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The Economic Effects of Vintage Differentiated Regulations: The Case of New Source Review

James B. Bushnell and Catherine Wolfram*

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Abstract

This paper analyzes the effects of the New Source Review (NSR) environmental regulations on coal-fired electric power plants. The New Source Review program, which grew out of the Clean Air Act of 1970, required new plants to install costly pollution control equipment but exempted existing plants with a grandfathering clause. Previous theoretical research has shown that vintage differentiated regulations, like NSR, can lead to distortions, and if the distortions are large, the short-run effect of a regulation like NSR may be to increase pollution rather than reduce it. Older, dirtier plants may be kept in service longer or run more intensively since replacing them becomes more expensive. In the case of NSR, there is also an effect associated with its enforcement. Since upgrading a plant could potentially qualify it as a new plant, the old plants may have done less maintenance leading to lower efficiency and higher emissions. This paper attempts to estimate the extent to which these mechanisms have impacted coal-fired electric power plants. We find suggestive evidence that NSR increased operating lifetimes of plants in areas where environmental regulations were most stringent. We also find evidence that the risk of NSR enforcement reduced capital expenditures at plants. However, we find no discernable effect on the operating costs or fuel efficiency of these plants.

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, baby cribs subject to safety standards or electric power plants subject to environmental regulations. There are several rationales for using a vintage differentiated regulation (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, exempting the owners of the existing units from the new regulation limits their incentives to oppose the regulation. Policy makers 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. First, if the regulations make it more expensive to build the new unit, old units will live 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 old units are at risk of triggering the new standards if they engage in significant retrofitting. This can lead to distortions if units subject to this oversight take costly steps to avoid having to meet the new standards. 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 home owners may hire unlicensed contractors or design their remodeling plans to preserve enough of the existing structure to avoid triggering the new standards, actions they might not have taken in the absence of the VDR.

This paper considers evidence that these types of distortions impacted electric power plants subject to environmental regulation. Specifically, we consider the effects of the New Source Review program which grew out of the Clean Air Act of 1970. Under this program, new fossil fuel fired power plants have been required to install various forms of pollution control equipment. The type of control equipment they were required to install has varied over time, by plant fuel type and across counties within the U.S. In an attempt to counteract the incentive to defer retirements of grandfathered plants, the regulations also 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 in late 1999. The lawsuits alleged that a number of utilities had performed modifications to their 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, 2000).

We begin by considering evidence that NSR has increased the lives of electric generating units. We compare retirements across units located in areas where the pollution control requirements for new plants are more and less stringent. If the grandfathering of regulations were extending the lives of plants, one would expect the effect to be more pronounced in areas requiring more stringent controls on new plants. In fact, we find that plants in more tightly regulated areas are *more* likely to retire than those in the less regulated areas. By itself, this result indicates that other considerations overwhelm any impact of the grandfathering on the lifetimes of plants. However, such an interpretation implicitly assumes that any plant that retires would have to be replaced by a plant in the same local area. To address this consideration, we examine the regulatory environment of the broader region in which the plants operate. We find that plants in tightly regulated areas are much less likely to retire if they are surrounded by other tightly regulated areas. This can be interpreted as an effect of grandfathering, as owners of such plants would find it more costly to economically replace their production. Owners of plants in regions with many nearby, more lightly regulated counties, would find less advantage in the fact that the tight regulations do not apply to their existing, grandfathered facility.

We next consider whether coal units at risk of triggering NSR changed their operations in the late 1990s when the threat of NSR enforcement became acute. We argue that plants that had already installed the most expensive type of pollution control equipment provide a useful control group. Comparing capital and operations and maintenance expenditures across the two types of plants, we see some evidence that at-risk plants 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 at the at-risk plants 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 the Clean Air Act, and NSR has had. The following section summarizes the evidence on retirements. Sections 4 and 5 present our empirical approach to testing for an effect of NSR on unit operations and the results from applying those tests.

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 a universal adoption of the new standards. During the 1970s, however, less

[1] See Ellerman and Joskow (2000).

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 new source review (NSR) program was created as part of the 1977 amendments to the Clean Air Act (CAA). 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 SOx. In addition to limiting the maximum emission of SOx, the 1977 amendments required specific levels of post-combustion removal of the pollutant. The requirement for removal effectively mandated the use of flue gas de-sulfurization (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 or major modification to an existing source of air pollution. In this way, the NSR program was intended to counteract the incentives provided by the 1970 and 1977 amendments to extend the lifetime of existing facilities and avoid replacement that would require more costly mitigation technology. Attempting to police attempts to artificially extend the lifetime of plants, however, involved interpretation of activities falling in a grey area between "routine maintenance" and "major modifications." Almost from the inception of the NSR program there has been controversy over what activities constituted a major modification to an existing facility.

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 and lifetime extending, and therefore subject to NSR requirements. 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 could be allowed under NSR 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 firm to NSR and routine maintenance activities that would not. Beginning in 1996, the EPA began to revisit the implications of the WEPCo case as to what activities would trigger NSR. Starting with an internal review, the EPA revised its view of many maintenance activities. Proposed rulemakings in 1996 and 1998 described a goal of lessening the burden of NSR compliance and making the program more flexible. However, they also signaled that the EPA was reconsidering the WEPCo rule.

In 1998, the EPA's enforcement division issued an information request to several utility companies regarding past work at their power plants. The information requests signaled that EPA was moving toward a more aggressive position with regards to applying NSR standards. 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 15-20 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 new source compliant pollution control equipment or the immediate shut down 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." Such activities might include "[r]epair or replacements of steam tubes, and [r]eplacement of turbine blades." Unlike the modifications taken in the WEPCo case, these actions would not involve costs equivalent to a significant fraction of the power plant. 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 in view 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 and productivity of those existing plants.

Thus the classic incentive problems with vintage differentiated regulations - that they created biases against the replacement of older, dirtier facilities with newer, cleaner ones – created a dynamic in which a second incentive problem threatened to further distort decision making over the upkeep and operation of existing facilities.

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.[3]" 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." Utility groups also argued that these policies "strongly discouraged projects to improve efficiency.[4]" The National Coal Council stated that the NSR policies "strongly discourages utilities from undertaking [efficiency 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." The Council claimed

[2] A background paper by EPA, EPA (2002), describes the history and controversy surrounding NSR enforcement.
[3] Utility Air Regulatory Group, 2001
[4] UARG, 2001

that NSR was "the greatest current barrier to increased efficiency at existing units.[5] "

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 have improved both the fuel efficiency and reliability of the generation units. An EPA regional administrator ruled that such a project would constitute a major modification and would trigger NSR. In order to comply, 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 the administration of G.W. Bush. 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.[6]"

During this period, there was hope that the NSR regulations would be replaced by a more comprehensive cap and trade system under the proposed "clear skies initiative." After that initiative faltered in congress, the EPA turned to administratively revising its policies towards the definition of routine maintenance. Several proposals circulated between the end of 2002 and summer 2003. Finally in August 2003, the Equipment Replacement Provision (ERP) was issued by EPA. 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

[5] NCC 2000

[6] EPA, 2002

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

The implementation of the clean air act in general, and its NSR provisions in particular, have provided fertile ground for research into the incentive effects of environmental regulation. As described by Stavins (2006), the CAA represents one of the classic examples of vintage differentiated regulation. Another important aspect of the CAA is that its stringency and the resulting incentive effects varied across regions depending, among other factors, upon the attainment status of individual regions.[7]

Most previous empirical work on NSR has focused on the incentives of vintage differentiation on the retirement of old plants and entry of newer, cleaner ones. Maloney and Brady (1988) find that there was a slowing of capital turnover in electricity during the 1970s in regions with more stringent SOx restrictions. Nelson, Tietenberg, and Donihue (1993) use a three stage least squares model to estimate the interaction between plant age, regulation, and emissions in the electricity industry over the same time period (1969-1983). Like Maloney and Brady, they utilize the variation in local regulation to identify these effects. They find that the differential regulation did increase the age of capital, but the extended age did not significantly impact overall emissions. Becker and Henderson (2000) do not focus specifically on NSR, but do utilize variation in local regulations to find some evidence that grandfathered regulations led to longer plant lives.

There has been relatively little empirical work addressing the second potential incentive effect, that caused by the regulatory policing of plant operations and maintenance. 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. List, Millmet, and McHone (2004)

[7]Gollop and Roberts (1983) construct a measure of varying 'regulatory intensity' to measure the costs of compliance with SOx regulation during the 1970s. Becker and Henderson (2000) as well as Greenstone (2002) study the impact of variation in attainment status on manufacturing activity.

utilize the variation in attainment status to examine plant level modification decisions in New York State from 1980-1990. Under the argument that the costs of complying with NSR requirements are higher in non-attainment areas for most industries, the disincentive to invest in plant, for fear of triggering NSR, should be strongest in non-attainment areas. They find that plants were less likely to undertake modifications if they were located in non-attainment areas, although they did not find much effect on the retirement of existing plants.

It is important to note that both the 1977 and 1990 amendments to the Clean Air Act substantially impacted both the levels and variation in the costs of compliance, particularly with respect to SOx in the case of electric utilities. The 1977 ammendments effectively mandated scrubbers on new coal plants. For new coal plants, this substantially narrowed the differential between attainment and non-attainment regions for compliance with NSPS. A study commissioned by the EPA for its 2001 NSR background paper details the costs of compliance for various generation technologies for attainment and non-attainment regions.[8] For a new coal-steam boiler, ICF estimated that compliance costs would range from .73 to .98 cents/KWh in attainment areas and .84 to .98 cents/KWh in non-attainment regions. The vast majority of this compliance cost is the cost of scrubbers to remove SOx.

The 1990 amendments established a market for SOx emissions credits that encompassed mainly large coal plants, known as 'phase 1' plants, during the late 1990s and all major generation sources, "phase 2" plants, starting in 2000. In theory, the establishment of this market should have reduced the bias toward extending the lifetimes of older, dirtier plants since all plants were faced with the marginal cost of reducing SOx emissions. Thus during the 1990s the variation in compliance with SOx standards decreased and the new source bias towards older plants was reduced, at least with respect to SOx emissions from electricity generation plants.

Thus, while several early papers have shown that the CAA extended the lifetime of existing dirty plants, there is reason to believe that the picture may have changed over the last two decades. In the following sections, we first revisit the question of plant retirements and utiliza-

[8] ICF 2001

tion. We then turn to the potential impact of the change in EPA's enforcement of NSR on the operations of existing power plants.

