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

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Abstract

This paper analyzes the effects of the New Source Review (NSR) environmental regulations on coal-fired electric power plants. 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 evidence that the risk of NSR enforcement reduced capital expenditures at plants. However, we find no discernable effect on the operating costs, fuel efficiency or operating lifetimes of these plants.

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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 costly 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 for 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. Exactly what type of control equipment they are 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 was subject to debate. Sparring over the application of the retrofitting requirement 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 coal-fired electric generating units. Coal units are subject to far more expensive pollution control standards than are oil and gas plants, and we show that the lives of coal plants extended significantly in the 1990s. We next compare retirements across units located in areas where the pollution control requirements for new plants are more and less stringent and find no evidence that units in the more stringent areas have lower propensities to retire. As we discuss below, neither comparison provides a perfect test of whether NSR caused utilities to keep units open longer than they otherwise would have, although the second test applies under slightly less restrictive assumptions than the first. We are left concluding that the evidence of an effect on retirements is inconclusive.

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 units reduced their capital expenditures more than the control plants, but no 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 NSR has had. Generally, the existing empirical evidence of its effects is dated and uses less clean tests than we propose. 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.\footnote{See Ellerman and Joskow (2000).} 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 1970’s, however, less progress than was expected was made toward achieving the ambient air-quality goals established in the 1970 amendments.

Partially in reaction to frustrations over this lack of progress, the 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 SO2. In
addition to limiting the maximum emission of SO₂, the 1977 amendments required specific levels of post-combustion removal of the pollutant. The requirement for removal effectively mandated the use of flue gas 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 1990’s 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 as far as 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]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.

²A background paper by EPA, EPA (2001), describes the history and controversy surrounding NSR enforcement.
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.” 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.” 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 that NSR was “the greatest current barrier to increased efficiency at existing units.”

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

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3Utility Air Regulatory Group, 2001
4UARG, 2001
5NCC 2000
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.”

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 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.

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6EPA, 2002
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 (2005), 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 1970's in regions with more stringent SO2 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. Both of these studies use indirect measures of local regulatory conditions, such as the budgets of the local regulatory agencies, rather than more direct measures such as the attainment status of the region, which have only more recently become available.

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 has been driven by the belief that the enforcement of NSR has negatively impacted productivity. List, Millmet, and McHone (2004) 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 SO2 in the case of electric utilities. The 1977 amendments effectively mandated scrubbers on new coal plants. For coal plants, this appears to have 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. 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 SO2.

The 1990 amendments established a market for SO2 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 SO2 emissions. Thus during the 1990’s the variation in compliance with SO2 standards decreased and the new source bias towards older plants was reduced, at least with respect to SO2 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 utilization. We then turn to the potential impact of the change in EPA’s enforcement of NSR on the operations of existing power plants.

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8ICF 2001
3 The Effects of NSR on Unit Retirements

One of the main distortions attributed to vintage differentiated regulations is that old, grandfa-
thered units are kept in service longer than they would absent the regulation since replacing them
with a new unit becomes more expensive. In addition, old units may be run more intensively
then they otherwise would since new units have pollution abatement technology which imposes
an additional variable cost. This section attempts to assess the impact NSR has had on retire-
ments. The following section takes up the impact of NSR on unit capacity factors, as the data
and identification issues are related to our analysis of plant operating efficiency.

Most of the vintage differentiated regulation literature has demonstrated this 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.

Electric utilities operated as franchise monopolies and were subject to cost-of-service regula-
tion for most of the period we study, so a model based on perfect competition with free entry
has limited relevance to our setting. 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 distortions in retirement decisions. If firms were perfectly compensated
for the cost of new capacity regardless of whether it had pollution control equipment, their deci-
sions about when to install new capacity and would be unaffected by the regulations. However,
there are 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 when 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. This company must have capacity to supply peak demand, so its only decision is whether to keep its old capacity around or retire it and replace it with new capacity. Also assume that operating costs for either type of capacity are monotonically increasing over time. Without a rate case, revenue will be essentially constant, so the utility would pick the optimal way to supply the peak demand by comparing $R - C^G(t)$ to $R - C^N(1)$ in every period, where $C^i(t)$ capture the costs of running plant $i$ for one year over year $t$ of the unit’s life, $i \in \{G, N\}$ where $G$ indexes a grandfathered plant and $N$ a new plant. The utility will operate the capacity with the highest net margin (lowest costs). 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 and build new plants later than they otherwise would have. Put another way, the time $T$ at which $R - C^G(T) = R - C^N(1)$ exactly, is higher.

The second reason the 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.

