a-c depict the year effects for *Scrubbed* and *Not Scrubbed* plants from specifications with $\ln(TotalO\&M)$ as the dependent variable. In Figure 4a, the newer, scrubbed plants appear to increase their rate of expenditures on O&M slightly faster than the older plants, which may

[17]Note that this restriction requires that the plant itself was built before 1988. We have not imposed a similar requirement on the nonscrubbed plant, although results are almost identical when we do as there was only one nonscrubbed plant built after 1988.

[18]Once we exclude plants for which scrubber installation was either unknown or after 1987, we have 20 *Small* and 22 *Large* plants that are *Scrubbed* and 33 *Young* and 9 *Old* plants that are *Scrubbed*. T-tests only reject that the mean sizes are equal in the *Scrubbed* and *Not Scrubbed* plants in the case of the *Small* plants. In the other three categories, the t-tests fail to reject and the differences in means are smaller than with the full data set.

have already been at higher annual O&M expenditure levels. When we control for age- and size-specific trends in Figure 4b the difference diminishes. When we exclude plants that might have installed scrubbers during the pre-period, the *Scrubbed* plants appear to spend on O&M at an increasing rate relative to *Not Scrubbed* plants, although the differences are statistically different in only three of the ten pre-period years.

The data that we use to estimate equation (9) for fuel and emissions is only available beginning in 1996, so we have a very short (two-year) pre-period. Our plant-level database contains information on heatrates beginning in 1988, and we have produced figures similar to 3a-c and 4a-c using $\ln(HeatRate)$ as the dependent variable. In all specifications, the trends in $\ln(HeatRate)$ were similar across *Scrubbed* and *Not Scrubbed* plants, and in no case could we reject the hypothesis that the year effects were the same across the two groups of plants. This provides some comfort that trends in *Scrubbed* and *Not Scrubbed* heat rates were similar, although the result should be interpreted cautiously, both because it is estimated at the plant- and not the unit-level and because the plant-level heat rate data can be noisy.

The second approach we take to controlling for pre-period differences in input use trends is to condition on the trends directly by estimating versions of the following equation:

$$\ln\left(I_{i\tau}\right) = \beta_1 \ln\left(Q_{i\tau}\right) + \beta_2 Not\ Scrubbed_i + \beta_3 X_{i\tau} + \beta_4 P_i + \varepsilon_{i\tau} \tag{11}$$

for input I at plant i in year τ. We estimate separate versions of equation (11) for $\tau \in \{1998, 1999, ...2004\}$. We expect β_2 to follow the same pattern as in equation (9): negative for $I \in \{capital\}$ in 1998-2002 if the heightened enforcement of NSR caused utilities to cut back on investing in plants that were at risk of triggering expensive upgrades in pollution control equipment (*Not Scrubbed* plants), but positive for $I \in \{fuel\}$ for $Tau \in \{1998 - 2002\}$ if low capital investment caused fuel efficiency to degrade. Any post-enforcement catch-up would be reflected in positive values of β_2 in 2003 and 2004. As in equation (9), Q measures electrical output and $X_{i\tau}$ is a vector of contemporaneous control variables. P_i is a vector that includes levels of input use and, in some specifications, output (Q) from the years before the NSR enforcement period began. This approach is very similar to one used by Greenstone (2004). Essentially, the variable P_i controls flexibly for the pre-existing trends in input use, and β_2 is identified by differences between *Scrubbed* and *Not Scrubbed* plants in the NSR enforcement period conditional on these trends.

Potential Endogeneity of Output Levels

One further issue we confront in estimating factor demand equations as in (9) is the potential for simultaneity in the relationship between Q and I. This would arise if units adjusted their output to accommodate shocks to their efficiency, for example lowering output when a malfunctioning piece of equipment causes the unit to be less fuel efficient. This is analogous to the simultaneity of inputs problem identified in much of the production function literature.[19] We choose to address the simultaneity problem by instrumenting for Q with electricity demand at the state level. This instrument is highly correlated with unit-level output but uncorrelated with information that an individual plant manager has about a particular unit's shock to productivity. We do not instrument for Q when we estimate equation (11). Under the assumption that capital investment in previous periods measures the plant-specific productivity shock (this is the assumption used by Olley and Pakes (1996)), $\varepsilon_{i\tau}$ will not be correlated with Q.

4 Empirical Results

This section presents the results from estimating equations (9) and (11). Because the data sets and control variables differ across nonfuel and fuel inputs, we consider the two sets of results separately.

[19]See Griliches and Mairesse (1998) for an overview of the issue and survey of various approaches to dealing with it. Recent papers by Olley and Pakes (1996) and Levinsohn and Petrin (2003) propose structural approaches to addressing simultaneity. Ackerberg, Caves and Frazer (2005) compares and critiques the approaches proposed by them. Fabrizio, Rose and Wolfram (2007) address the simultaneity problem by instrumenting.

4.1 Capital and Operations and Maintenance Expenditures

Table 2 reports results from estimating equation (9) using the log of total capital expenditures as the dependent variable (ln($TotalCapital$)). In light of the analysis in the previous section, all specifications include plant-fixed effects. We also estimate every specification with year-fixed effects that vary for big and small plants and old and young plants. In column (1), which includes all of the plants in the dataset and is estimated using OLS, the coefficient on $Not\ Scrubbed *$ $NSR\ Enforcement\ Period$ is negative, suggesting that plants that were concerned about NSR reduced capital expenditures relative to control plants during the period of heightened NSR enforcement. The coefficient is statistically indistinguishable from zero.

The specification reported in column (2) is nearly identical to column (1), except that we use $ln(StateSales)$ as the instrument for $ln(Output)$. The coefficient on $ln(StateSales)$ in the first-stage regression is positive, since higher demand in a year (e.g. due to hotter weather) causes plants to run more intensively over the year. The F-statistic soundly rejects the hypothesis that the coefficient is zero (F=14.59), suggesting that our instrument is not weak a la Staiger and Stock (1997).[20] Note that the coefficient on ln($Output$) increases substantially between the OLS and IV specifications. This is consistent with a negative correlation between input shocks and output. Purely mechanically, plants must be shut down and the boilers cold for most capital projects to proceed. Also, since our data are measured yearly, this could reflect the fact that plant outages due to capital equipment failure necessitate large capital expenditures in the following months.

When we instrument for output, the coefficient on $Not\ Scrubbed * NSR\ Enforcement\ Period$ increases in absolute value. Output at $Not\ Scrubbed$ plants increased during the treatment period (this could be independent of the enforcement and driven by the demand shocks captured in our instrument), so with a larger coefficient on output suggesting a tighter relationship between output and capital expenditures, the effects of the reduced capital expenditures during the NSR

[20]F-statistics from the other IV specifications are reported in the final row of the table. They are also both above 11.5.

period are accentuated. Also, the standard error goes down slightly, so the negative coefficient is now statistically significant at the five percent level.