One major challange in analyzing the impact of any regulation on the lifetimes of facilities is the need to characterize what kind of plant, if any, would replace it. In electricity, this is a non-trivial task as the trends in invesment have changed substantially since the CAA was intially passed. We have developed a detailed data base of fossil fuel unit additions and retirements since the 1970s.[9] Table 1 describes the fossil-fuel generation capacity constructed in the U.S. from 1970 through 2003 by major fuel type. To a first-order, the prefered generation technology for large power plants was coal during the 1980s. During the 1990s, there was a pronounced shift towards natural gas technologies. Since 1998, new plants have almost exclusively been fueled by natural gas.[10] While environmental regulations could have factored into this shift, increasing concern over capital costs combined with the deregulation of natural gas and the adoption of more effecient 'combined-cycle' generation technology created a strong preference for natural gas. The shift to natural gas was also aided by the rise of unregulated 'non-utility' generation firms and the dramatic growth in regional wholesale power markets. For various reasons, non-utility firms prefered the less capital intensive, more flexible gas technologies. The increase in regional trade meant that new power supplies were much less likely to come from nearby facilities sited within the service territory of the local utility company.

3 The Effects of Environmental Regulation on Plant Construction and Retirement

At least since 1972, air quality regulations have established technological requirements and emissions standards for power plants. While these regulations clearly influence mitigation technology choices, they also could have indirectly affected decisions about plant retirements as well as the choice of fuel type and locations of new power plants. It is important to consider, however, that

[9] The data are described in the Appendix. We focus on fossil-fuel powered plants as nuclear and hydroelectric plants are subject to very different environmental regulations.

[10] Most recently, increases in gas prices are leading firms to renew their interest in coal, although this last trend falls beyond our sample period.

the implementation of the environmental regulations overlap with other important changes in the power sector. This section examines the impacts of air quality regulations, particularly NSR, on power plant investment and retirements.

3.1 Air Quality Regulations and Power Plant Lifetimes

One of the most striking distinctions between the electricity industry and other major polluting industries is the fact that power plants were subject to economic regulation for most of the twentieth century. Most of the prior literature on vintage differentiated regulation has demonstrated an effect using a general model of investment in a perfectly competitive environment (see Stavins, 2005, or Maloney and Brady, 1988). In this setting, firms will invest in production facilities as long as their expected total profits cover their cost of investment. Investment takes place until the market price provides net revenues that just equal the cost of investment. If new plants are required to install pollution control equipment, the cost of investment, the cost of operations or both will go up, so equilibrium market price must increase. Firms decide to retire capacity when revenues will no longer cover the cost of operating it, which is assumed to increase monotonically over time. If the regulation leads to higher equilibrium prices, existing capacity will find it profitable to remain in service for longer.

At first glance, the economic regulation of electric utilities would limit the applicability of this model. In fact, in a pure cost-of-service world where rates adjust perfectly to reflect additional costs (*i.e.,* without regulatory lag) and where the regulated return on investment equals the firm's true cost of investment, it is not clear that a vintage differentiated regulation would lead to any distortions in retirement decisions. If firms were perfectly compensated for the cost of new capacity regardless of whether it had pollution control equipment, their decisions about when to install new capacity would be unaffected by the regulations. However, there are at least two reasons why electric utilities in the U.S. may have kept old power plants around longer under NSR.

First, rates did not adjust perfectly to cover new costs, so between rate cases (and in the

1990s fewer rate cases were heard as states moved towards restructured environments), firms' revenues did not adjust if their costs changed. Consider a utility with an obligation to serve who supplies all of its own power. Without a rate case, revenue will be essentially constant, so the utility would pick the least cost way to supply its demand. If new plants must install and run costly pollution control equipment, then the old capacity will have higher margins for longer and firms will delay retiring the old plants.

The second reason why investor-owned utilities may have been averse to installing pollution control equipment is that regulators were allegedly setting the rates of return too low, especially in the late 1980s and early 1990s. As a result, firms would be reluctant to make any kind of capital investment, and even more averse to building new capacity if the capital costs were inflated by the requirement to install pollution control equipment.

3.2 Retirements over Time

Given the increasing costs of new source performance standards (NSPS) imposed on new units, one might expect grandfathering to extend the lifetimes of existing units. We would like to be able to identify what a unit's age at retirement would have been absent the NSPS (T^{NoNSPS}) and compare it to the actual age at retirement. The difference ($T^{Actual} - T^{NoNSPS}$) would measure how much longer units are kept in service because of environmental regulation. To obtain T^{NoNSPS} we would need to isolate the component of the new unit costs attributable to the pollution control equipment.

To get a sense for the general patterns in retirements, Figures 1-3 plot 3-year centered moving averages of the age at retirement for coal-, oil- and gas-fired units by retirement year since 1970 as well as the number of plants that retired in each year. Since 1980, there has been a reduction in the number of coal plants retiring, and since 1990 an increase in the average age at retirement. There has been an increase in the retirements of gas plants during the 1990s, while the average age at retirement has fluctuated around 35 since 1970.

One, extremely rough, approach to identifying T^{NoNSPS} is to compare the age at retirement of coal, gas and oil units over time. The pollution control equipment required at new gas and oil plants are much less expensive then the equipment required at a coal plant. If all other determinants of cost at these plants were equivalent and assuming that the optimal proportion of coal, gas and oil plants stayed roughly constant over the period, the difference in retirement age across plant types would speak to the magnitude of $T^{Actual} - T^{NoNSPS}$. These are unrealistic assumptions, but it is useful to present the data, in part since this comparison may be informing public opinion about an NSR grandfathering effect.

3.3 Retirements and Attainment Status

Ideally, we would like to observe unit retirements in an environment where new plants only faced costs associated with the new generation technology, but not the new environmental regulations. Unfortunately, no such completely unregulated counter-factual exists. What we can do instead is compare retirements across environments where the pollution control costs vary. We would expect to see later retirements the higher the pollution control costs are for replacement plants. Any difference across areas with high pollution control costs and areas with low pollution control costs provides a lower bound on $T^{Actual} - T^{NoNSPS}$. As discussed above, such an approach requires assumptions about what, and where, the replacement plant would be.

Because new plants built in non-attainment areas needed to install more expensive pollution control equipment, an old plant may be more valuable in counties where replacements would have to be built in non-attainment areas. Note that because of the growing trend in regionalized power markets, this replacement need not be located in the same county as the retiring plant.

Variations in regional attainment status could identify a grandfathering effect under several strong, though not implausible, assumptions. First, we need to assume that there was some inherent value to having a unit in the same region (for now we consider the state as the relevant region), if not the same county as the retiring plant. This could be true if, for instance, transmission constraints favor generation in the same state. Certainly, transmission 'losses,' which are magnified with distance, can significantly increase the cost of imported power. We also assume that all retired units will be replaced by units whose costs meaningfully vary by attainment status.

The impact of local attainment status for the various criteria pollutants varies by fuel type. For coal plants, the dominant mitigation costs relate to sulfur (SOx) emissions, although there are also nontrivial costs associated with mitigating NOx. The 1977 amendments effectively required scrubbers for new power plants whether it was located in an SOx attainment area or not. For natural gas plants the dominant concern is NOx emissions, and the impact of local attainment status could significantly impact mitigation costs. The combination of all these factors complicates an analysis of the impacts of environmental regulations on investment and retirements. For example, variations in state-level restrictions on SOx emissions may be much less relevant if the prefered replacement technology is a low-sulfur gas plant, as was true in the 1990s.

To get a rough sense for how attainment status affected the siting of new plants, Tables 2a and 2b summarize the aggregate investments in power plants by fuel-type, as well as attainment status for ozone and SOx.[11] There is little construction in SOx non-attainment areas, which themselves constitute about 2% of the U.S. counties. There is considerably more investment in ozone non-attainment areas, but a general trend favoring investment in attainment areas that accelerates in the late 1990s.

There are other confounding interpretations of the effect of local attainment status (*i.e.,* the status of the county in which the plant is located) on plant life. In general attainment status may be highly correlated with economic activity, and therefore electricity demand. Additionally, local non-attainment can make it *more* attractive to retire a plant, particularly if low-cost nearby replacements are available. This is because new plants in non-attainment areas are required to obtain offsets of their new emissions from facilities located within the same county. Thus the owner of an older power plant in a non-attainment area may find it profitable to retire the plant

[11]For the purposes of this table, 'attainment' refers to the status of the county in which the plant was constructed in the year the plant came on line. Note that this covers a smaller time horizon than Table 1 because of the more limited availability of attainment status.

and sell the 'rights' to emit in that region to some new, most likely non-electricity, facility.

To assess the impact of county and state attainment status on the probability that a unit is retired, controlling for other factors, we estimated the following proportional hazard model:

$$
\begin{aligned}
h(t, X_{it}, \beta, \mu_{it}) &\equiv Pr[unit\ i\ retires\ in\ year\ t|\ unit\ i\ still\ in\ service\ in\ year\ t-1] \quad (1)\\
&= h_0(t) * exp(\beta_0 + \beta_1 NA\_County_{it} + \beta_2 NA\_County_{it} * NA\_State_{it}\\
&\quad +\beta_3 Age_{it} + \beta_4 Size_{it} + \beta_5 State\_Capacity\_Factor\_Growth_{it} + \epsilon_{it})
\end{aligned}
$$

where i indexes a unit and t a year. The variables NA_County_{it} and NA_State_{it} refer, respectively to the attainment status of the county where plant i is located, and the percentage of non-attainment counties in the state in which plant i is located. The $State\_Capacity\_Factor\_Growth$ is a measure of changes in the utilization of existing plants, with a higher value indicating increased utilization. This variable will capture both growth in electricity demand and the expansion of alternative supply. We estimate Cox proportional hazard models that allow the baseline hazard $h_0(t)$ to vary non-parametrically over time and, where relevant, across fuel types.

We specify the county and state attainment status variables with care, as the retirement of a large electric generating unit could push an area into attainment. To avoid potential reverse causality problems, we measure attainment status with a lag. In other words, this variable measures the attainment status two years before the retirement of the plant. For now, we only have attainment status from 1978-2000. Since we use a two-year lag on attainment, we limit our analysis to the retirements that occurred between 1981 and 2002.[12]

Results from estimating the hazard model are presented in Table 3. The first two columns report results estimated on coal, oil and gas units together, although the baseline hazards are allowed to vary by fuel type, while the second column reports results for just coal. The table reports hazard ratios ($exp(X'\beta)$).

[12]We are also using lagged capacity factor, for which our first year of data was 1980, thus we start our analysis in 1981.

One clear message from these specifications is that units are *more* likely to retire if they are located in non-attainment counties. The estimated hazard ratios for *Ozone NA County* and SO_2 *NA County* are greater than 1 across all three columns, and the null hypothesis that they are equal to one is easily rejected. The coefficient estimates in column 1 suggest that units in ozone non-attainment areas are three times as likely to retire as a comparably sized and aged unit in an attainment area. The coefficient on SO_2 *NA County* is only slightly smaller. These results suggest that various factors, such as state and local level negotiations designed to bring counties into attainment, the value of emissions offsets, and other unobserved economic considerations that may be correlated with attainment status overcome any grandfathering effect on utility companies' incentives to keep plants in non-attainment areas open.

