NCEE
NATIONAL CENTER FOR
ENVIRONMENTAL ECONOMICS

How did air quality standards affect employment at U.S. power plants? The importance of stringency, geography, and timing

Glenn Sheriff, Ann E. Ferris, and Ron Shadbegian

Working Paper Series

Working Paper # 15-01
May , 2015
Revised August, 2016

U.S. Environmental Protection Agency
National Center for Environmental Economics
1200 Pennsylvania Avenue, NW (MC 1809)
Washington, DC 20460
http://www.epa.gov/economics

How did air quality standards affect employment at U.S. power plants? The importance of stringency, geography, and timing

Glenn Sheriff, Ann E. Ferris, and Ron Shadbegian

NCEE Working Paper Series
Working Paper # 15-01
May, 2015
Revised August, 2016

How did air quality standards affect employment at US power plants? The importance of stringency, geography, and timing

By Glenn Sheriff, Ann E. Ferris, and Ron Shadbegian*

Geographical differences in U.S. Clean Air Act requirements are often used to identify environmental regulatory impacts. The standard approach abstracts from aspects of the law affecting which areas are regulated, how strictly they are regulated, and when regulatory changes occur. We find that omitting these factors can bias results by contaminating the control group, leading to underestimation of historical employment impacts and overestimation of projected impacts from tightening regulations. Results indicate that 1990 changes to ozone nonattainment provisions reduced power plant employment without significantly affecting generation, suggesting that installation of pollution controls contributed to labor-saving technical change at affected sources.

Keywords: air pollution, electricity, employment, regulation
Subject Area Classifications: 4, 59
JEL Codes: Q52, Q53

* Sheriff: US EPA, National Center for Environmental Economics, 1200 Pennsylvania Ave. NW (1809T), Washington, DC 20460, sheriff.glenn@epa.gov. Ferris: US EPA, 1200 Pennsylvania Ave. NW (1809T), Washington, DC 20460, ferris.ann@epa.gov. Shadbegian: National University of Singapore, Lee Kuan Yew School of Public Policy 469C Bukit Timah Road, Li Ka Shing Building, Level 2, Singapore 259772, ronshadbegian@gmail.com. We thank David Evans, Kira Fabrizio, Seema Kakade, Valerie Mueller, Kellie Ortega, Reed Walker, Catherine Wolfram, Ann Wolverton, and participants at the IZA Workshop on Labor Market Effects of Environmental Policies and the University of Colorado Boulder Environmental and Resource Economics Workshop for helpful discussions and suggestions. The views expressed in this article are those of the authors and do not necessarily represent those of the US EPA. Although the research in this paper was funded by the US EPA, it has not been subjected to the Agency's peer and policy review. No official Agency endorsement should be inferred.

Environmental regulation's potential impact on labor demand is of great importance to policy makers, but has received relatively little attention from economists. Through its impact on production costs and technology, changes in environmental regulation may shift economic activity within and across sectors. Resulting job displacement may have lasting economic and health impacts on workers (see, for example Jacobson, LaLonde and Sullivan, 1993; Sullivan and Von Wachter, 2009). Moreover, job loss in a particular sector can be relevant to the political economy of how policy is implemented (Joskow and Schmalensee, 1998). Ozone National Ambient Air Quality Standards (NAAQS) are particularly salient due to high projected costs.[1] In 2011 the Obama administration took the unusual step of asking the EPA to withdraw its proposed rule to tighten the ozone standard, citing among other factors the importance of reducing regulatory burdens as the economy recovered from recession.[2]

Compliance costs have an ambiguous theoretical impact on output and input use in the regulated sector (Berman and Bui, 2001; Morgenstern, Pizer and Shih, 2002; Gray and Shadbegian, 2014). Will regulations lead to plant closures and job loss? Or will installation and operation of pollution-control equipment create jobs? Perhaps environmental rules will cause firms to invest in productivity-enhancing upgrades that increase output while reducing employment? Examples of studies examining some of these issues include local air regulation in southern California (Berman and Bui, 2001), the EPA's 1998 "Cluster Rule" for pulp and paper manufacturing (Gray et al., 2014), the Acid Rain SO_2 Trading Program (Ferris, Shadbegian and Wolverton, 2014), and the NOx Budget Trading Program (Curtis, 2014). Here, we take advantage of the timing, stringency, and geography of ozone NAAQS to assess how tightening regulations in the 1990s affected plant-level generation and labor demand in the electric power sector.