Figure 3c above suggested that capital expenditures at *Scrubbed* and *Not Scrubbed* plants tracked each other most closely once we excluded plants that could have been installing scrubbers during the pre-period (1988-1997). Columns (3) and (4) report OLS and IV results on this subset of the data. Comparable to columns (1) and (2), the coefficients on $Not\ Scrubbed * NSR\ Enforcement\ Period$ are both negative, and larger and statistically significant in the IV specification.

Finally, columns (5) and (6) report specifications where the NSR enforcement period ends in 2000. It is possible that utilities were confident that a Bush Administration would interpret NSR less strictly and did not need the detailed policy statement in the Equipment Replacement Provision to signal that the cost of investing in their *Not Scrubbed* plants had again fallen. Consistent with this hypothesis, the coefficients on $Not\ Scrubbed * NSR\ Enforcement\ Period$ in columns (5) and (6) are larger in absolute value than the comparable coefficients in columns (3) and (4). The magnitude of the coefficient in column (6) suggests that plants concerned about triggering NSR reduced capital spending by over seven percent relative to the control plants during the period when NSR enforcement was most likely.

In all columns of Table 2, we include two additional control variables. $Not\ Scrubbed * Post\ NSR\ Enforcement\ Period$ tests whether utilities changed their investment patterns at *Not Scrubbed* plants after the heightened enforcement of NSR. The positive coefficient is consistent with a policy of accelerating investments to "make up" for the period of low investment, though the standard errors on the coefficient are large and it is never statistically distinguishable from zero. Finally, the coefficient on *Scrubber Added After* 1997 suggests that plants increase their capital expenditures by around 20 percent when they add scrubbers, though it is also estimated with considerable noise and statistically indistinguishable from zero.

Table 3 reports estimates of equation (11) using ln(*Total Capital*) levels in 1998 to 2004. The table is based on the same sample as reported in columns (3)-(6) of Table 2 (*i.e.,* excluding plants that may have had installed scrubbers after 1988). The signs of the coefficient estimates are consistent with those reported in Table 2, suggesting slower growth in capital at *Not Scrubbed* plants in the 1998-2002 period. The implied magnitudes of the effects, eight percent less capital investment at *Not Scrubbed* plants in 2000 and more than three percent in 1998, imply a slightly larger effect than reflected in Table 2.[21] *Not Scrubbed* plants invested significantly more capital in 2003, perhaps suggesting they were making up for several years of low investment.

As the number of observations by year reported in Table 3 indicates, we have a fair amount of attrition in our data set. This is primarily due to divestitures, wherein plants are transferred to nonutility owners who are no longer required to report plant financial statistics to the regulatory agencies. Between 1998 and 2004, there were only 25 coal units retired (out of over 800 in our data set) and 8 coal plants retired (out of over 300 in our data set). As a result, it seems unlikely that the attrition is related to efficiency.[22] We estimated versions of both the specifications reported in the fifth column of Table 2 and the specifications reported in Table 3 using a balanced panel and obtained similar results to those reported.

Tables 4 and 5 report similar specifications for the operations and maintenance expenditures. Generally, the coefficients on $Not\ Scrubbed * NSR\ Enforcement\ Period$ are small and statistically indistinguishable from zero across all specifications, save during a handful of years in the specifications based on equation (11) and reported in Table 5.

The results discussed in this section suggest that the increased enforcement of NSR during the 1998-2002 period may have reduced capital spending at plants at risk of triggering a costly review. NSR enforcement does not seem to have systematically reduced spending on O&M.

[21]In light of the differences in age and capacity identified in Section 3, we re-estimated the specifications reported in Table 3 using five-part linear splines in both *Age* and *Size* instead of the third-order polynomial. The results were very similar to those reported.

[22]Divestitures were essentially mandated by some state regulatory agencies as part of the electricity industry restructuring. See Bushnell and Wolfram (2005).

4.2 Fuel Efficiency and Emissions

The data we use to estimate equation (9) for fuel inputs are available with much finer disaggregation than the capital and O&M expenditures both over time and across units, but are unfortunately only available beginning in 1996. As described more fully in the appendix, the fuel input data are collected by the EPA every hour from each unit. Since we have nearly 900 units operating over 9 years, we begin with an hourly data set with over 55 million observations. The NSR effects that we are looking for require nowhere near this level of detail, but the control variables that we use, output and temperature, vary hour to hour in important ways. To balance these factors, we aggregated observations for each unit up to the weekly level.[23] Since the temperature data are only available after July 1996, we don't use the first half of 1996 in our specifications, although unreported specifications that omitted temperature and included observations from the first half of 1996 were very similar to the reported results.

Table 6 reports specifications for which the dependent variable is $ln(HeatRate)$. All specifications include unit-fixed effects and year-fixed effects that vary depending on whether a unit is $Large$ or $Small$ and depending on whether it is $Young$ or Old. The specification in column (1) is based on all units in the data set and uses 1998-2002 as the treatment period, while column (2) is estimated using all non-scrubbed units and scrubbed units if their scrubbers were intsalled before 1988. Column (3), which is based on the same data sample as column (2), uses 1998-2000 as the treatment period, and column (4) uses instrumental variables to estimate a similar specification to column (3).[24] Note that in the case of fuel efficiency, instrumenting has the classic effect and dampens its relationship with output. The variable of interest, $Not\ Scrubbed * NSR\ Enforcement\ Period$, is small and statistically indistinguishable from zero in all specifications. The coefficient is so precisely estimated that we can reject the hypothesis that $Not\ Scrubbed$ units' heat rates increased (*i.e.,* fuel efficiency decreased) by one percent in

[23]In related work, we used the hourly data to estimate a nonparametric relationship between output and fuel efficiency (Bushnell and Wolfram, 2005). The estimated relationship is quite close to the log-log specification we use here.

[24]Hourly sales data were not available for 6 states in 2004, so there are slightly fewer observations in column (4) than in column (3). OLS results using the column (4) data set were very similar to those reported in column (3).

every specification.

Table 7 reports results that consider whether emissions rates changed with heightened NSR enforcement. The first two columns of Table 7 are estimated using $ln(NOxRate)$ as the dependent variable, and the last two columns use $ln(SO2Rate)$ as the dependent variable. Sulfur dioxide (SO2) and nitrogen oxide (NOx) are the most expensive pollutants for coal-fired power plants to mitigate.[25] All specifications include unit-fixed effects and year- fixed effects that vary depending on whether a unit is *Large* or *Small* and depending on whether it is *Young* or *Old*. Also, Table 7 only reports results using 1998-2000 as the treatment period, but results from other specifications similarly showed no discernible effect. The specifications in columns (1) and (3) of Table 7 are estimated using OLS, while the specifications in columns (2) and (4) are estimated using instrumental variables.[26] The specifications in all of the columns of Table 7 suggest that increased NSR enforcement had no appreciable effect on SO2 emissions.