However, when one considers a measure of the ease with which an economically viable replacement plant could be constructed, the story changes. In the last two columns, the coefficient on the interaction of local attainment status with the attainment status of other counties in the state (*Ozone NA County x Fraction of NA Counties in State*) is statistically significantly less than one, suggesting that plants in non-attainment counties that are in states with a high fraction of other non-attainment counties retire later, all else equal.[13] This suggests that a grandfathering effect could be at work when one expands the set of potential replacement plants to include those constructed in other locations within the state. For a coal plant in a state where all other counties are non-attainment, the coefficient estimates suggest that this effect offsets the factors that otherwise drive up the attractiveness of retiring a plant in a non-attainment area, as the product of the coefficient on *Ozone NA County x Fraction of NA Counties in State* and *Ozone NA County* is less than one (though the product is not statistically smaller than one).[14]

One potential concern is that the concentration of non-attainment areas in a state is correlated with other factors that encourage firms to keep plants open. The variable *State_Capacity_Factor_Growth* controls for changes in state electricity demand relative to the installed capacity. In an alterna-

[13]The mean of the interacted variable is .165.

[14]Note that our excluded category includes all plants in attainment counties, whether they are in states with a high fraction of non-attainment counties or not. We assume that these plants can be replaced by another plant in the same county, so the surrounding counties are not as relevant.

tive specification we added a variable measuring the growth in manufacturing establishments by state, both in addition to and as a substitute for the $State\_Capacity\_Factor\_Growth$ variable. The results were unchanged from those reported here.

Our measure of regional non-attainment status is somewhat crude, and we intend to examine alternative specifications in future analyses. Generally, the results in this section suggest that, although firms appear to find it valuable to close plants in non-attainment areas, the advantages conveyed to incumbent plants by the grandfathering of environmental regulations push firms to keep plants active.

4 The Effects of NSR on Unit Operations

The next two sections consider the effects of NSR on generating units' productive efficiency. The analyses in this section exclusively examine coal units as these were subject to the most stringent pollution control requirements and were the only targets of the 1999 lawsuits.

To assess the impact of NSR enforcement activities, we would ideally like to characterize units as either being $AtRisk$ of triggering NSR or $NotAtRisk$. A unit could be in the latter category if it had already installed all of the pollution control equipment that would be required of a new unit, suggesting that triggering an NSR permit requirement would not impose substantial additional costs. We could then compare efficiency across the two types of units around the various NSR enforcement events to evaluate whether fear of increased NSR enforcement impacted efficiency at units that were $AtRisk$. The $NotAtRisk$ units serve as controls for other changes in coal-fired power plant operations. Our base specifications use the time between 1998-2002 as the period of heightened NSR enforcement. We start the period in 1998 since this is when the EPA issued information requests to several utilities in preparation for the eventual November 1999 lawsuits. We end the period in 2002 because, by the end of that year, the Bush Administration had signaled its willingness to relax the enforcement of NSR. We explore the sensitivity of our results to the specific delineation of the enforcement time period.

4.1 Identifying *AtRisk* Units

An important first step to our approach is identifying *AtRisk* units. We take a number of factors into consideration in doing this, starting with the basic rules governing new sources. Environmental regulations (see 40CFR52) specified that new coal units, or existing coal units that triggered a new source review, 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 nitrous oxides (NOx), sulfur dioxide (SOx) and particulates. Retrofitting a plant with a flue gas desulfurization device (also called a scrubber) to remove SOx was far more costly than retrofitting a plant with a NOx control device. 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). Also, while the standard for NOx removal varied between attainment and non-attainment areas and over time, the nationwide control technology required for SOx has been scrubbers since at least 1984.[15] For these reasons, we characterize plants that had scrubbers installed (*i.e.,* were *Scrubbed*) by 1998 as *NotAtRisk* since they had already installed the most expensive pollution control device that would be required if they were to trigger a new source review.[16]

Ideally, *Scrubbed* units would be identical to *NonScrubbed* units on all dimensions except the fact that they had pollution control equipment installed. This is hardly the case. Table 2a compares characteristics between scrubbed and non-scrubbed units, while Table 2b compares

[15] The nationwide standard has not been uniformly applied and 12 of the 48 units built since 1984 were built without scrubbers. All those units were subject to the 1999 lawsuits.

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

characteristics at the plant level.[17] In both tables, the time-varying variables are measured in 1996, before the NSR enforcement period began. As the top two rows demonstrate, 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. In the specifications below, we take several econometric approaches to address the differences between $Scrubbed$ and $NotScrubbed$ units. Note that while the means of the $Size$ and Age variables differ substantially between $Scrubbed$ and $NotScrubbed$ units, the distributions are largely overlapping, as demonstrated in Figures 4 and 5. One approach we take to control for age and size specific trends is to divide the distributions in half and, in some specifications, into five subgroups. Figures 4 and 5 suggest that there is enough overlap in the distributions to identify a $Scrubbed$ effect within subgroups.

The third rows of both Tables 4a and 4b suggest that the scrubbed and non-scrubbed plants have almost identical heat rates, although this represents the offsetting effects of two factors. Newer and bigger plants 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 scrubbed plants also have higher capacity factors and this result is robust to controlling for age and size with third-order polynomials. The coefficient on the $Scrubbed$ dummy is .063 (se = .011). The mean of the variable measuring the average hourly temperature across units are statistically indistinguishable. Scrubbed plants were less likely to be divested, and since Bushnell and Wolfram (2005) document modest improvements in productive efficiency after divestitures, we consider the sensitivity of our results to controlling for effects of the divestitures.

One check on the assumption that $Scrubbed$ units were not at risk of triggering NSR en-

[17] Electric power plants often comprise multiple generating units. While fuel use is meaningfully measured at the unit level, other inputs are commonly shared across units at the plant, so our specifications will use plant-level or unit-level observations where appropriate.

forcement is to consider whether they were less likely to be subject to the lawsuits filed by the Department of Justice beginning in 1999. This is an imperfect test since the lawsuits named plants not units, and occasionally in our data there are plants where only a fraction of the units have scrubbers installed. Nevertheless, the second to last row of Tables 4a and 4b show that units with scrubbers were less likely to be at plants named in the lawsuits, and this relationship holds up if we estimate a simple cross-unit probit of the lawsuit dummy on variables measuring capacity, age, average 1996 heat rate, divestiture dummy and lawsuit dummy.

There is a particular way in which the existence of a scrubber could be correlated with changes in operations during the time period we consider. The Clean Air Act Amendments of 1990 created a market for permits for the right to emit SOx. The program was phased in and 100-plus of the dirtiest units (referred to as the Phase 1 units) had to buy permits to cover emissions greater than some baseline beginning in 1995 and the remaining units had to buy permits to cover emissions beginning in 2000. It is possible that the Phase 1 plants that are $Scrubbed$ altered their input use post-1995 in very different ways than units that are $NotScrubbed$. Thirteen of the Phase 1 units were required to install scrubbers, but many of the remaining plants reduced SOx by switching to lower sulfur coal. We measure fuel inputs in mmBtus, so even with a switch in coal-type, if our heat input variable is measured accurately across fuel types, this should not create measurement error. It is possible, however, that the process of switching fuel types impacted non-fuel inputs. To allow for this possibility, we estimate some specifications that omit all Phase 1 units.

4.2 Measuring Productive Efficiency

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 the major input categories:

$$Q_{it} = f\left(Fuel_{it}, Labor_{it}, Materials_{it}, Capital_{it}, \epsilon_{it}\right) \tag{2}$$

for unit i in time period t, where Q measures electrical output and $Fuel$, $Labor$, $Materials$

and *Capital* capture the important input categories. For several reasons, we chose not to take this approach and instead use reduced-form factor-demand equations of the following form for our base specifications:

$$\begin{aligned} \ln(I_{it}) &= \beta_1 \ln(Q_{it}) + \beta_2 NotScrubbed * NSR\_Enforcement\_Period_{it} \\ &+ \beta_3 NotScrubbed * Post\_NSR\_Enforcement\_Period_{it} + \beta_4 X_{it} + \kappa_t + \mu_i + \varepsilon_{it} \end{aligned} \quad (3)$$

for unit or plant i in period t where I indexes the input category, Q is output of the plant, $NotScrubbed * NSR\ Enforcement\ Period$ is a dummy variable equal to one during the enforcement period for $NotScrubbed$ units, X_{it} is a set of control variables. We hypothesize that β_2 will be negative for $I \in \{capital, materials\}$ if the heightened enforcement of NSR caused utilities to cut back on investing in and maintaining their plants, while β_2 will be positive for $I \in \{fuel\}$ if low maintenance caused fuel efficiency to degrade. $NotScrubbed * Post\ NSR\ Enforcement\ Period$ 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 and material use at $NotScrubbed$ plants to make-up for any reductions made during the enforcement period.

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.[18] 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 there are no data on quantities. Also, because capital and O&M expenditures are comprised of a myriad of different physical inputs, properly defining a variable that measures the physical inputs would be extremely difficult. Last, note that we do not include the prices of the inputs, but to the extent that prices are constant within a time period across units, the time effects (κ_t) pick up trends in prices. Also, in some specifications, we allow κ_t to vary by age, size, region or other covariates which could be correlated with input prices.

[18] We also have data on the number of employees at the plants. Estimates using employees as the input showed no statistically significant effect of $NotScrubbed * NSR\_Enforcement\_Period$.

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.

We estimate factor demand equations for several reasons. First, the argument that NSR enforcement has impacted power plant operations suggests that by reducing their capital or operations and maintenance expenditures, utilities have compromised their units' fuel efficiencies and so are spending more on fuel for a given level of output. While estimating a production function with a dummy variable for $NotScrubbed$ plants during the NSR enforcement episode might show a reduction in technical efficiency (assuming utilities had been optimizing their input mix before the enforcement period), we are interested in dissecting the use of individual inputs. We are particularly interested in assessing whether NSR enforcement caused the plants to reduce fuel efficiency, since fuel use is highly correlated with pollution output.

The second reason to estimate factor demand equations is because the dynamics in a power plant's production process are not captured by the typical production function. For instance, for some operations and maintenance expenditures, a negative effect on fuel efficiency may not show up in the year when the maintenance is deferred. We analyze factor use over a multi-year NSR enforcement period, so we should be able to detect lagged responses so long as they manifest within several years.

To identify the effects of NSR enforcement, we use data on nearly 900 coal generating units housed at over 300 plants. 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. When we estimate equation (3), several sources of variation in the data help us identify an NSR effect. First, we include fixed-effects at either the unit or the plant level. These help control for a whole set of time-invariant unit- or plant-specific factors including its technological configurations, age, size, etc. We then compare the average input use at $NotScrubbed$ plants during the period of heightened NSR enforcement to the average input use at *Scrubbed* plants, controlling for Q, X and an average unit effect. Changes in input use at *Scrubbed* plants, which we hypothesize are not at risk, can help us control for industry-wide trends.