We would like to be able to identify what a unit’s age at retirement would have been absent NSR ($T_{\text{NoNSR}}$) and compare it to the actual age at retirement. The difference ($T_{\text{Actual}} - T_{\text{NoNSR}}$) would measure how much longer units are kept in service because of NSR. To obtain $T_{\text{NoNSR}}$ we would need to isolate the component of the new unit costs attributable to the pollution control equipment. To make this clear, decompose $C^N$ as follows: $C^N = C^N + C^P$ where $C^P$ measures
the costs due to pollution control equipment.\textsuperscript{9} While $C^N$ may be higher than it otherwise would have been absent the environmental restrictions, it still may be lower than $C^G$ due to technological progress in other areas. Ideally, we would like to observe unit retirements in an environment where new plants only faced costs associated with $C^N$. What we can do instead is compare retirements across environments where the pollution control costs vary. We would expect to see retirements later the higher the pollution control costs are for replacement plants, and any difference across areas with high pollution control costs and areas with low pollution control costs provides a lower bound on $T^{Actual} - T^{NoNSR}$.

\section*{3.1 Retirements over Time}

We have developed a detailed data base of fossil fuel unit retirements since the 1970s.\textsuperscript{10} We focus on fossil-fuel powered plants as nuclear and hydroelectric plants are subject to very different environmental regulations. To get a sense for the general patterns in retirements since 1970, Figures 1-3 plot the average age at retirement for coal-, oil- and gas-fired unit by retirement year since 1970. As Figures 1-3 demonstrate, coal units are retiring later, while the age at retirement for gas and oil units has remained virtually unchanged since the 1970s.

One, extremely rough, approach to identifying $T^{NoNSR}$ 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 than 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 $T^{Actual} - T^{NoNSR}$. These are unrealistic assumptions, but it is useful to present the data, in part since this comparison may be what is informing public opinion about an NSR effect.

To parametrize the patterns depicted in Figures 1-3, we estimated a simple OLS regression of

\textsuperscript{9}To avoid clutter, we drop the t indexes. The effects we’re describing apply for all t.

\textsuperscript{10}The data are described in the Appendix. We are in the process of extending the data base further back in time and verifying its comprehensiveness for the early years.
the age at retirement on a third-order polynomial trend, a dummy equal to one if the retiring unit was a coal unit, a dummy equal to one for all years after 1978 (when the more stringent scrubber requirements for new coal units was implemented) and a dummy equal to one for coal units retired after 1978. The value of the coal dummy was 16.9 (standard error, adjusted for clustering at the state level = 6.5), suggesting that between 1970 and 2004, coal units had much longer lives than oil or gas units. The value of the dummy for coal units after 1978 was negative, but small and statistically indistinguishable from zero ($\beta = -4.0$, se = 7.2). A similar specification with a dummy equal to one for all years after 1990 (replacing the post-1978 dummy) and the post-1990 dummy interacted with the coal dummy showed that coal units retired in the 1990s were on average 11.4 years older than coal units retired before 1990 (se=5.1), controlling for the common fossil fuel trend. A similar regression with state fixed effects yielded a very similar coefficient on the coal dummy interacted with the post-1990 dummy ($\beta = 12.1$, se = 4.6). To attribute this increase to NSR, one would need to appeal to a heightened awareness of the regulations caused by the WEPCo case. Of course, many other factors could explain the shift.

3.2 Retirements by Local Attainment Status

The general patterns in retirements plotted in Figures 1 to 3 do not control for any other factors that could impact a utility’s decision to retire capacity. This section estimates hazard models of retirements on a smaller subset of data for which we have more information on unit-level covariates, as well as a more comprehensive picture of the universe of units in service (retirements from 1990-2003) in any given year. We model the retirement decision as a function of additional variables both as controls and because one covariate, the attainment status of the county in which a unit is located, could potentially help us identify an NSR effect on retirements. Because new plants built in non-attainment counties needed to install more expensive pollution control equipment, an old plant may be more valuable in that county.

Attainment status could identify an NSR effect under several strong, though not implausible assumptions. First, we need to assume that there was some inherent value to having a unit in
a non-attainment county. This could be true if, for instance, the transmission grid had been upgraded to get power from that location or because the location were close to load, close to cooling water, close to a natural gas pipeline, etc. Then, if that unit retires, building a new unit either requires building a unit in a less desirable location or building a unit in the same location. We also assume that all retired units will be replaced by natural gas- or oil-fired units, since the new source requirements for coal units did not vary by attainment status.

We have to be careful about how we measure the local attainment status, as the retirement of a large electric generating unit could push a county into attainment. To avoid potential reserve causality problems, we measured attainment status before the period of the retirements. For now, we only have attainment status from 1990, so we limit our analysis to the retirements depicted in Figures 1-3 that occurred after 1990.\footnote{Also, the data on the units in service is only complete in our data set after 1988.}

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

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h(t, X_{it}, \beta, \mu_{it}) = \Pr(\text{unitiretiresinyear}|\text{unitistillinserviceinyear} - 1) = h_0(t) * \exp(\beta_0 + \beta_1 \text{County}_{it} + \text{OnlineYear}_{it} + \beta_2 \text{Size}_{it} + \beta_3 \text{StateReserveMargin}_{it} + \epsilon_{it})
\]

where \(i\) indexes a unit and \(t\) a year. We estimate Cox proportional hazard models that allow the baseline hazard \(h_0(t)\) to vary non-parametrically over time. In some specifications, we estimate different baseline hazards for plants of different fuel types.