As noted above, a feared perverse outcome is that rigorous enforcement of NSR inhibited firms from investing in capital leading to higher emissions from existing plants than there would be if they were not policed. Our results are inconsistent with this outcome, at least over the short time period when NSR was strictly enforced. Note that our specifications test whether emissions at grandfathered plants are higher under rigorous enforcement of NSR than they would have been under a lax enforcement regime. It is theoretically possible that an increase in emissions from existing plants subject to tight NSR enforcement could more than offset the reduction in emissions from the new plants driven by their compliance with the New Source Performance Standards, suggesting that emissions are overall higher with the regulation than they would be absent *any* regulation. As we find no discernible impact on emissions at the existing plants, we do not consider this counterfactual.

[25] Carbon dioxide was not mitigated during our sample period, and CO2 emissions are proportional to fuel efficiency.

[26] The results in Table 7 include three dummy variables to control for changes in regional regulations that impacted NOx emissions rates, including the Ozone Transport Commission NOx Budget Program and the NOx Budget Trading Program. While highly significant, the inclusion of the dummy variables does not affect the coefficients on $Not\ Scrubbed * NSR\ Enforcement\ Period$, suggesting that there are roughly equal fractions of scrubbed and unscrubbed plants across the regions affected and not affected by these regulations.

5 Conclusion

This paper considers the effects of NSR on coal-fired power plant operations. A vintage-differentiated regulation such as NSR can distort behavior in several ways. Perhaps most obviously, it may cause owners of existing plants to keep their capital in service for longer since building a new plant becomes more expensive. Early work on NSR found some evidence of this effect (Maloney and Brady, 1988 and Nelson, Tietenberg and Donihue, 1993). At the same time, monitoring of existing plants to ensure that significant, life-extending upgrades include state-of-the-art pollution-control equipment may cause firms to invest less in their plants. We find some evidence that this effect was relevant at coal-fired power plants, but no evidence that this led to reduced fuel efficiency or increased emissions. There are several possible interpretations of this result. It could imply that industry claims about the efficiency impacts of heightened enforcement were overblown, or even that the new bias against capital introduced by NSR offset some pre-existing bias in favor of capital. However, given the complexities and durable nature of power plants, it is also possible that continued under-investment in the capital stock would have eventually led to a decline in fuel efficiency. We find some evidence that the reductions in capital investment during this period were offset when the rules were subsequently relaxed.

Over the past decade, the New Source Review program has come under fire from both environmentalists and the utility companies. The environmentalists, apparently frustrated that plants exempt from regulations in the 1970s are still in service today, contend that utilities are routinely flouting the regulations and performing major overhauls to their plants without applying for permits. While this might be true, it is possible that the utilities would have overhauled their plants even in the absence of the regulations, so the question boils down to how stringently the EPA should enforce the NSR requirement and whether the old units should be required to install pollution control equipment.

Since the early 1990's the EPA has moved away from command-and-control regulation and has implemented or proposed implementing market-based cap-and-trade programs. This calls into question the role of performance standards such as NSR. For instance, the Acid Rain Program caps the number of SO2 permits available nationwide, so if the EPA took steps to require the older plants to install scrubbers, this would just mean that those plants could sell their permits and other plants could increase their emissions of SO2. In light of this shift, EPA regulators with whom we have spoken suggest that NSR is now most effective as a tool for preventing local "hot spots" of pollution. With performance standards for greenhouse gas emissions potentially on the horizon, there will again be questions about the extent to which new source performance standards should be imposed on existing plants that retrofit. This paper provides evidence that applying these standards can induce distortions in capital investment.

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Data Appendix

Our primary data sources are BaseCase and PowerDat, databases produced by Platts (see www.Platts.com). Platt's compiles data on power plant operations and characteristics from numerous public sources, performs limited data cleaning and data analysis and creates cross references so that the data sets can be linked by numerous characteristics (e.g. power plant unit, state, grid control area, etc.). We relied on information from Platt's for the following four broad categories.

Annual Capital and Operations and Maintenance Expenditures

PowerDat collects information on annual plant-level financial and operating statistics from the annual FERC Form 1 (filed by investor-owned utilities), EIA Form 412 (filed by municipal and other government utilities), and RUS Form 7 & 12 (filed by electric cooperatives) filings.

Hourly Fuel Inputs

BaseCase contains hourly power-plant unit-level information derived from the Continuous Emissions Monitoring System (CEMS) database collected by the Environmental Protection Agency. The EPA assembles this detailed, high quality data to support various emissions trading programs. The CEMS data are collected for all fossil-fueled power plant units that operate more than a certain number of hours a year. The dataset contains hourly reports on heat input, gross electricity output and pollutant output. We calculate the Heat Rate by dividing heat input (measured in mmBtus) by gross electricity output (measured in MWh). We limit the sample to hours when units were operating for the entire hour, and by construction of the variable Heat Rate, to hours in which the unit was producing positive gross electricity output. We also limit the unit-level data set to units that are larger than 70 MWs so that our data set comprises a set of relatively homogenous coal-fired units that are most likely to be the focus of environmental concerns.

Hourly State-level Demand

Data on state level demand at the hourly level are taken from the PowerDat database, also compiled by Platts. Platts compiles this information from survey data collected by the EIA and reported in its form 714.

Unit Characteristics

Unit characteristics, such as age, size and type of pollution control equipment, are taken from the “Base Generating Units” and “Estimated Fossil-Fired Operations” data sets within BaseCase. We supplemented information on the installation dates of scrubbers with information from the EIA Form 767.

We merged data from BaseCase to several additional sources.

Annual State-level Demand

Annual data on state-level demand are from the Energy Information Administration (EIA), ”Electric Sales, Revenues and Prices,” formerly called the, ”Electric Sales and Revenues.”

Hourly Ambient Temperature

We obtained hourly temperature data by weather station from the Unedited Local Climatological Data Hourly Observations data set put out by the National Oceanographic and Atmospheric Administration. Further documentation is available at:

http://www.ncdc.noaa.gov/oa/documentlibrary/ulcd/lcdudocumentation.txt

We calculated the Euclidean distance between each weather station-power plant combination, using the latitude and longitude for each power plant and for each weather station. Then, for each month, we found the weather station closest to each power plant that had more than 300 valid temperature observations. For hours when the temperature was missing, we interpolated an average temperature from adjoining hours.

Divestiture Information

We take information on divestitures from the, ”Electric Utility Plants That have Been Sold and Reclassified as Nonutility Plants” table in the Energy Information Administration, Electric Power Monthly, March (various years). We use information on the name of the plant divested, the buying and selling entities and the divestiture date. We cross-checked the divestiture dates against EIA Form 906, which requires each plant owner to report monthly production. We checked whether the change in the identity of the plant-owner reporting to form 906 coincided with the divestiture dates reported in Electric Power Monthly. The majority of any discrepencies were less than 2 months.

Lawsuit Information

The list of plants named in lawsuits by the EPA/DOJ was compiled from multiple sources.