Using equation (3) to identify the NSR effect relies on the assumption that input use at *Scrubbed* and *NotScrubbed* plants followed the same trend before the enforcement period. If this assumption does not hold, then β_2 will reflect the differences in the pre-enforcement period trends. For instance, if input use were growing faster at *Scrubbed* plants than at *NonScrubbed* plants in the pre-enforcement period, β_2 will overstate the negative effect of NSR. We take several steps to control for pre-enforcement period trends. First, we allow κ_t to vary by observable plant characteristics, such as age, size, geographic region and whether the plant was eventually divested as part of the state-level industry restructuring.[19]

The second approach we take is to condition on the pre-enforcement period trends directly, by estimating versions of the following equation:

$$\ln\left(I_{i\tau}\right) = \beta_1 \ln\left(Q_{i\tau}\right) + \beta_2 NotScrubbed_i + \beta_3 X_{i\tau} + \beta_4 P_i + \varepsilon_{i\tau} \tag{4}$$

for input I at plant i in year τ. We estimate separate versions of equation (4) for $\tau \in \{1998, 1999, ...2004\}$. We expect β_2 to follow the same pattern as in equation (3): negative for $I \in \{capital, materials\}$ in 1998-2002 if the heightened enforcement of NSR caused utilities to cut back on investing in and maintaining plants that were at risk of triggering NSR (*NotScrubbed* plants), but positive for $I \in \{fuel\}$ for $Tau \in \{1988 - 2002\}$ if low maintenance 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 (3), 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, lagged output (Q) in 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

[19] Some have alleged that utilities reduced capital and maintenance expenditures at plants they knew they would eventually sell.

linearly for the pre-existing trends in input use, and β_2 is identified by differences between $Scrubbed$ and $NotScrubbed$ plants in the NSR enforcement period conditional on the trends.

One further issue we confront in estimating factor demand equations as in equation (3) 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.[20] 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 (4). To the extent that capital investment in previous periods is correlated with the plant-specific productivity shock (this is the assumption used by Olley and Pakes (1996)), $\varepsilon_{i\tau}$ is less likely to be correlated with Q.

5 Unit Operation Results

This section presents the results from estimating equations (3) and (4). Because the data sets and control variables differ across fuel and nonfuel input categories, we consider the two sets of results separately.

5.1 Capital and Operations and Maintenance Expenditures

To examine the impact of NSR on non-fuel plant expenditures, we utilize data on various plant financial and operating statistics filed with regulatory agencies by investor- and municipally-owned utilities. The data sources are described more fully in the data appendix. The data are reported at the plant level, and there are 329 coal-fired plants represented in our sample. We

[20]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 and Caves (2005) compares and critiques the approaches proposed by them. Fabrizio, Rose and Wolfram (2006) addresses the simultaneity problem by instrumenting.

use data reported from 1988 through 2004, although the 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 analyze capital costs using the "total cost of plant" variable, which measures the aggregate 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.

Since data are reported at the plant level, we are forced to aggregate unit characteristics to form our control and treatment groups. For example, some plants have units that are scrubbed and others that are not. We define a plant with a scrubber as one in which the capacity weighted average of the scrubbed units at the plant is greater than .5.[21] In other words, a plant is treated as more at risk for NSR enforcement if less than half its units have scrubbers. Similar aggregation is performed to separate "Phase 1" plants. A plant's age is defined as the capacity weighted average age of its component units.

Table 5 reports results from estimating equation (3) using the log of total capital expenditures as the dependent variable ($\ln(TotalCapital)$). The specification reported in the first column includes plant fixed effects and year fixed effects. The coefficient on $NotScrubbed * NSR\ Enforcement\ Period$ indicates a positive effect, suggesting that at-risk plants invested more, though the coefficient estimate is statistically indistinguishable from zero. Figure 6a plots year-effects estimated separately for the $Scrubbed$ and $NotScrubbed$ plants using the same sets of controls as the first column of Table 5 (*i.e.,* plant fixed effects, $Scrubber\ Added\ After$ 1997 and $\ln(Output)$). As this figure highlights, however, $Scrubbed$ and $NotScrubbed$ plants showed different pre-enforcement period trends. Since, as Table 4b suggests, plants with scrubbers are much bigger and newer, column 2 re-estimates equation (3) allowing small plants (plants less than 800 MW) and young plants (plants less than 30 years old) to have different year-effects.[22] Including

[21] The distribution is highly skewed towards either 1 (all scrubbed) or 0 (no units scrubbed). Out of 329 plants in our sample, 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.

[22] We have also estimated versions that allowed for five age categories and five capacity categories and obtained very similar results to those in Table 5 and Fiugre 6.

these controls reverses the sign of the coefficient on $NotScrubbed * NSR\_Enforcement\_Period$, though it is still statistically indistinguishable from zero. Also, as Figure 6b demonstrates, the treatment and control groups demonstrate different pre-enforcement period trends even with these controls.

We took two additional steps to address differences between *Scrubbed* and *NotScrubbed* plants. First, one reason that Figure 6b might indicate that capital at plants with scrubbers grew faster than capital at plants without scrubbers until 1998 is that some of the plants in our control group were installing scrubbers during the early 1990s. Since the capital cost of a scrubber can be 30% of the cost of the plant, scrubber installations could affect the trend in capital spending appreciably. To account for this, we excluded observations before the last scrubber at a plant was installed. Our sample is reduced in this specification both because we are dropping observations from the early 1990s for the plants that installed scrubbers during the 1990s and also because we do not know the date of scrubber installation for about one-fifth of our control group. We drop the *Scrubbed* plants if we do not know the scrubber installation date. As column 3 of Table 5 demonstrates, this has little effect on the coefficient estimates, though in (unreported) figures, we see that the exclusion does bring the year-effects for the treatment and control groups closer together. Second, we excluded all Phase 1 plants, since Phase 1 plants with scrubbers presumably had very different patterns of capital investment from plants without scrubbers in the late 1990s after the acid rain program took effect for these plants. As Figure 6c demonstrates, the *Scrubbed* and *NotScrubbed* plants based on this sample appear to follow the same trend until 1998, when investment at *NotScrubbed* plants slows down relative to *Scrubbed* plants. Beginning in 2001, investment accelerates at *NotScrubbed* plants until capital spending reaches the same level in 2004. This pattern is consistent with what one might expect if the heightened enforcement of NSR caused utilities to reduce capital expenditures until the threat of enforcement was removed and they accelerated investment to "make up" for the period of low investment.

The coefficient estimates based on the sample represented in Figure 6c and estimated using

OLS are reported in column 4. While the signs of the coefficients are consistent with an NSR effect in 1998-2002 and a period of catch-up after 2002, they are not statistically different from zero. Comparable coefficients estimated using $\ln(StateSales)$ to instrument for $\ln(Output)$ suggest a slightly larger and statistically significant negative effect of NSR on capital investment in the 1998-2002 period. The magnitude of the coefficient suggests that plants at risk of triggering NSR reduced captial spending by 6.1% during the 1998-2002 time period relative to plants that were not at risk. Note that the coefficient on $\ln(Output)$ increases substantially between columns 4 and 5 (*i.e.,* between the OLS and IV specifications). This is consistent with a negative correlation between input shocks and output, as for example, if large capital expenditures are associated with outages at the plant.

Table 6 reports estimates of equation (4) using $\ln(TotalCapital)$ levels in 1998 to 2004. The top of the table is based on the same sample as reported in column 3 of Table 5 (*i.e.,* all plants but excluding elements of the control vector P_i for years before a plant installed its scrubber), while the bottom of the table uses only Phase 2 plants. Generally, the coefficient estimates are consistent with those reported in Table 5, suggesting reductions in capital at $NotScrubbed$ plants in the 1998-2002 period and modest increases in spending after 2002 when Phase 1 plants are included.

As the number of observations by year reported in Table 6 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. As Figure 1 suggests, there are very few unit retirements (and even fewer plant retirements) during our sample period. As a result, we doubt that the attrition is related to efficiency. We estimated versions of both the specifications reported in the fifth column of Table 5 and the specifications reported in Table 6 using a balanced panel and obtained similar results to those reported.

Tables 7 and 8 and Figures 7a-7c present similar specifications for the operations and maintenance expenditures. Generally, the coefficients on $NotScrubbed * NSR\_Enforcement\_Period$

are negative and roughly of the same magnitude as the coefficients in the capital specifications, though they are statistically indistinguishable from zero across all specifications, save during a handful of years in the specifications based on equation (4) and reported in Table 8.

We take the results discussed in this section to suggest that the increased enforcement of NSR during the 1998-2002 period may have reduced capital spending at plants at risk of triggering a review, but does not seem to have systematically reduced spending on O&M. There is some evidence of a catch-up period after 2002, though these results are less robust.

5.2 Fuel Efficiency

The data we use to estimate equation (3) 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, for a first look at the data, 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 9, which reports the fuel efficiency results, is organized in the same format as Tables 5 and 7, reporting OLS results using more controls and finer cuts of the sample in columns 1-3 (note that in order to save space, we exclude the column that uses Phase 1 and Phase 2 plants but excludes observations before the scrubber installation date) and reporting IV results in the last column. Note that in the case of fuel efficiency, instrumenting has the expected effect and dampens

[23]In future work, we intend to use the richness of the hourly data to estimate more flexible functional forms, particularly in specifying the relationship between output and fuel efficiency.

its relationship with output. The variable of interest, $NotScrubbed{*}NSR\_Enforcement\_Period$, is small and statistically indistinguishable from zero in all specifications, and is quite precisely estimated. We can reject the hypothesis that $NotScrubbed$ units heat rates increased (*i.e.,* fuel efficiency decreased) by 1% in every specification.

6 Conclusion

We began by outlining two types of distortions that vintage differentiated regulations, like NSR, can impose in the short run (*i.e.,* until all of the grandfathered units are phased out). First, old units may be kept in service longer since replacing them becomes more expensive. Second, since upgrading a unit could potentially qualify it as "new," the old units may do less maintenance and invest less in their plants, potentially leading to lower efficiency and higher emissions.

This paper considers the effects of NSR on coal-fired power plant retirements and operations. Our evidence on retirements is intriguing, but not conclusive. We find some evidence that plant lifetimes were extended if the plant operated in a state where new plants were more tightly regulated. We also find evidence suggesting that utilities invested less capital in units at risk of triggering NSR. However, whatever the NSR effects were, they did not appear to impact the efficiency of the plants. At-risk units showed no worse fuel efficiency than the control group over the period when NSR enforcement was at its height. This could imply that industry claims about the efficiency impacts of heightened enforcement were overblown, or that the impacts of any 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. Also over the past decade, the EPA has moved away from command and control regulation and has implemented or proposed implementing market-based cap and trade programs. In light of this shift, it seems unlikely that the EPA would take that tack. For instance, the Acid Rain Program caps the number of SOx 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 SOx.

Utilities have contended that enforcing NSR will cause them to under-invest in their plants and that their efficiency will be sacrificed as a result. Our results suggest that NSR has had little of the distortionary effects on day-to-day decisions, but might have impacted capital expenditures. It seems possible that much of the utilities' rhetoric was designed to undermine the program in the face of the potentially costly lawsuits. That tack appears to have succeeded, as the Bush Administration implemented new rules in August 2003 that effectively eliminated the risk that an existing power plant would be forced to retrofit emissions controls under the NSR provisions. One recent court decision ruled in favor of the utility, citing the fact that the violations the company was accused of would be legal under the new standards.