Results from estimating the hazard model are presented in Table 1.\footnote{Future versions of the paper will report the expected survival times by fuel type in order to assess the extent to which controlling for the covariates in the hazard models alters the patterns depicted in Figures 1-3.} The first column reports results estimated on coal, oil and gas units together, although the baseline hazards are allowed to vary by fuel type, while the second through fourth columns report results for just coal, just oil
and just gas units, respectively. The table reports hazard ratios \( \exp(X'\beta) \) and asterix indicate results that are statistically distinguishable from one at the five percent level.

The main message from these specifications is that units are if anything more likely to retire in non-attainment counties rather than less likely, as the theory of an NSR effect would suggest. While the results are based on a short time period, which we hope to extend, and are noisy when we break them out by unit, the estimated hazard ratio for \( NonattainmentCounty \) in column 1 is considerably greater than 1, and the null hypothesis that it is equal to one is easily rejected. The coefficient estimate suggest that units in non-attainment areas are nearly three times as likely to retire. When we break out the specification by unit type, we see that most of the effect for coal units works through the SO2 non-attainment counties, while most of the effect for gas units works through ozone non-attainment counties. These results could suggest that state and local level negotiations designed to bring counties into attainment are able to overcome utility companies’ incentives to keep plants in non-attainment areas open.

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 asses 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 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 it 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 were required to mitigate multiple pollutants, including nitrous oxides (NOx), sulfur dioxide (SO2) and particulates. By far the most expensive type of pollution control technology for a new coal unit was the flue gas desulfurization device (also called a scrubber) required to remove SO2. Industry estimates suggest that installing and operating a scrubber was ten times more expensive than the comparable costs for the most expensive type of pollution control equipment required to remove NOx (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 SO2 has been scrubbers since at least 1984.\textsuperscript{13} For these reasons, our baseline specifications characterize plants that had scrubbers installed (i.e. were Scrubbed) 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.\textsuperscript{14}

\textsuperscript{13}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.

\textsuperscript{14}To address concerns that units with old scrubbers feared that triggering NSR would require an expensive upgrade to their scrubbing equipment, we will compare scrubbed and not scrubbed plants by age. Unfortunately, the data we have on the date when the scrubber was installed is poor.
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 2 compares unit characteristics across scrubbed and non-scrubbed units. 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 plants have fewer useful years over which to spread the costs.\textsuperscript{15} Also, the scrubber fixed costs may not scale with plant size, so the smaller plants can spread the fixed cost over less output. We attempt to address the differences in the specifications below by including third-order polynomials in age and capacity during the treatment period as control variables.

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 $\ln(\text{HeatRate})$ on a third-order polynomial in age and a third-order polynomial in size plus the *Scrubbed* dummy, the coefficient on the *Scrubbed* is $-.021$ (se = .011). 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 $0.063$ (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 include a dummy variable equal to one after the sale if a unit is divested.

One check on the assumption that *Scrubbed* units were not at risk of triggering NSR enforcement 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 frequently in our data there are plants where only a fraction of the units have scrubbers installed. Nevertheless, units with scrubbers were less likely to be at plants named

\textsuperscript{15}Figure 4 plots the fraction of units with scrubbers by installation year.
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 one way in which the existence of a scrubber could be correlated with changes in fuel efficiency during the particular period we consider. The Clean Air Act Amendments of 1990 created a market for permits for the right to emit SO2. 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 actions the Phase 1 plants took post-1995 to reduce their SO2 emissions impacted their heat rates. Thirteen of the Phase 1 units were required to install scrubbers, but many of the remaining plants reduced SO2 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 real productivity. 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:

\[ Q_{it} = f (\text{Fuel}_{it}, \text{Labor}_{it}, \text{Materials}_{it}, \text{Capital}_{it}, \epsilon_{it}) \] (2)

for unit \( i \) in time period \( t \), where \( Q \) measures electrical output and \( \text{Fuel}, \text{Labor}, \text{Materials} \) and \( \text{Capital} \) capture the important input categories. For several reasons, we chose not to take this approach and instead estimate reduced-form factor-demand equations of the following form:
\[
\ln (I_{it}) = \beta_1 \ln (Q_{it}) + \beta_2 AtRisk * NSREnforcementPeriod_{it} \\
+ \beta_3 X_{it} + \kappa_t + \mu_i + \varepsilon_{it}
\]

for unit or plant \(i\) in period \(t\) where \(I\) indexes the input category, \(Q\) is output of the plant, \(AtRisk * NSREnforcement\) is a dummy variable equal to one during the enforcement period for \(AtRisk\) units, \(X_{it}\) is a set of control variables. For inputs, we consider fuel as well as capital and operations and maintenance (O&M) expenditures.\(^{16}\) For consistency with the industry standard for describing fuel use, we divide \(Fuel\) by \(Q\) and use the \(HeatRate\)—the inverse of fuel efficiency.