The January 2002 report, "New Source Review: An Analysis of the Consistency of Enforcement Actions with the Clean Air Act and Implementing Regulations," published by the Office of Legal Policy of the Department of Justice, lists plants named in the initial group of enforcement actions that were filed in November 1999. This report also includes the plants specified in the Administrative Compliance Order that was filed against the Tennessee Valley Authority (TVA), also in November 1999. The lawsuit against Duke Power, filed in December 2000, is also described in this report. We identified lawsuits filed after the publication of the DOJ report through the press and/or individual DOJ/EPA press releases.

Table 1a: Summary of Plant Level Data, 1996
Scrubbed* versus *Not Scrubbed

Variable	***Scrubbed***		***Not Scrubbed***		T-statistic for Difference in Means
	Mean	Std. Dev.	Mean	Std. Dev.	
Dependent Variables					
Total O&M *($ Mill)*	29.6	26.9	18.5	16.4	3.44
Total Capital *($ Mill)*	727	556	355	363	5.52
Independent Variables					
Age *(years)*	24	13	37	14	-7.48
Size *(MW)*	1048	721	904	743	1.52
Capacity Factor	.64	.15	.53	.18	5.54
Divest	.14	.35	.21	.41	-1.33
# of Plants	77		252		

Table 1b: Summary of Unit Level Data (Units Larger Than 70 MW), 1996
Scrubbed* versus *Not Scrubbed

Variable	***Scrubbed***		***Not Scrubbed***		T-statistic for Difference in Means
	Mean	Std. Dev.	Mean	Std. Dev.	
Dependent Variables					
Heat Rate *(mmbtu/kwh)*	11.4	3.4	11.4	4.3	-.05
NOx Rate (lbs/mmbtu)	5.5	3.2	6.7	3.3	-4.21
SO2 Rate (lbs/mmbtu)	6.3	5.3	18.1	11.9	-19.5
Independent Variables					
Age *(years)*	20	10	32	10	-14.23
Size *(MW)*	441	255	310	241	6.37
Capacity Factor	.79	.12	.68	.17	9.34
Divest	.12	.33	.19	.39	-2.32
Temperature	58	8.9	59	6.5	-.11
# of units	193		658*		

*6 units in the sample added scrubbers after 1996 and are classified as *Not Scrubbed* for our analysis. Data on *NOx Rate*/*SO2 Rate* are not available for 6/2 *Scrubbed* and 19/13 *Not Scrubbed* units.