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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 five broad categories.

Retirements

PowerDat collects annual information on units that are in-service as well as units that have been retired. The data base is comprehensive after 1988, but lists retirements back to the 1960s. PowerDat also reports information on the year the unit came online, its size, and the county and state in which it is located.

We merged the PowerDat information on retirements with a data set from UDI (a company now owned by Platts) that contained a comprehensive survey of all retirements of power plants from the early 1970s through the early 1990s. We merged retired units that appeared in both databases by name and unit number. We restricted the sample to oil, gas, and coal plants that one of the two databases believed to have at least 70MW of capacity. When there were discrepancies between entries found in both data sets for plant capacity, retirement year, or online year, we used an average of the two values in our analysis. (For a large handful of units that Platts recorded as coming online in "1900" but had more reasonable online years in the UDI data, we used the UDI online years.) We used the Platts fuel type data whenever it or both databases had fuel type entries; and used the UDI entry when it was the only available data. There were a handful of units that retired after attainment data became available that were listed only in the UDI data, but they were all at plant locations in the Platts data so this merge gave us the county data that we needed to match to these units to the attainment status data.

Annual 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.

State-level Demand

Data on state level demand 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.

State-level Capacity Factor

The capacity factor variable is defined as the total MWh produced in the state divided by the aggregated generation capacity installed in the state. For 1980-1999, the data are the same as those used in Fabrizio, Rose, and Wolfram (2006). Generation capacity are taken from a combination of the Energy Information Administration's (EIA) Inventory of Electric Utility Power Plants (1980-85), and data from UDI. Total MWh sales is taken from EIA's "Electric Sales and Revenues" (1988-2000) and EIA's "Electric Power Annual."

For 2000-2004, total MWh generation is taken from EIA form 906, and installed generation capacity is taken from EIA form 860.

Ambient Temperature-Hourly

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. As a precaution we drop hourly observations from a plant for the 45 days previous and 15 days following the divestiture date reported in Electric Power Monthly.

As of December 2001, divestitures have taken place in 24 states. In 2002 and 2003, the only divested units were either in Texas, which we exclude from our sample, or were nuclear power plants.

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. The Greenwire News Service provided information on the status of NSR enforcement actions, as well as reports on new enforcement actions.

County Attainment Status

The county-level SOx, ozone and NOx attainment data were obtained from Michael Greenstone, and are the same designations used in Greenstone (2002). A detailed description of these data is provided in the appendix of that paper.

Table 1a: New Unit Capacity (MW) by Fuel Type

Half Decade		Fuel Type				
		Coal	Oil	Gas	% Coal	Total
1970-73		35624	2679	15687	66%	53990
1973-78		56618	15797	25097	58%	97512
1978-82		58196	3757	7900	83%	69853
1983-87		32834	0	4347	88%	37180
1988-92		9816	806	15529	38%	26151
1993-97		4563	781	25112	15%	30456
1998-03		815	0	122507	1%	123322

Table 1b: Retired Unit Capacity (MW) by Fuel Type

Half Decade		Fuel Type				
		Coal	Oil	Gas	% Coal	Total
1970-73		900	101	532	59%	1533
1973-78		1994	459	989	58%	3442
1978-82		1450	175	1901	41%	3527
1983-87		1423	1058	1900	32%	4381
1988-92		822	1085	405	36%	2312
1993-97		671	3444	661	14%	4775
1998-03		2131	2807	2109	30%	7047

Figure 1: Coal Unit Retirement Age by Retirement Year

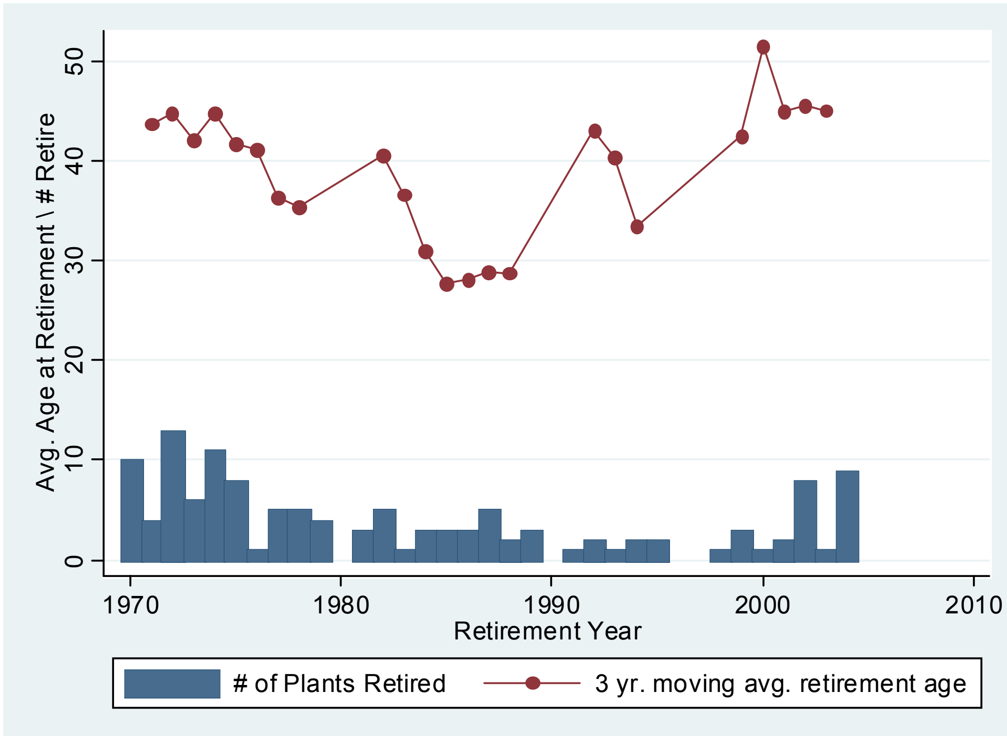

Figure 2: Oil Unit Retirement Age by Retirement Year

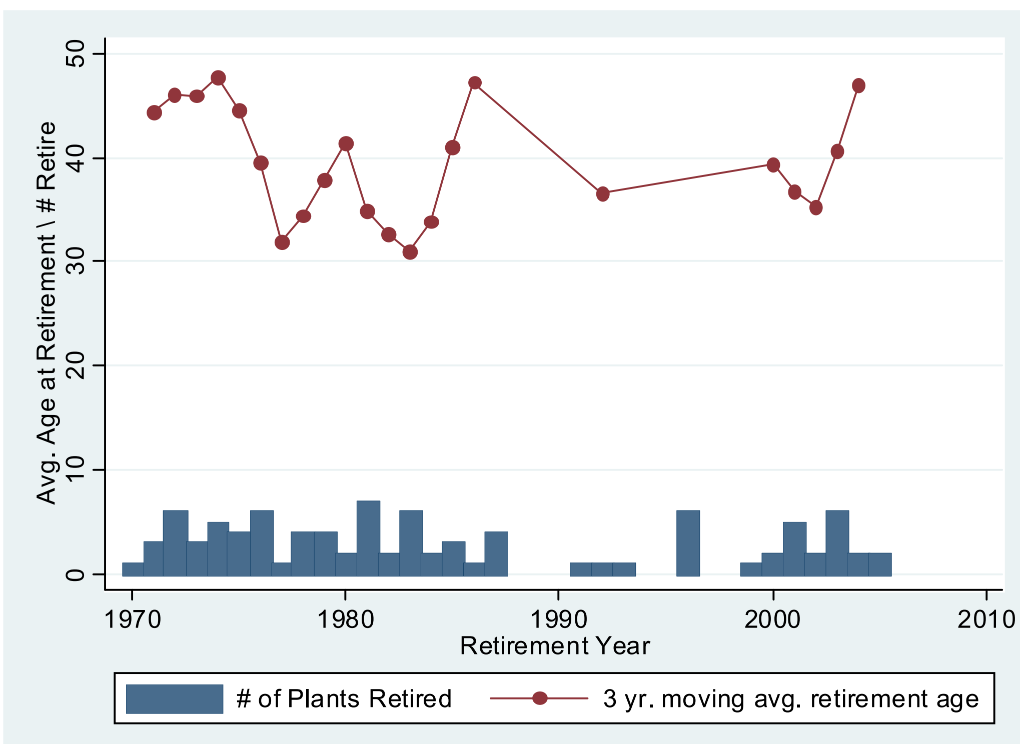

Figure 3: Gas Unit Retirement Age by Retirement Year

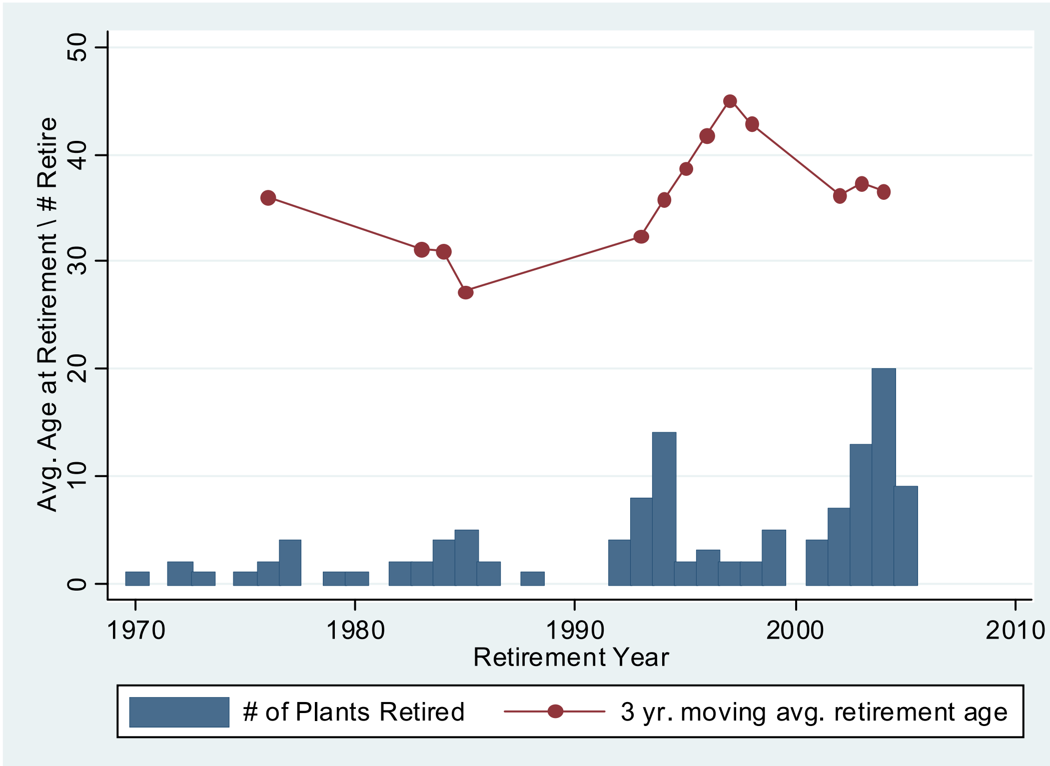

Table 2a: New Unit Capacity (MW) by Attainment for Ozone

Half Decade	Gas		Oil		Coal		% of Counties Non-Attain
	Attain	Non-Attain	Attain	Non-Attain	Attain	Non-Attain	
1978-82	2800	4945	637	3119	46898	9952	20.0%
1983-87	1373	2974	0	0	27022	5812	
1988-92	4594	10935	536	271	5367	4449	11.6%
1993-97	15983	9129	614	168	3610	953	
1998-00	27671	4846	0	0	375	0	6.6%