The set of controls, the granularity with which we observe input use (\(i.e.,\) what \(t\) measures), and the unit of observation (\(i.e.,\) what \(i\) measures, plant or 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 or cooling tower.

We estimate factor demand equations for several reasons. First, the arguments that enforcement effects have impacted power plant efficiency suggest 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 \(AtRisk\) plants during the NSR enforcement episodes might show a reduction in technical efficiency (assuming they had been optimizing their input mix before the enforcement episode), we are interested in dissecting the use of individual inputs. Second, 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 and most capital expenditures, the negative effects on fuel efficiency may not show up in the year when the maintenance is deferred.\(^{16}\)

\(^{16}\)We consider expenditures and not quantities because there is 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 (\(\kappa_t\)) pick up trends in prices.
To identify the effects of NSR enforcement, we use data on nearly 900 coal generating units housed at nearly 250 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. Several sources of variation in the data help us identify an NSR effect. For all specifications, we include fixed-effects at either the unit or the plant level. These help control for a whole set of time-invariant unit-specific factors including a unit’s technological configurations, age, manufacturer, etc. We then compare the average input use at AtRisk plants during the period of heightened NSR enforcement to the average input use at plants NotAtRisk, controlling for $Q$, $X$ and an average unit effect. Changes in input use at units that are NotAtRisk can help us control for industry-wide trends.

One issue we confront in estimating (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.\footnote{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 (2003) compares and critiques the approaches proposed by them. Markiewicz, Rose and Wolfram (2005) addresses the simultaneity problem by instrumenting.} 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.

## 5 Unit Operation Results

This section presents the results from estimating equation (3). Because the data sets and control variables differ across fuel and non-fuel input categories, we consider the two types of results separately.
5.1 Nonfuel Operating and Capital Expenditures

To examine the impact of NSR on non-fuel plant expenditures, we utilize data taken from the Federal Energy Regulatory Commission’s (FERC) Form 1. All investor-owned utilities are required to report various financial and plant operating statistics annually to the FERC. Many of these statistics are reported in the form 1 data set. Unlike the heat rate analysis described below, these data are reported at the plant, rather than unit level. There are 349 coal-fired steam plants represented in our data sample. Data are 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 focus on two components of the Form 1 data: the total cost of plant, which is the aggregate depreciated value of land, buildings, and machinery for each plant, and total operating and maintenance expenses, which comprise the bulk of non-fuel operating expenditures at power plants. The total cost of plant is a measure of the total book value of a plant, so we are interested in the changes in this level relative to the average for the plant over our sample. For each of these variables we estimate the impact of NSR enforcement risk using equation (3).

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 at plant ‘with’ FGD as one in which the capacity weighted average of the scrubbed units at the plant is greater than .5. In other words, a plant is treated as more at risk for NSR enforcement if less than half its units have FGD. Similar aggregation is performed to separate “old”, “new” and “Phase 1” plants. A plant’s age is defined as the capacity weighted average age of its component units.

Tables 3a and 3b report results from estimating equation (3) using the log of total operating and maintenance expenditures as the dependent variable ($\ln(\text{TotalO&M})$). Each specification includes plant fixed effects, year fixed effects and third-order polynomials in $\text{Size}$.

\footnote{The distribution is highly skewed towards either 1 (all scrubbed) or 0 (no units scrubbed). Out of 349 plants in our sample, less than 1/3 (107) have any units with scrubbers. Of those, 78 plants are fully scrubbed, and 11 more have a capacity weighted average between .5 and 1.}
ENFORCEMENT and OnlineYear * NSREnforcement. Since, as Table 2 suggests, units with scrubbers are much bigger and newer, the polynomials are included to try to allow for different changes over time for plants by size and age. Table 3a report OLS results while Table 3b reports results where we instrument for plant output using ln(StateSales). Generally, instrumenting tends to increase the coefficient on ln(Output). Though this is the opposite of what we would expect given the typical description of the endogeneity of output, it makes sense in the case of power plants. Because the boiler must be off in order to perform maintenance, O&M expenditures are likely to increase in years when the plant is offline for longer. Instrumenting for ln(Output) helps us isolate the changes in expenditures due to increased output driven by increases in state level demand which is for the most part independent of maintenance outages at a particular plant.