Figure 1: Plant Age Distribution – *Not Scrubbed* versus *Scrubbed*

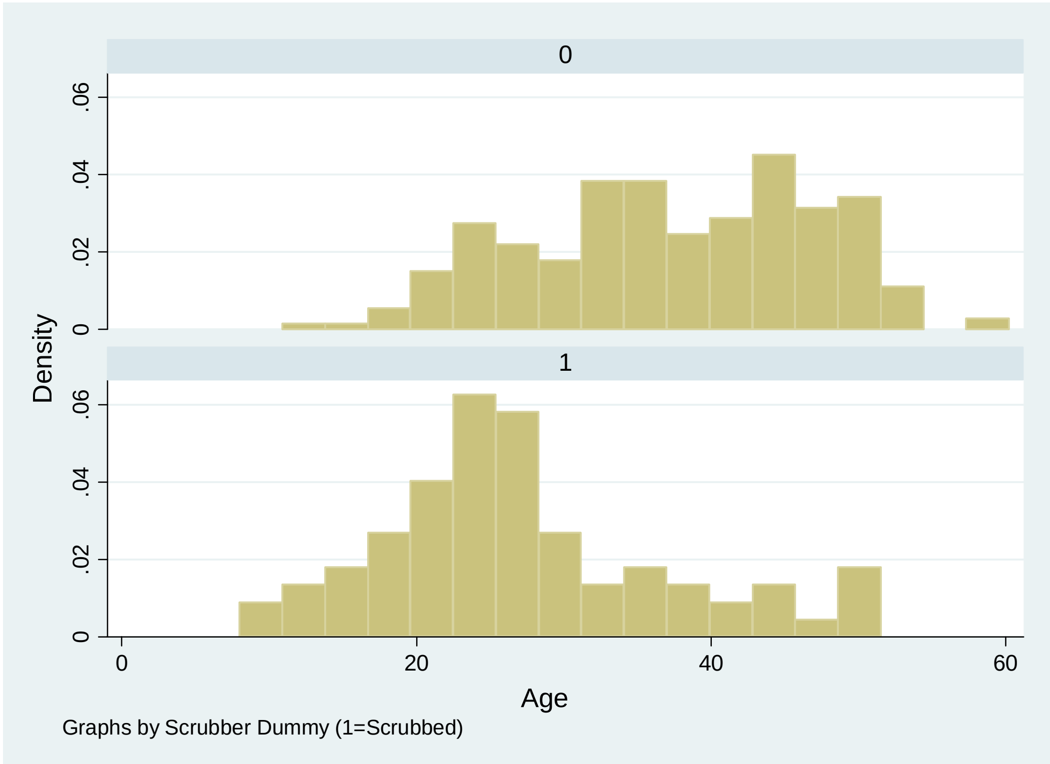

Figure 2: Plant Size Distribution – *Not Scrubbed* versus *Scrubbed*

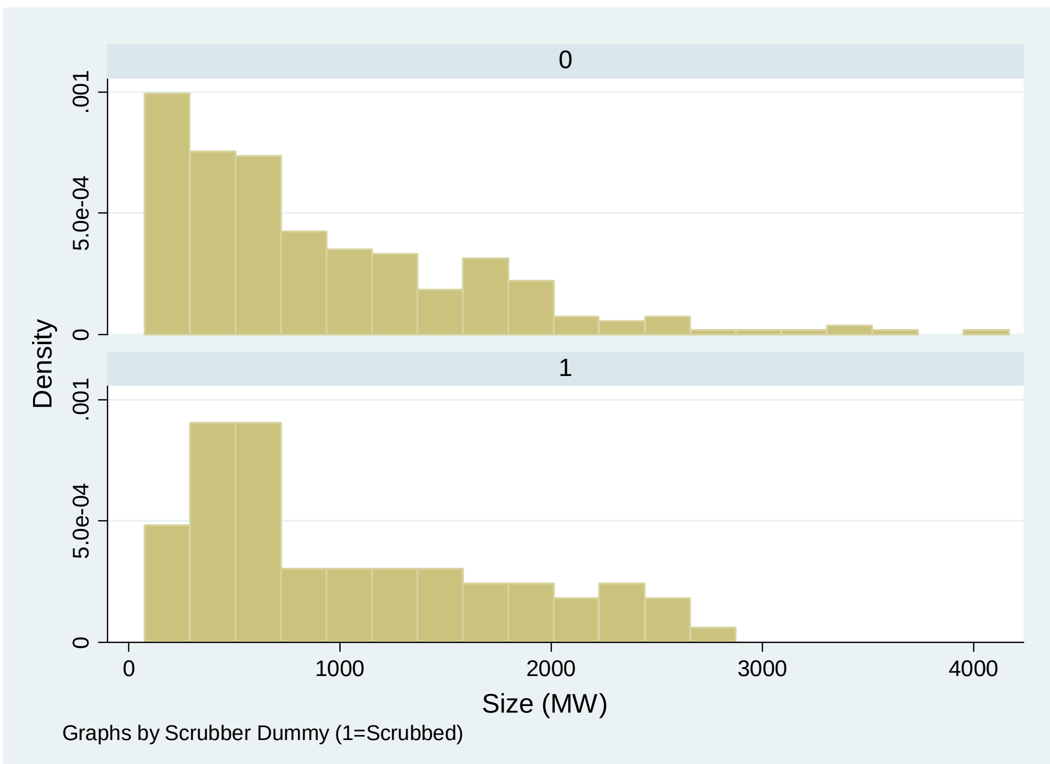

Figure 3a: Plant Capital – Trends by Plant Category

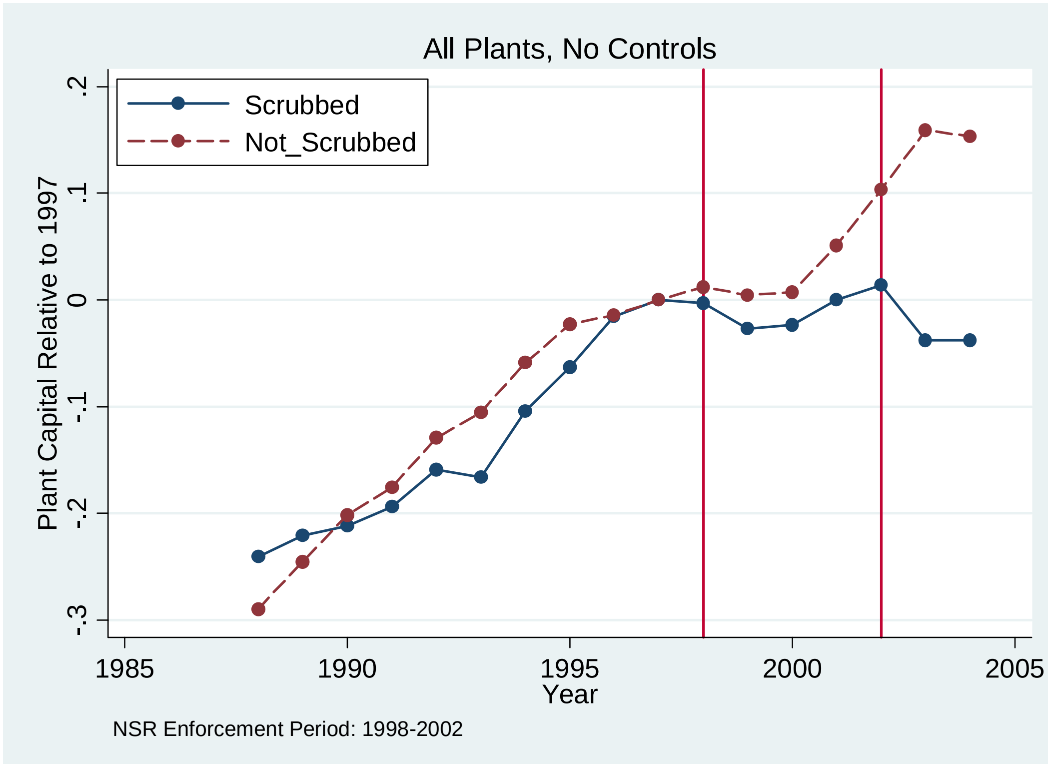

Figure 3b: Plant Capital – Trends by Plant Category

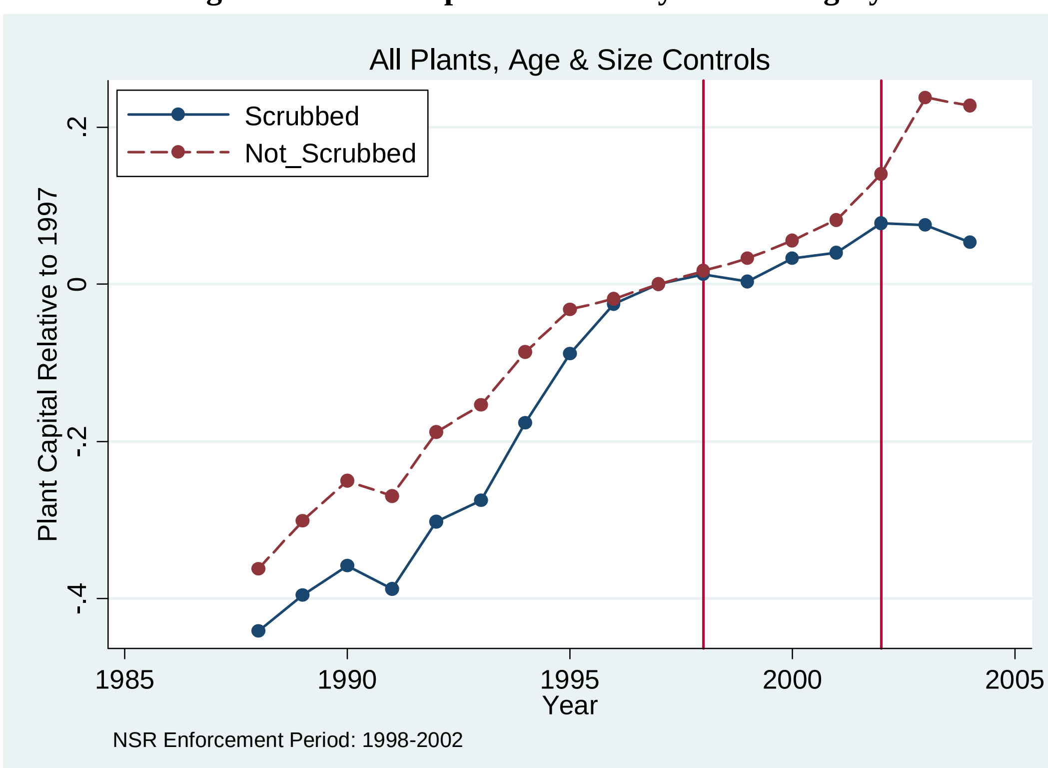