Table 2b: New Unit Capacity (MW) by Attainment for SOx

Half Decade	Gas		Oil		Coal		% of Counties Non-Attain
	Attain	Non-Attain	Attain	Non-Attain	Attain	Non-Attain	
1978-82	7900	0	3628	129	53486	4710	2.8%
1983-87	4347	0	0	0	32681	153	
1988-92	15529	0	806	0	9746	70	1.8%
1993-97	24779	334	614	168	4563	0	
1998-00	32261	256	0	0	375	0	1.1%

Table 3: Cox Proportional Hazard Models: 1981-2002 Unit Retirements

Sample:	**All Fossil Fuel Units[a]**	**All Fossil Fuel Units[a]**	**Coal Units**
Ozone NA County	3.18**	3.00**	7.55**
	(.58)	(.68)	(2.75)
SO_2 NA County	2.09**	2.84**	6.36**
	(.45)	(.64)	(2.28)
Ozone NA County × Fraction		.57*	.04**
of NA Counties in State		(.17)	(.05)
Age	1.05**	1.05**	1.07
	(.01)	(.01)	(.05)
Size	.994**	.995**	.993
	(.001)	(.001)	(.006)
State Capacity Factor Growth	.26*	.14**	.002
	(.15)	(.08)	(.015)
Observations Used in Estimation	33,507	33,507	18,346
Likelihood Ratio	-934	-766	-192

Table reports hazard ratios (standard errors) from Cox proportional hazard models.
Standard errors adjusted for clustering on a unit.
** denotes a *p*-value of .05 or less for the test: hazard $\text{ratio}_j = 1.00$.
* denotes a *p*-value of .10 or less for the test: hazard $\text{ratio}_j = 1.00$.
[a] Baseline hazard rate allowed to vary by fuel type (coal, gas and oil).
NA stands for Nonattainment.

Table 4a: 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.	
Age *(years)*	20	10	32	10	-14.17
Size *(MW)*	441	255	309	241	6.39
Heat Rate *(mmbtu/kwh)*	11.4	3.4	11.4	4.3	-.05
Capacity Factor	.79	.12	.68	.17	9.34
Temperature	58	8.9	58	6.5	-.08
Divest	.12	.33	.19	.39	-2.31
Lawsuit	.12	.33	.29	.46	-5.73
Phase 1	.26	.44	.33	.47	-1.83
# of units	193		659*		

Table 4b: 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.	
Age *(years)*	23	13	37	14	-28.7
Size *(MW)*	1048	721	904	743	7.08
Heat Rate *(mmbtu/kwh)*	10.6	.86	10.6	1.1	-1.33
Capacity Factor	.64	.15	.53	.18	19.29
Total OM Cost *($ Mill)*	29.6	26.9	18.5	16.4	10.92
Cost of Plant *($ Mill)*	727	556	355	363	13.58
Divest	.14	.35	.21	.41	-4.5
Lawsuit	.10	.31	.21	.41	-9.92
Phase 1	.26	.43	.30	.44	-1.18
# of Plants	77		252		

*6 units in the sample added scrubbers after 1996

Figure 4: Plant Age Distribution – *NotScrubbed* versus *Scrubbed*

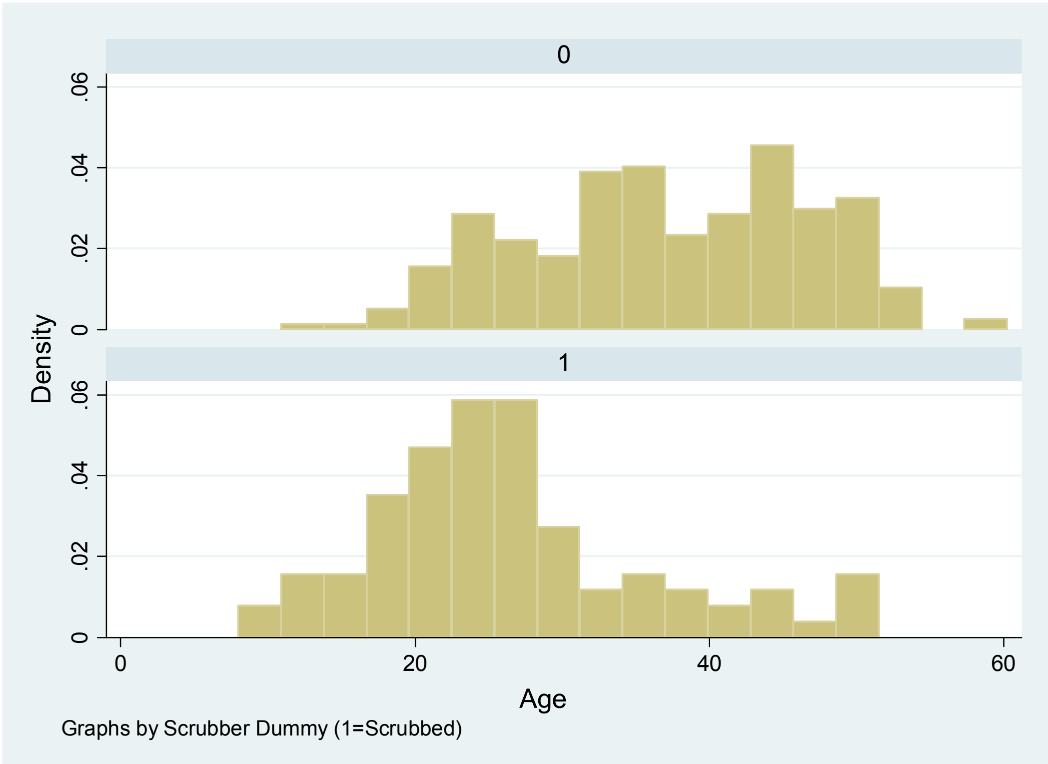

Figure 5: Plant Size Distribution – *NotScrubbed* versus *Scrubbed*

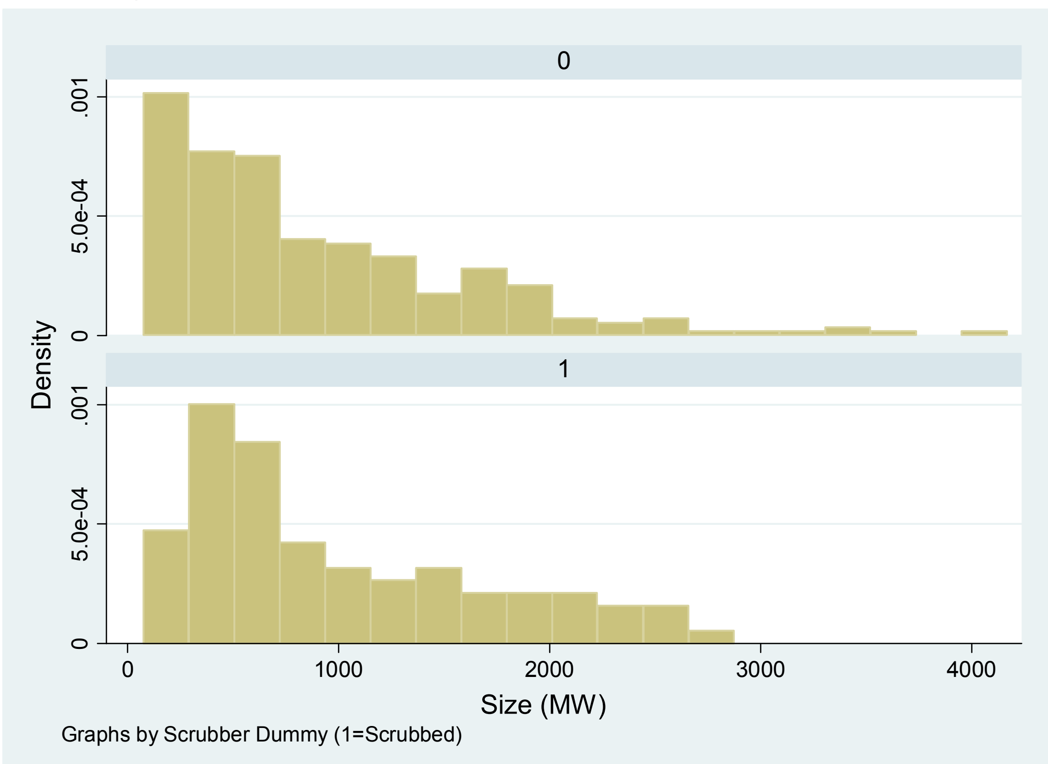

Table 5: Plant Capital – Fixed Effect Method
Dependent Variable: *ln(Total Capital)*

Sample:	All Observations	All Observations	Post FGD Install	Post FGD Install, Phase 2 Plants	Post FGD Install, Phase 2 Plants
NotScrubbed*	0.032	-0.037	-0.012	-0.034	-0.063**
NSR Enforcement Period	(0.031)	(0.035)	(0.020)	(0.022)	(0.028)
NotScrubbed*Post	0.168*	0.079	0.129	0.020	-0.008
NSR Enforcement Period	(0.090)	(0.111)	(0.107)	(0.035)	(0.040)
Scrubber Added After 1997	0.172	0.201	0.200	0.205	0.217
	(0.147)	(0.131)	(0.131)	(0.149)	(0.168)
ln(Output)	0.272***	0.281***	0.277***	0.200**	0.590***
	(0.084)	(0.083)	(0.088)	(0.077)	(0.190)
Estimation Method	OLS	OLS	OLS	OLS	IV
Year Effects Included?	Yes	Yes	Yes	Yes	Yes
Age- & Capacity-Specific Year Effects Included?	No	Yes	Yes	Yes	Yes
Observations	5067	5067	4708	3409	3409
R^2	0.96	0.96	0.97	0.97	

Standard errors adjusted for clustering at the plant level.
* significant at 10%; ** significant at 5%; *** significant at 1%
All specifications include plant fixed effects. Data are annual, plant level observations from 1988-2004.
Instrument for ***ln(Output)***: ***ln(State Sales)***