Across both tables, the coefficients on NotScrubbed * NSREnforcement are small and statistically indistinguishable from zero. The coefficients also change signs across the sub-samples of plants under consideration. Figure 5 plots the year effects for both Scrubbed and NotScrubbed plants from an OLS specification similar to equation (3) that did not include the third-order polynomials. The two types of plants do seem to differ from one another beginning in 1997, suggesting that controlling for the effects by age and size are important to the insignificant results in the tables.

Tables 4a and 4b present similar specifications for the capital expenditures. Here, unlike with the O&M specifications, there appears to be evidence that utilities scaled back their capital spending in the face of NSR. The coefficients on NotScrubbed * NSREnforcement are all negative and statistically different from zero for the full set of plants. The coefficient from the instrumented set of results suggest that plants at risk of triggering NSR reduced capital expenditures by 9% (se=4%). The results are negative but very imprecisely estimated for the small set of plants where most units are new and negative and statistically different from zero for the set of plants where most units are old. When we limit the analysis to the set of plants that have

\[\text{Figure 6 plots the year effects for Scrubbed and NotScrubbed plants.}\]
mostly Phase 2 units, the coefficient estimate is lower than for all of the units, suggesting that
Phase 1 units with scrubbers increased capital expenditures after 1995 or that Phase 2 units
without scrubbers increased capital spending after 2000. Future work will try to unpack these
effects.

5.2 Fuel Efficiency

The data we use to estimate equation (3) for fuel inputs are available with much finer disaggre-
gation than the 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.20
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.

Tables 5a and 5b, which report the fuel efficiency results, are organized in the same format
as Tables 3a-4b, reporting OLS results in Table 5a and results that instrument for output in
Table 5b. In the case of fuel efficiency, instrumenting has the expected effect and dampens
its relationship with output. The variable of interest is small and statistically indistinguishable
from zero in all specifications, and is quite precisely estimated. We can reject the hypothesis that
AtRisk units heat rates increased (i.e., fuel efficiency decreased) by 1% in every specification
except the OLS specification for new units.

To evaluate the possibility that the effect of the delayed capital expenditures impacted heat
rates with some delay, we also estimated specifications that included a variable interacting

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20In 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.
NotScrubbed * NSREnforcement with a time trend. The coefficient on this variable was also small and statistically indistinguishable from zero, suggesting that at least between 1998 and 2002, there was no gradual degradation in fuel efficiency.

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 inconclusive: coal-fired electric generating units do seem to have retired at older ages compared to oil and gas fired plants in the 1990s. However, comparing retirements across non-attainment and attainment counties suggests that, if anything, units in non-attainment counties, where the regulations for new plants are more stringent, are more likely to retire. We find some evidence suggesting that utilities invested less capital in units at risk of triggering NSR, but no evidence that they spent less on operations and maintenance at these units. Similarly, at risk units showed no worse efficiency improvements than the control group over the period when NSR enforcement was at its height.

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 SO2 permits available nationwide, so if the EPA took steps to require the older plants to install scrubbers, this would just mean that those plants could sell their permits and other plants could increase their emissions of SO2.

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 hugely 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.
References


Data Appendix

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

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 in which it is located.

Annual Operations and Maintenance Expenditures

PowerDat collects information on annual plant-level expenditures from the FERC Form 1s filed by utilities.

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. These data report the monthly minimum, maximum, mean, and standard deviation of load by utility, as well as the average daily maximum over a month. Platts compiles this information from survey data collected by the EIA and reported in its form 714.

Unit Characteristics

Unit characteristics are taken from the “Base Generating Units” and “Estimated Fossil-Fired Operations” data sets within BaseCase.

We merged data from BaseCase to several additional sources.

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 discrepancies 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

We obtained county-level SO2, ozone and NO2 attainment data was obtained from Title 40, Part 81 of the Code of Federal Regulations dated July 1, 1990. We characterized a county as nonattainment if any part of the county was out of attainment.
Figure 1: Coal Unit Retirement Age by Retirement Year

Symbol size proportional to total capacity retired.

Figure 2: Oil Unit Retirement Age by Retirement Year

Symbol size proportional to total capacity retired.
Figure 3: Gas Unit Retirement Age by Retirement Year

Symbol size proportional to total capacity retired.
Table 1: Cox Proportional Hazard Models: 1990-2003 Retirements