Figure 3c: Plant Capital – Trends by Plant Category

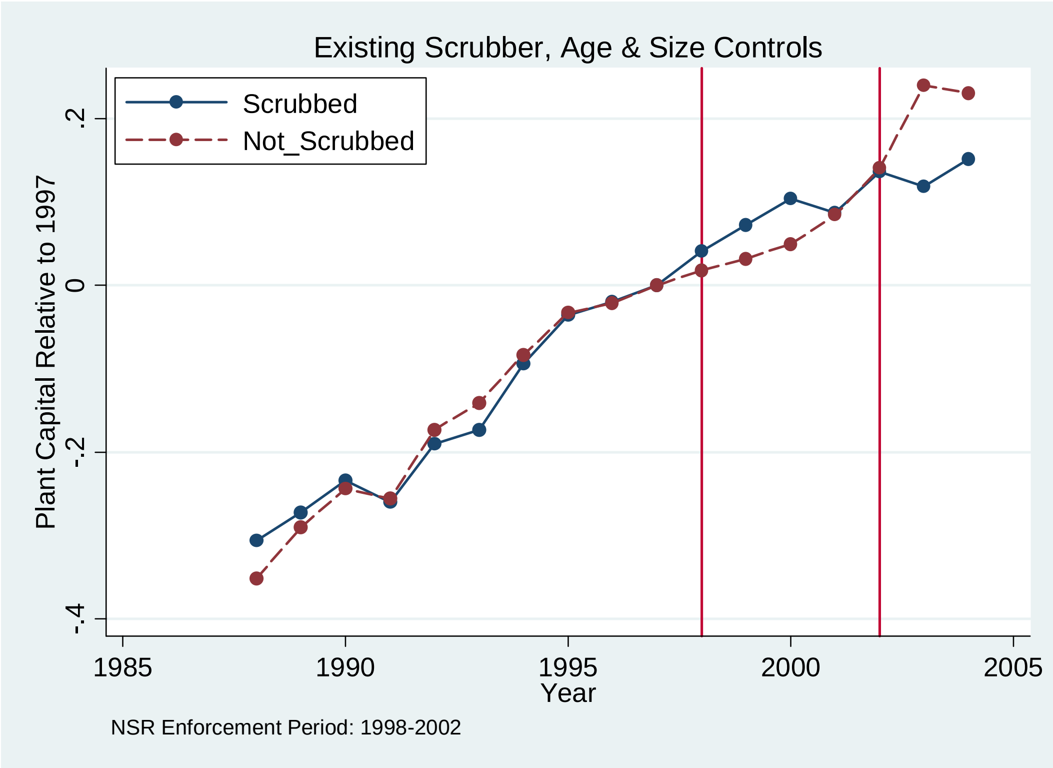

Figure 4a: Plant Operations and Maintenance Expenditures – Trends by Plant Category

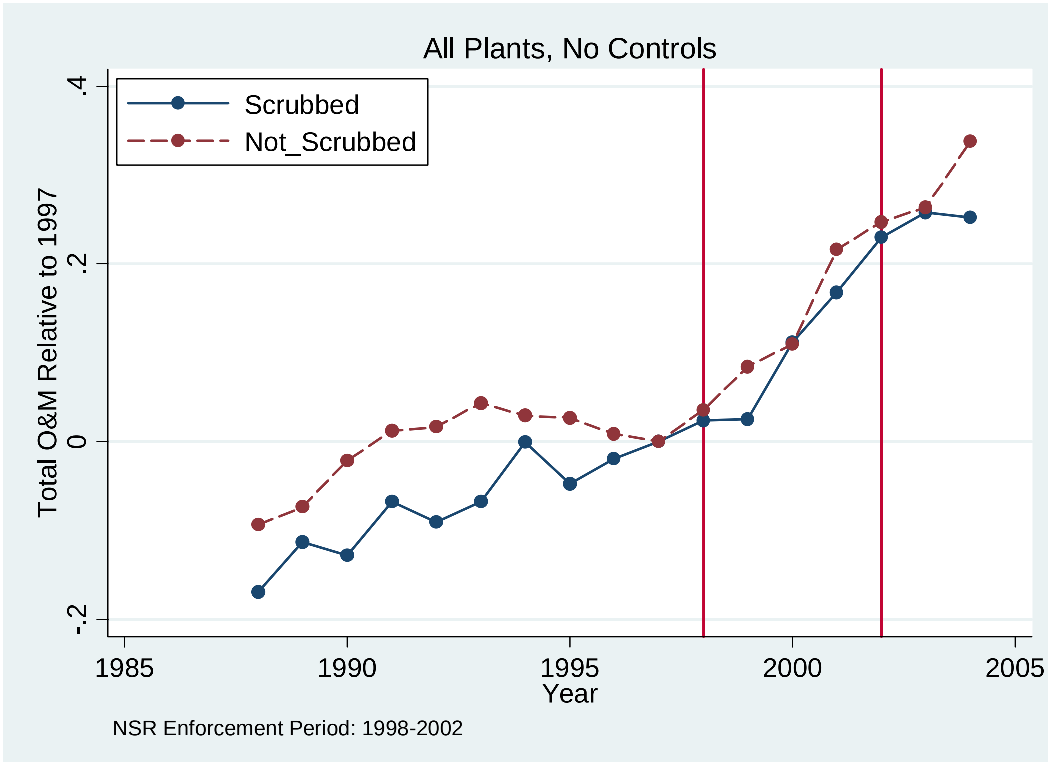

Figure 4b: Plant Operations and Maintenance Expenditures – Trends by Plant Category

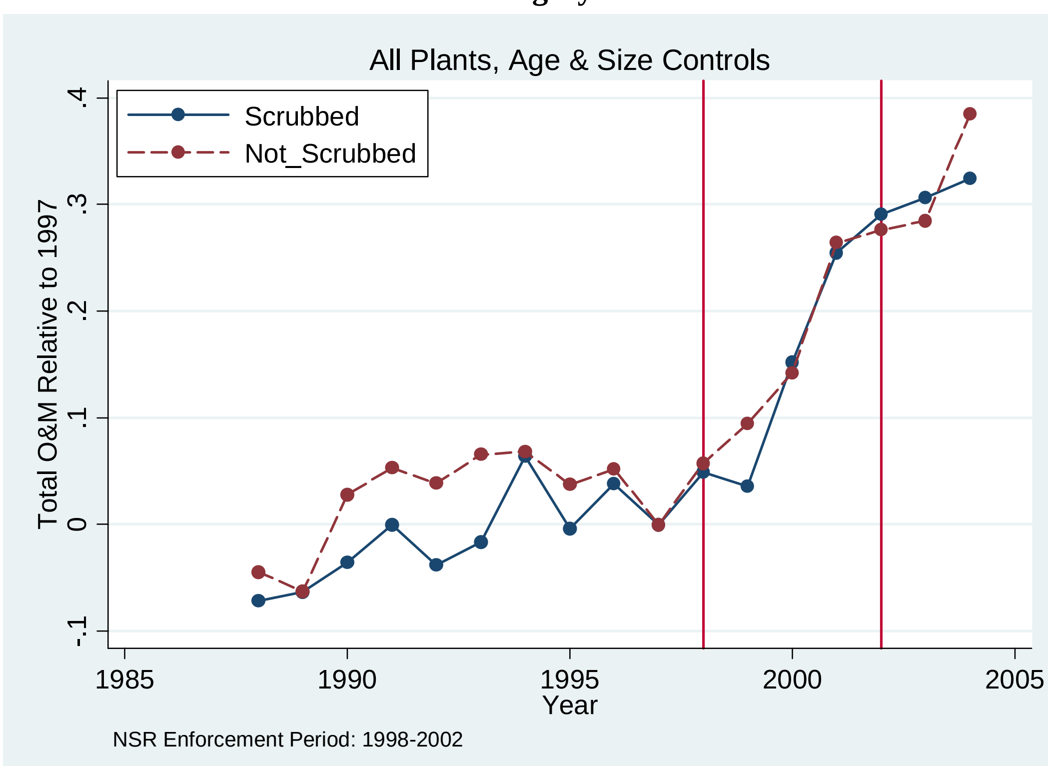

Figure 4c: Plant Operations and Maintenance Expenditures – Trends by Plant Category