Figure 6a: Plant Capital – Trends by Plant Category
All Plants, No Controls

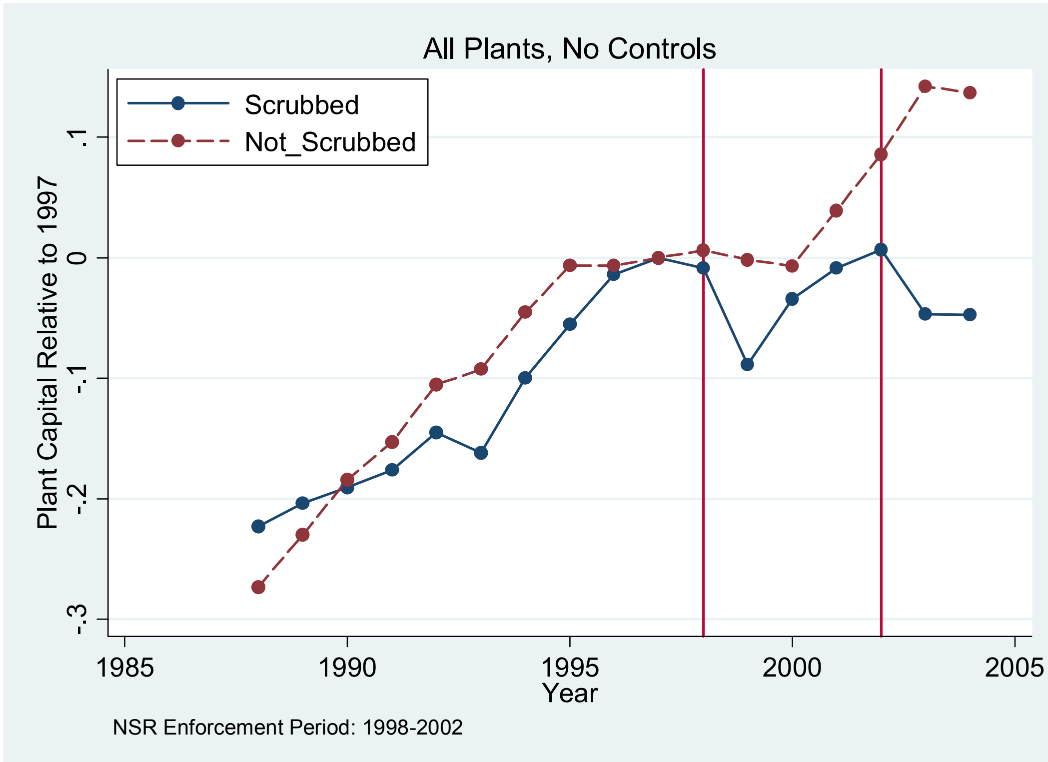

Figure 6b: Plant Capital – Trends by Plant Category
All Plants, Controls for Age- & Size-Specific Trends

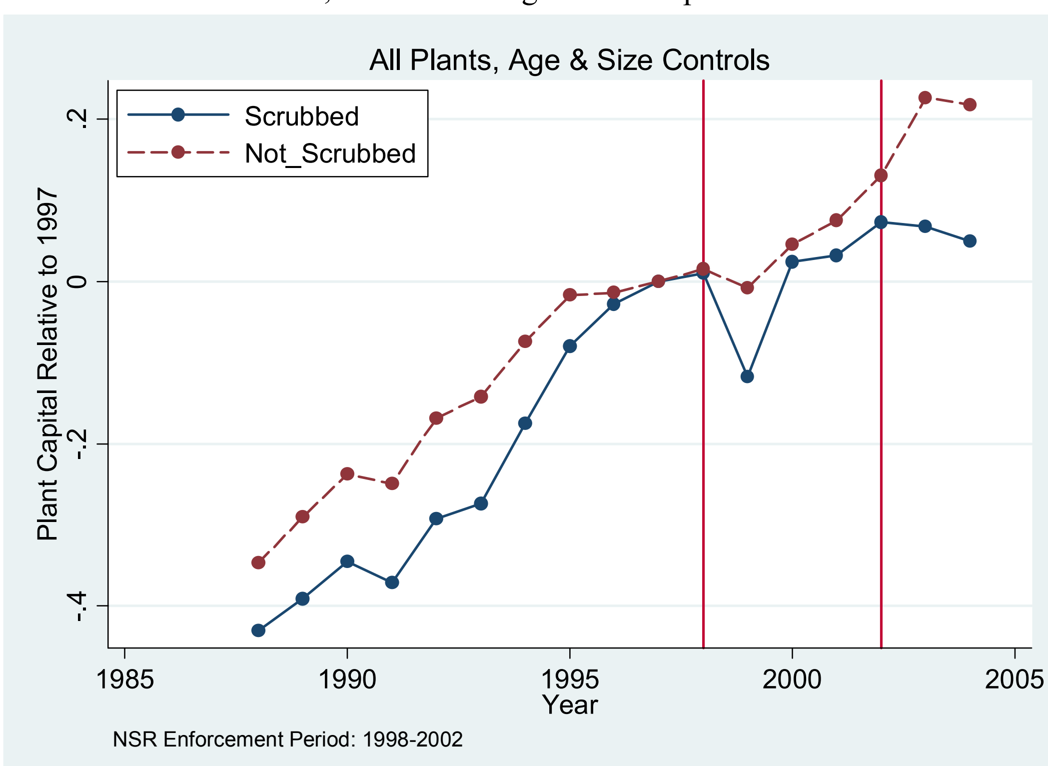

Figure 6c: Plant Capital – Trends by Plant Category

Phase 2 Plants, Post-Installation of FGD, Controls for Age- & Size-Specific Trends

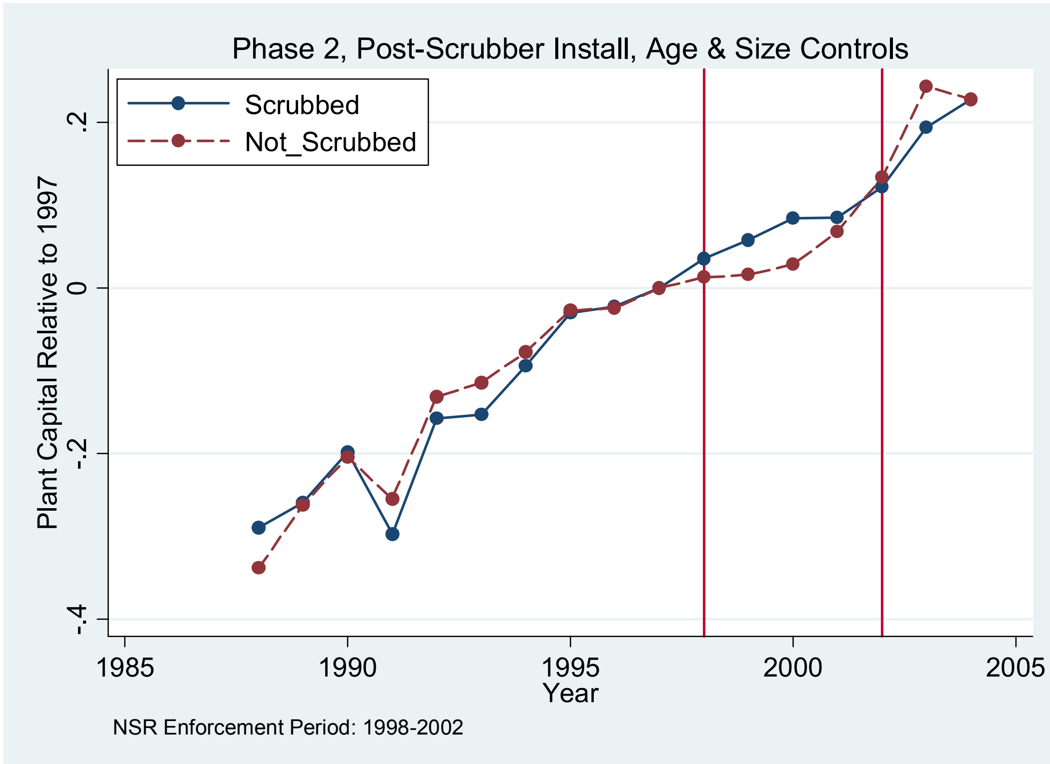

Table 6: Plant Capital – Lagged Controls Method
Dependent Variable: *ln(Total Capital)*

	1998	1999	2000	2001	2002	2003	2004
			All Plants, Post-Scrubber Installation				
NotScrubbed	-0.034**	-0.067	-0.081*	-0.035	0.017	0.093*	0.075
	(0.015)	(0.052)	(0.048)	(0.051)	(0.042)	(0.055)	(0.070)
Observations	255	230	211	201	191	190	163
R^2	.99	0.95	0.96	0.96	0.98	0.96	0.95
			Phase 2 Plants, Post-Scrubber Installation				
NotScrubbed	-0.051***	-0.110*	-0.136**	-0.065	0.024	0.006	-0.010
	(0.017)	(0.058)	(0.056)	(0.061)	(0.052)	(0.046)	(0.062)
Observations	187	168	157	149	141	139	116
R^2	.99	0.96	0.97	0.96	0.97	0.98	0.97

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

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***, $\ln(\text{Total Capital})_{1988} - \ln(\text{Total Capital})_{1997}$, $\ln(\text{Output})_{1988} - \ln(\text{Output})_{1997}$

Table 7: Plant Operations and Maintenance Expenditures – Fixed Effect Method
Dependent Variable: *ln(Total O&M)*

Sample:	All Observations	All Observations	Post FGD Install	Post FGD Install, Phase 2 Plants	Post FGD Install, Phase 2 Plants
NotScrubbed* NSR Enforcement Period	-0.044	-0.026	0.026	-0.018	-0.061
	(0.036)	(0.038)	(0.035)	(0.038)	(0.042)
NotScrubbed*Post NSR Enforcement Period	-0.049	-0.040	0.007	0.048	0.006
	(0.049)	(0.051)	(0.048)	(0.055)	(0.071)
Scrubber Added After 1997	0.005	-0.008	-0.010	-0.036	-0.018
	(0.072)	(0.080)	(0.080)	(0.089)	(0.096)
Ln(Output)	0.393***	0.393***	0.377***	0.362**	0.951***
	(0.122)	(0.122)	(0.132)	(0.173)	(0.233)
Estimation Method	OLS	OLS	OLS	OLS	IV
Year Effects Included?	Yes	Yes	Yes	Yes	Yes
Age- & Capacity-Specific Year Effects Included?	No	Yes	Yes	Yes	Yes
Observations	5067	5067	4708	3409	3409
R^2	0.93	0.93	0.93	0.93	

Standard errors adjusted for clustering at the plant level.
* significant at 10%; ** significant at 5%; *** significant at 1%
All specifications include plant fixed effects. Data are annual, plant level observations from 1988-2004.
Instrument for ***ln(Output)***: ***ln(State Sales)***

Figure 7a: Plant Operations and Maintenance Expenditures – Trends by Plant Category