<table>
<thead>
<tr>
<th>Sample:</th>
<th>All Fossil Fuel Units&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Coal Units</th>
<th>Oil Units</th>
<th>Gas Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonattainment County</td>
<td>2.15* (0.42)</td>
<td>0.73 (.47)</td>
<td>0.92 (.38)</td>
<td>2.85* (.65)</td>
</tr>
<tr>
<td>SO&lt;sub&gt;2&lt;/sub&gt; Nonattainment County</td>
<td>1.37 (.39)</td>
<td>14.3* (10.5)</td>
<td>1.39 (1.09)</td>
<td>0.65 (1.09)</td>
</tr>
<tr>
<td>Age</td>
<td>1.04* (.006)</td>
<td>1.11* (.05)</td>
<td>1.13* (.02)</td>
<td>1.03* (.006)</td>
</tr>
<tr>
<td>Size</td>
<td>0.996* (.001)</td>
<td>0.993 (.002)</td>
<td>0.999 (.001)</td>
<td>0.996 (.001)</td>
</tr>
<tr>
<td>State Capacity Factor</td>
<td>3.27* (1.17)</td>
<td>0.09 (.17)</td>
<td>0.94 (1.20)</td>
<td>3.54* (1.14)</td>
</tr>
<tr>
<td>Observations Used in Estimation</td>
<td>20,727</td>
<td>8,324</td>
<td>1,964</td>
<td>10,439</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>-970</td>
<td>-114</td>
<td>-116</td>
<td>-718</td>
</tr>
</tbody>
</table>

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 ratio<sub>j</sub> = 1.00.

<sup>a</sup> Baseline hazard rate allowed to vary by fuel type (coal, gas and oil).
Table 2: Summary of Data for Units Larger Than 70 MW, 1996  
Scrubbed versus Not Scrubbed

<table>
<thead>
<tr>
<th>Variable</th>
<th>Scrubbed</th>
<th></th>
<th>Not Scrubbed</th>
<th></th>
<th>T-statistic for Difference in Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>20</td>
<td>10</td>
<td>32</td>
<td>10</td>
<td>-13.7</td>
</tr>
<tr>
<td>Size (MW)</td>
<td>433</td>
<td>256</td>
<td>310</td>
<td>242</td>
<td>5.97</td>
</tr>
<tr>
<td>Heat Rate (mmbrtu/kwh)</td>
<td>11.4</td>
<td>3.4</td>
<td>11.4</td>
<td>4.3</td>
<td>-0.04</td>
</tr>
<tr>
<td>Capacity Factor</td>
<td>.79</td>
<td>.12</td>
<td>.68</td>
<td>.17</td>
<td>9.74</td>
</tr>
<tr>
<td>Temperature</td>
<td>58</td>
<td>8.8</td>
<td>58</td>
<td>6.5</td>
<td>-.25</td>
</tr>
<tr>
<td>Divest</td>
<td>.12</td>
<td>.32</td>
<td>.19</td>
<td>.39</td>
<td>-2.55</td>
</tr>
<tr>
<td>Lawsuit</td>
<td>.12</td>
<td>.32</td>
<td>.30</td>
<td>.46</td>
<td>6.03</td>
</tr>
<tr>
<td>Phase 1</td>
<td>.25</td>
<td>.43</td>
<td>.33</td>
<td>.47</td>
<td>2.17</td>
</tr>
<tr>
<td># of units</td>
<td>199</td>
<td></td>
<td>653</td>
<td></td>
<td></td>
</tr>
<tr>
<td># of observations</td>
<td>86,994</td>
<td></td>
<td>277,060</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 4: Fraction of Units with Scrubbers by Installation Year

Symbol size proportional to total number of units installed. Obs. grouped by half-decade.
Figure 5: Trends in Fixed O & M by Plant Category

Figure 6: Trends in Total Cost of Plant by Plant Category
### Table 3a: Operating and Maintenance Expenses
**Dependent Variable: \( \ln(\text{Total O&M}) \)**

<table>
<thead>
<tr>
<th>Sample:</th>
<th>All Plants</th>
<th>Mainly New Plants Only</th>
<th>Mainly Old Plants Only</th>
<th>Mainly Phase 2 Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{NotScrubbed}^* )</td>
<td>0.021</td>
<td>-0.014</td>
<td>0.021</td>
<td>0.021</td>
</tr>
<tr>
<td>(0.035)</td>
<td>(0.055)</td>
<td>(0.045)</td>
<td>(0.036)</td>
<td></td>
</tr>
<tr>
<td>( \ln(\text{Output}) )</td>
<td>0.232***</td>
<td>0.718**</td>
<td>0.118***</td>
<td>0.268***</td>
</tr>
<tr>
<td>(0.069)</td>
<td>(0.283)</td>
<td>(0.037)</td>
<td>(0.082)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>5278</td>
<td>1301</td>
<td>3977</td>
<td>3764</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.92</td>
<td>0.90</td>
<td>0.94</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Standard errors adjusted for clustering at the plant level.
* significant at 10%; ** significant at 5%; *** significant at 1%
All specifications include plant fixed effects, year fixed effects and third-order polynomials in \( \text{Size} \)*\( \text{NSR Enforcement} \) and \( \text{Online Year} \)*\( \text{NSR Enforcement} \).
Data are annual, plant level observations from 1988-2003.