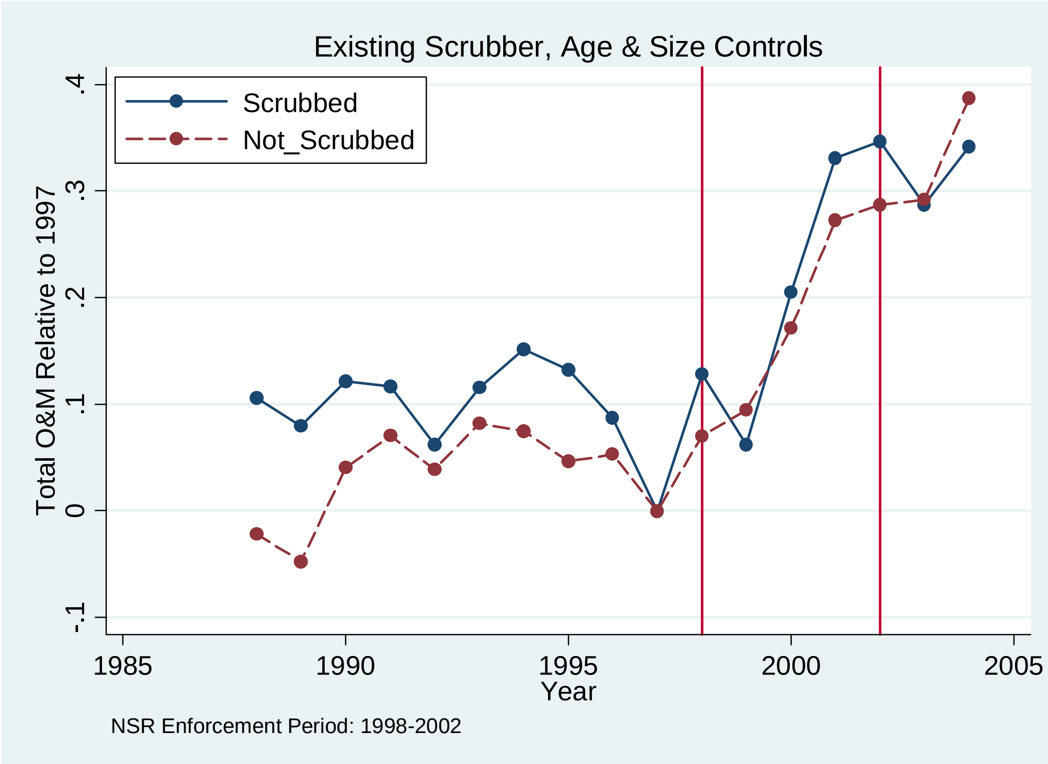

Table 2: Plant Capital – Fixed Effect Method
Dependent Variable: *ln(Total Capital)*

	(1)	(2)	(3)	(4)	(5)	(6)
Sample:	All Observations	All Observations	No or Pre-Existing Scrubbers	No or Pre-Existing Scrubbers	No or Pre-Existing Scrubbers	No or Pre-Existing Scrubbers
Not Scrubbed* NSR Enforcement Period	-0.047	-0.070**	-0.025	-0.057**	-0.038*	-0.076***
	(0.037)	(0.034)	(0.020)	(0.026)	(0.020)	(0.028)
Not Scrubbed*Post NSR Enforcement Period	0.089	0.059	0.103	0.087	0.047	0.028
	(0.115)	(0.108)	(0.084)	(0.084)	(0.044)	(0.045)
Scrubber Added After 1997	0.194	0.220	0.193	0.220	0.193	0.220
	(0.131)	(0.145)	(0.128)	(0.145)	(0.128)	(0.145)
ln(Output)	0.154***	0.600***	0.139**	0.647***	0.139**	0.647***
	(0.054)	(0.212)	(0.058)	(0.211)	(0.058)	(0.211)
Estimation Method	OLS	IV	OLS	IV	OLS	IV
NSR Enforcement Period	1998-2002	1998-2002	1998-2002	1998-2002	1998-2000	1998-2000
Observations	5063	5063	4519	4519	4519	4519
R^2	0.97		0.97		0.97	
First-stage F-statistic		14.59		11.84		11.80

Standard errors adjusted for clustering at the plant level.
* significant at 10%; ** significant at 5%; *** significant at 1%
Data are annual, plant-level observations from 1988-2004. All specifications include plant effects and year effects that are allowed to vary depending on whether plants are *Large* (>= 800 MW) or *Small* and *Young* (< 30 years old) or *Old*.
Instrument for ***ln(Output)***: ***ln(State Sales).***
The "No or Pre-Existing Scrubber" sample includes all *Not Scrubbed* plants as well as *Scrubbed* plants so long as their scrubbers were installed by 1988.

Table 3: Plant Capital – Lagged Controls Method
Dependent Variable: *ln(Total Capital)*

	1998	1999	2000	2001	2002	2003	2004
Not Scrubbed	-0.034**	-0.067	-0.081*	-0.033	0.002	0.090*	0.075
	(0.015)	(0.052)	(0.048)	(0.051)	(0.028)	(0.053)	(0.070)
Observations	255	230	211	200	190	189	163
R^2	.99	0.95	0.96	0.96	0.99	0.96	0.95

* significant at 10%; ** significant at 5%; *** significant at 1%

Sample includes all *Not Scrubbed* plants as well as *Scrubbed* plants so long as their scrubbers were installed by 1988. Each cell represents a coefficient from a regression where the dependent variable is measured in the year specified in the column header. All specifications include ***ln(Output)***, ***Scrubber Added After 1997***, third order polynomials in ***Age*** and ***Size***, ***ln(Total Capital)$_{1988}$ - ln(Total Capital)$_{1997}$***, ***ln(Output)$_{1988}$ - ln(Output)$_{1997}$***

Table 4: Plant Operations and Maintenance Expenditures – Fixed Effect Method
Dependent Variable: *ln(Total O&M)*