All Plants, No Controls

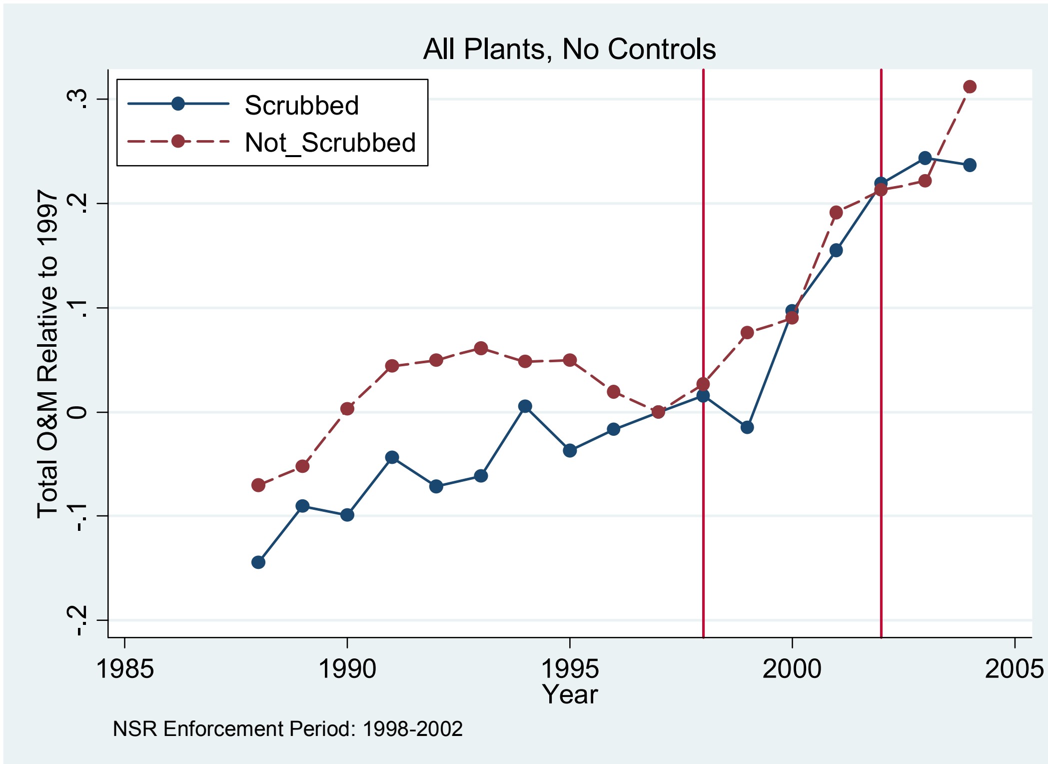

Figure 7b: Plant Operations and Maintenance Expenditures – Trends by Plant Category

All Plants, Controls for Age- & Size-Specific Trends

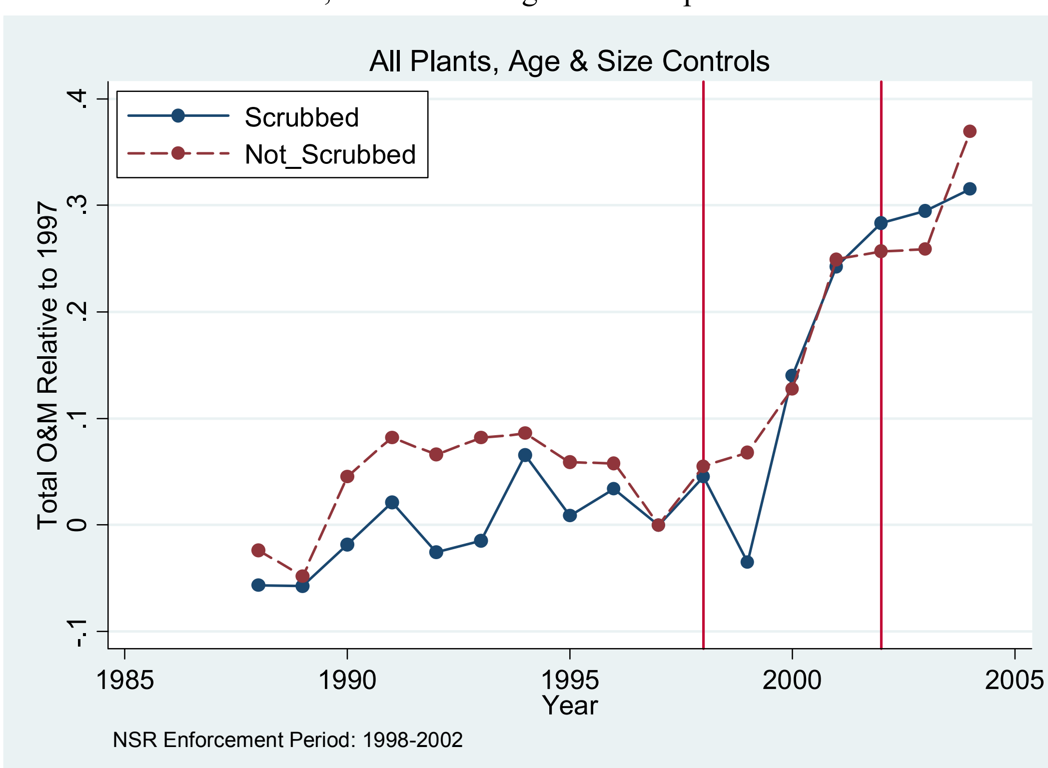

Figure 7c: Plant Operations and Maintenance Expenditures – Trends by Plant Category

Phase 2 Plants, Post-Installation of FGD, Controls for Age- & Size-Specific Trends

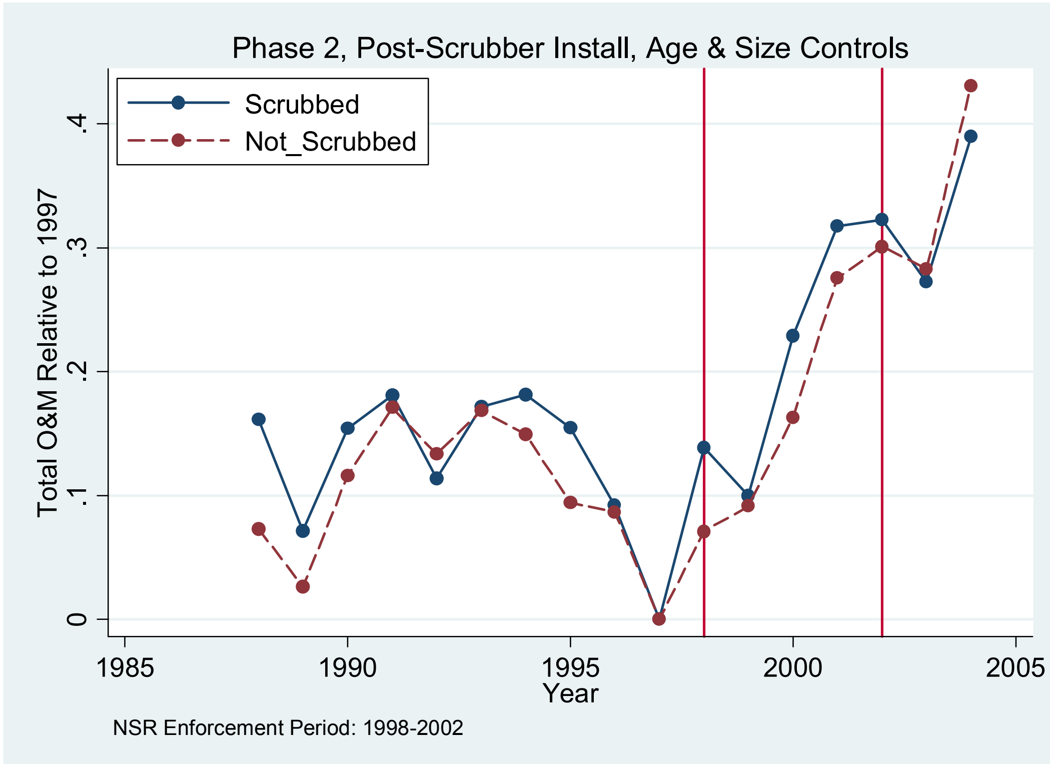

Table 8: Plant Operations and Maintenance Expenditures – Lagged Controls Method
Dependent Variable: *ln(Total O&M)*

	1998	1999	2000	2001	2002	2003	2004
	All Plants, Post-Scrubber Installation						
NotScrubbed	-0.055	0.003	-0.051	-0.130**	-0.155*	-0.008	-0.140**
	(0.042)	(0.047)	(0.054)	(0.057)	(0.085)	(0.096)	(0.069)
Observations	255	230	211	201	191	190	163
R^2	0.95	0.94	0.95	0.94	0.90	0.88	0.94
	Phase 2 Plants, Post-Scrubber Installation						
NotScrubbed	-0.085*	-0.035	-0.094	-0.116*	-0.082	0.024	-0.090
	(0.044)	(0.049)	(0.057)	(0.061)	(0.092)	(0.115)	(0.076)
Observations	187	168	157	149	141	139	116
R^2	0.96	0.95	0.95	0.95	0.91	0.87	0.94

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

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 O&M)$_{1988}$ - ln(Total O&M)$_{1997}$***, ***ln(Output)$_{1988}$ - ln(Output)$_{1997}$***

Table 9: Plant Heat Rates – Fixed Effect Method
Dependent Variable: *ln(Heat Rate)*

Sample:	All Observations	All Observations	Post FGD Install, Phase 2 Plants	Post FGD Install, Phase 2 Plants
NotScrubbed*	-0.009	-0.005	<0.001	0.001
NSR Enforcement Period	(0.006)	(0.007)	(0.008)	(0.008)
NotScrubbed*Post	-0.005	-0.003	0.008	0.013
NSR Enforcement Period	(0.009)	(0.010)	(0.012)	(0.012)
Scrubber Added After 1997	-0.008	-0.007	-0.028	-0.031
	(0.018)	(0.019)	(0.023)	(0.024)
ln(Output)	-0.308***	-0.308***	-0.322***	-0.202***
	(0.013)	(0.013)	(0.016)	(0.017)
Temperature	0.006	0.006	0.010*	0.013**
	(0.004)	(0.004)	(0.005)	(0.005)
Estimation Method	OLS	OLS	OLS	IV
Year Effects Included?	Yes	Yes	Yes	Yes
Age- & Capacity-Specific Year Effects Included?	No	Yes	Yes	Yes
Observations	344,224	344,224	226,675	226,675
R^2	0.48	0.48	0.52	

Standard errors adjusted for clustering at the plant level.
* significant at 10%; ** significant at 5%; *** significant at 1%
All specifications include unit fixed effects. Data are weekly, unit level observations from 1996-2004.
Instrument for ***ln(Output)***: ***ln(State Sales)***

Figure 8: Unit Heat Rates – Trends by Unit Category

Phase 2 Plants, Post-Installation of FGD, Controls for Age- & Size-Specific Trends