### Table 3b: Operating and Maintenance Expenses - IV
**Dependent Variable: \( \ln(\text{Total O&M}) \)**

<table>
<thead>
<tr>
<th>Sample:</th>
<th>All Plants</th>
<th>Mainly New Plants Only</th>
<th>Mainly Old Plants Only</th>
<th>Mainly Phase 2 Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{NotScrubbed}^* )</td>
<td>-0.012</td>
<td>-0.029</td>
<td>0.014</td>
<td>-0.038</td>
</tr>
<tr>
<td>(0.048)</td>
<td>(0.058)</td>
<td>(0.075)</td>
<td>(0.040)</td>
<td></td>
</tr>
<tr>
<td>( \ln(\text{Output}) )</td>
<td>0.774***</td>
<td>0.688</td>
<td>0.805***</td>
<td>0.805***</td>
</tr>
<tr>
<td>(0.142)</td>
<td>(0.428)</td>
<td>(0.153)</td>
<td>(0.157)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>5081</td>
<td>1251</td>
<td>3830</td>
<td>3627</td>
</tr>
</tbody>
</table>

See notes for Table 3a.
Instrument for \( \ln(\text{Output}) \): \( \ln(\text{State Sales}) \).
### Table 4a: Total Capital Cost of Plant
Dependent Variable: $\ln(\text{Total Cost of Plant})$

<table>
<thead>
<tr>
<th>Sample:</th>
<th>All Plants</th>
<th>Mainly New Plants Only</th>
<th>Mainly Old Plants Only</th>
<th>Mainly Phase2 Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{NotScrubbed}^\ast$</td>
<td>-0.067**</td>
<td>-0.023</td>
<td>-0.089**</td>
<td>-0.028</td>
</tr>
<tr>
<td>$\text{NSR Enforcement}$</td>
<td>(0.026)</td>
<td>(0.015)</td>
<td>(0.038)</td>
<td>(0.021)</td>
</tr>
<tr>
<td>$\ln(\text{Output})$</td>
<td>0.102***</td>
<td>0.094</td>
<td>0.106**</td>
<td>0.107**</td>
</tr>
<tr>
<td>(0.037)</td>
<td>(0.067)</td>
<td>(0.042)</td>
<td>(0.043)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>4916</td>
<td>1109</td>
<td>3807</td>
<td>3459</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.96</td>
<td>0.98</td>
<td>0.95</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Standard errors adjusted for clustering at the plant level.
* significant at 10%; ** significant at 5%; *** significant at 1%
All specifications include plant fixed effects, year fixed effects and third-order polynomials in $\text{Size} \times \text{NSR Enforcement}$ and $\text{Online Year} \times \text{NSR Enforcement}$.
Data are annual, plant level observations from 1988-2004.

### Table 4b: Total Capital Cost of Plant - IV
Dependent Variable: $\ln(\text{Total Cost of Plant})$

<table>
<thead>
<tr>
<th>Sample:</th>
<th>All Plants</th>
<th>Mainly New Plants Only</th>
<th>Mainly Old Plants Only</th>
<th>Mainly Phase2 Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{NotScrubbed}^\ast$</td>
<td>-0.094**</td>
<td>-0.061</td>
<td>-0.111**</td>
<td>-0.052</td>
</tr>
<tr>
<td>$\text{NSR Enforcement}$</td>
<td>(0.039)</td>
<td>(0.181)</td>
<td>(0.051)</td>
<td>(0.043)</td>
</tr>
<tr>
<td>$\ln(\text{Output})$</td>
<td>0.474***</td>
<td>0.906</td>
<td>0.568***</td>
<td>0.481***</td>
</tr>
<tr>
<td>(0.137)</td>
<td>(1.250)</td>
<td>(0.124)</td>
<td>(0.175)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>4722</td>
<td>1062</td>
<td>3660</td>
<td>3325</td>
</tr>
</tbody>
</table>

See notes to Table 4b.
Instrument for $\ln(\text{Output})$: $\ln(\text{State Sales})$.
Data are annual, plant level observations from 1988-2003.
### Table 5a: Heat Rate Regressions - OLS
Dependent Variable: $\ln(\text{Heat Rate})$