	(1)	(2)	(3)	(4)	(5)	(6)
Sample:	All Observations	All Observations	No or Pre-Existing Scrubbers	No or Pre-Existing Scrubbers	No or Pre-Existing Scrubbers	No or Pre-Existing Scrubbers
Not Scrubbed* NSR Enforcement Period	-0.025	-0.058	0.029	-0.024	0.042	-0.020
	(0.036)	(0.038)	(0.039)	(0.046)	(0.043)	(0.049)
Not Scrubbed*Post NSR Enforcement Period	-0.021	-0.065	0.086	0.060	0.039	0.008
	(0.049)	(0.060)	(0.054)	(0.074)	(0.044)	(0.061)
Scrubber Added After 1997	-0.024	0.012	-0.027	0.018	-0.026	0.019
	(0.076)	(0.084)	(0.078)	(0.092)	(0.078)	(0.092)
Ln(Output)	0.212***	0.861***	0.182**	1.022***	0.182**	1.019***
	(0.080)	(0.269)	(0.086)	(0.282)	(0.086)	(0.281)
Estimation Method	OLS	IV	OLS	IV	OLS	IV
NSR Enforcement Period	1998-2002	1998-2002	1998-2002	1998-2002	1998-2000	1998-2000
Observations	5063	5063	4519	4519	4519	4519
R^2	0.93		0.94		0.94	
First-stage F-statistic		14.59		11.84		11.80

Standard errors adjusted for clustering at the plant level.
* significant at 10%; ** significant at 5%; *** significant at 1%
Data are annual, plant level observations from 1988-2004. All specifications include plant effects and year effects that are allowed to vary depending on whether plants are *Large* (>= 800 MW) or *Small* and *Young* (< 30 years old) or *Old*.
Instrument for ***ln(Output)***: ***ln(State Sales).***
The "No or Pre-Existing Scrubber" sample includes all *Not Scrubbed* plants as well as *Scrubbed* plants so long as their scrubbers were installed by 1988.

Table 5: Plant Operations and Maintenance Expenditures – Lagged Controls Method
Dependent Variable: *ln(Total O&M)*

	1998	1999	2000	2001	2002	2003	2004
Not Scrubbed	-0.055	0.003	-0.051	-0.126**	-0.153**	-0.087	-0.140**
	(0.042)	(0.047)	(0.054)	(0.052)	(0.060)	(0.064)	(0.069)
Observations	255	230	211	200	190	189	163
R^2	0.95	0.94	0.95	0.94	0.93	0.92	0.94

* significant at 10%; ** significant at 5%; *** significant at 1%

Sample includes all *Not Scrubbed* plants as well as *Scrubbed* plants so long as their scrubbers were installed by 1988. Each cell represents a coefficient from a regression where the dependent variable is measured in the year specified in the column header. All specifications include ***ln(Output)***, ***Scrubber Added After 1997***, third order polynomials in ***Age*** and ***Size***, $\ln(\text{Total O\&M})_{1988} - \ln(\text{Total O\&M})_{1997}$, $\ln(\text{Output})_{1988} - \ln(\text{Output})_{1997}$

Table 6: Unit Heat Rates – Fixed Effect Method
Dependent Variable: *ln(Heat Rate)*

	(1)	(2)	(3)	(4)
Sample:	All Observations	No or Pre-Existing Scrubbers	No or Pre-Existing Scrubbers	No or Pre-Existing Scrubbers
Not Scrubbed* NSR Enforcement Period	-0.005	-0.007	-0.010	-0.011
	(0.007)	(0.008)	(0.007)	(0.007)
Not Scrubbed*Post NSR Enforcement Period	-0.003	-0.002	-0.002	<0.001
	(0.010)	(0.012)	(0.011)	(0.010)
Scrubber Added After 1997	-0.007	-0.007	-0.007	-0.002
	(0.019)	(0.019)	(0.019)	(0.018)
ln(Output)	-0.308***	-0.307***	-0.307***	-0.203***
	(0.013)	(0.013)	(0.013)	(0.019)
Temperature	0.006	0.007	0.007	0.009*
	(0.004)	(0.005)	(0.005)	(0.005)
Estimation Method	OLS	OLS	OLS	IV
NSR Enforcement Period	1998-2002	1998-2002	1998-2000	1998-2000
Observations	344,363	313,013	313,013	310,387
R^2	0.48	0.47	0.47	
First-stage F-statistic				200.9

Standard errors adjusted for clustering at the unit level.
* significant at 10%; ** significant at 5%; *** significant at 1%
Data are weekly, unit level observations from July 1996-December 2004. All specifications include unit effects and year effects that are allowed to vary depending on whether units are *Large* (>= 400 MW) or *Small* and *Young* (< 30 years old) or *Old*. Instrument for ***ln(Output)***: ***ln(State Sales).***
The "No or Pre-Existing Scrubber" sample includes all *Not Scrubbed* units as well as *Scrubbed* units so long as their scrubbers were installed by 1988.

Table 7: Emissions Rates – Fixed Effect Method

	(1)	(2)	(3)	(4)
Dependent variable:	***ln(NOx Rate)***		***ln(SO2 Rate)***	
Not Scrubbed* NSR Enforcement Period	0.002	-0.003	-0.003	-0.003
	(0.022)	(0.022)	(0.025)	(0.025)
Not Scrubbed*Post NSR Enforcement Period	-0.043	-0.035	0.029	0.030
	(0.041)	(0.042)	(0.042)	(0.042)
Scrubber Added After 1997	-0.025	-0.001	-1.824***	-1.817***
	(0.068)	(0.064)	(0.230)	(0.229)
ln(Output)	-0.167***	0.336***	-0.116***	-0.041
	(0.012)	(0.085)	(0.013)	(0.088)
Temperature	-0.157***	-0.161***	-0.006	-0.006
	(0.013)	(0.014)	(0.009)	(0.010)
Estimation Method	OLS	IV	OLS	IV
NSR Enforcement Period	1998-2000	1998-2000	1998-2000	1998-2000
Observations	308,952	306,328	311,965	309,339
R^2	0.66		0.84	
First-stage F-statistic		218.3		217.7

Standard errors adjusted for clustering at the unit level.
* significant at 10%; ** significant at 5%; *** significant at 1%
Data are weekly, unit level observations from July 1996-December 2004. All specifications also include a dummy variable indicating the beginning of the Ozone Transport Commission NOx Budget Program, which covered 9 states and DC and began in 1999, and two dummy variables indicating the beginning of the NOx Budget Trading Program in 2004—one variable for the units in the states that were already part of the Ozone Transport Commission and a second for the units in the 12 states newly covered by the NOx Budget Trading Program.
All specifications include unit effects and year effects that are allowed to vary depending on whether units are *Large* (>= 400 MW) or *Small* and *Young* (< 30 years old) or *Old*. Instrument for ***ln(Output)***: ***ln(State Sales).***
All specifications are estimated using the "No or Pre-Existing Scrubber" sample, which includes all *Not Scrubbed* units as well as *Scrubbed* units so long as their scrubbers were installed by 1988.