<table>
<thead>
<tr>
<th>Sample:</th>
<th>All Units</th>
<th>New Units</th>
<th>Old Units</th>
<th>Phase2 Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{NotScrubbed}^*$</td>
<td>-0.004</td>
<td>0.005</td>
<td>-0.006</td>
<td>-0.003</td>
</tr>
<tr>
<td></td>
<td>(.004)</td>
<td>(.006)</td>
<td>(.006)</td>
<td>(.006)</td>
</tr>
<tr>
<td>$\text{NSR Enforcement}$</td>
<td>-0.002</td>
<td>-0.026</td>
<td>0.000</td>
<td>-0.011</td>
</tr>
<tr>
<td></td>
<td>(.007)</td>
<td>(.031)</td>
<td>(.007)</td>
<td>(.007)</td>
</tr>
<tr>
<td>$\text{Divest}$</td>
<td>-0.308***</td>
<td>-0.370***</td>
<td>-0.298***</td>
<td>-0.324***</td>
</tr>
<tr>
<td></td>
<td>(.013)</td>
<td>(.032)</td>
<td>(.014)</td>
<td>(.015)</td>
</tr>
<tr>
<td>$\ln(\text{Output})$</td>
<td>0.006</td>
<td>0.002</td>
<td>0.007</td>
<td>0.009*</td>
</tr>
<tr>
<td></td>
<td>(.004)</td>
<td>(.006)</td>
<td>(.005)</td>
<td>(.005)</td>
</tr>
<tr>
<td>$\text{Temperature}$</td>
<td>-0.192***</td>
<td>-0.176***</td>
<td>-0.195***</td>
<td>-0.201***</td>
</tr>
<tr>
<td></td>
<td>(.015)</td>
<td>(.035)</td>
<td>(.017)</td>
<td>(.017)</td>
</tr>
<tr>
<td>Observations</td>
<td>344,224</td>
<td>59,699</td>
<td>284,525</td>
<td>236,316</td>
</tr>
<tr>
<td>$R^2$</td>
<td>.48</td>
<td>.62</td>
<td>.46</td>
<td>.52</td>
</tr>
</tbody>
</table>

Standard errors adjusted for clustering at the unit level.
* significant at 10%; ** significant at 5%; *** significant at 1%
All specifications include unit fixed effects and third-order polynomials in $\text{Size} \times \text{NSR Enforcement}$ and $\text{Online Year} \times \text{NSR Enforcement}$.
Data are weekly unit level observations from July 1996-December 2004.

### Table 5b: Heat Rate Regressions - IV
Dependent Variable: $\ln(\text{Heat Rate})$

<table>
<thead>
<tr>
<th>Sample:</th>
<th>All Units</th>
<th>New Units</th>
<th>Old Units</th>
<th>Phase2 Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{NotScrubbed}^*$</td>
<td>-0.005</td>
<td>0.001</td>
<td>-0.006</td>
<td>-0.005</td>
</tr>
<tr>
<td></td>
<td>(.004)</td>
<td>(.007)</td>
<td>(.006)</td>
<td>(.005)</td>
</tr>
<tr>
<td>$\text{NSR Enforcement}$</td>
<td>0.002</td>
<td>-0.009</td>
<td>0.003</td>
<td>-0.004</td>
</tr>
<tr>
<td></td>
<td>(.007)</td>
<td>(.024)</td>
<td>(.007)</td>
<td>(.008)</td>
</tr>
<tr>
<td>$\ln(\text{Output})$</td>
<td>-0.192***</td>
<td>-0.176***</td>
<td>-0.195***</td>
<td>-0.201***</td>
</tr>
<tr>
<td></td>
<td>(.015)</td>
<td>(.035)</td>
<td>(.017)</td>
<td>(.017)</td>
</tr>
<tr>
<td>$\text{Temperature}$</td>
<td>0.010**</td>
<td>0.007</td>
<td>0.011**</td>
<td>0.012**</td>
</tr>
<tr>
<td></td>
<td>(.005)</td>
<td>(.006)</td>
<td>(.006)</td>
<td>(.005)</td>
</tr>
<tr>
<td>Observations</td>
<td>304,394</td>
<td>52,689</td>
<td>251,705</td>
<td>209,362</td>
</tr>
</tbody>
</table>

See notes to Table 5a.

Instrument for $\ln(\text{Output})$: $\ln(\text{State Sales})$.
Data are annual, plant level observations from 1988-2004.
Figure 7: Trends in Heat Rates by Unit Category

Heat Rate
Trends by Plant Category

Heat Rate Relative to 2004

Year

FGD
No_FGD

Heat Rate
Appendix Table 1: Summary Statistics for Hazard Models (1990-2003)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>17.2</td>
<td>16.0</td>
</tr>
<tr>
<td>Size (MW)</td>
<td>230</td>
<td>193</td>
</tr>
<tr>
<td>State Capacity Factor (%)</td>
<td>42</td>
<td>9</td>
</tr>
<tr>
<td>Nonattainment(^a) (%)</td>
<td>36</td>
<td>48</td>
</tr>
<tr>
<td>SO(_2) Nonattainment (%)</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>% Coal</td>
<td>28</td>
<td>45</td>
</tr>
<tr>
<td>% Gas</td>
<td>64</td>
<td>48</td>
</tr>
<tr>
<td># of units</td>
<td>2293</td>
<td></td>
</tr>
<tr>
<td># of retirements</td>
<td>191</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) This variable is equal to one if the county in which the plant was located was categorized as nonattainment for either SO\(_2\) or ozone in 1990 (14 of the 49 SO\(_2\) nonattainment counties were also nonattainment for ozone). Only one county in 1990 was nonattainment for NO\(_x\) and it was also nonattainment for ozone.