[1] The US EPA projected annualized costs of \$19-\$25 billion to reduce the ozone NAAQS from an average 8-hour concentration of 0.084 ppm to 0.070 ppm, the top of the range supported by Clean Air Scientific Advisory Committee (US EPA, 2008).

[2] `http://www.whitehouse.gov/the-press-office/2011/09/02/statement-president-ozone-national-ambient-air-quality-standards`

Over the past two decades it has become common to use geographical heterogeneity in regulatory stringency mandated by the 1977 and 1990 Clean Air Act Amendments (CAAAs) as a quasi-experiment to test hypotheses regarding effects of environmental regulation. In this framework, areas designated as attaining ambient standards serve as a control group with which to compare outcomes in more heavily regulated nonattainment areas. This approach has been used to study pollution levels (Henderson, 1996; Kahn, 1997; Greenstone, 2003, 2004; Auffhammer, Bento and Lowe, 2009), housing prices (Chay and Greenstone, 2005), productivity (Greenstone, List and Syverson, 2012), county tax revenue (Carr, 2011), industrial sector diversity (Carr and Yan, 2012), plant investment decisions (Henderson, 1996; Becker and Henderson, 2000; List and McHone, 2000; List, McHone and Millimet, 2003; List et al., 2003; List, McHone and Millimet, 2004; List, Millimet and McHone, 2004; Becker, 2005; Condliffe and Morgan, 2009; Morgan and Condliffe, 2009), and employment (Greenstone, 2002; Kahn and Mansur, 2013; Walker, 2011, 2013).

Our work differs in three aspects from this body of research. First, we allow nonattainment designation impacts to vary over time, even for counties whose status does not change.[3] This innovation is potentially important for several reasons. Nonattainment designation does not cause an instantaneous change in regulation. Instead, it initiates a multi-year process in which states promulgate regulations and submit them for federal approval. Abstracting from this aspect of the law runs the risk of erroneously counting as-yet untreated plants as highly regulated. In addition, as regulations change over time, so does the implication of being in a nonattainment area. Only after the 1990 CAAAs, for example, were oxides of nitrogen (NOx) subject to federal ozone NAAQS regulations. Allowing nonattainment impact to vary over time avoids counting NOx sources in ozone nonattainment as highly regulated when they were not. Finally, this approach

[3]Walker (2013) also allows for time-varying impacts, but only for plants in counties that switch attainment status over time.

allows us to use plant fixed effects to control for unobserved heterogeneity without placing plants that were always in nonattainment in the control group.[4]

Second, we observe that the northeastern and mid-Atlantic states were part of the Ozone Transport Region (OTR) established by the 1990 CAAAs. The OTR regulated all counties within those states as ozone nonattainment areas, regardless of local air quality. Technically, however, areas with good local air quality were in attainment of the ozone NAAQS and recorded as such in the U.S. Code of Federal Regulations (CFR) and the EPA's Greenbook. Using these data sources to analyze the post-1990 period categorizes these areas as untreated, even though they were more heavily regulated than some nonattainment areas.

Third, previous literature focused on estimating impacts of CAAA regulations using a binary "nonattainment" indicator for more stringent regulation. We explore the possibility that the more detailed ozone nonattainment classifications of varying stringency introduced in the 1990 CAAAs may have led to a range of different employment impacts.

We present three main results. First, accounting for time-varying aspects of the regulation and the geographic scope allows us to identify labor impacts that would not have been picked up otherwise. Second, we find that these impacts were limited to the subset of plants located in Moderate, Serious, and Severe ozone nonattainment areas.[5] The less stringent classifications had no significant labor impact. Finally, we find that the change in ozone regulation had a negative impact on power plant employment, but no significant impact on generation. This finding suggests that the mechanism of the impact was a labor-saving technology change rather than a loss in competitiveness.

We show the policy relevance of the difference in stringency in the context of using historical results to evaluate future regulations. Ozone NAAQS have been tightened twice in the past 20 years, with areas previously in attainment redesig-

[4] Matching techniques may help address this problem (List et al., 2003; Kahn and Mansur, 2013).

[5] Since the only Extreme area was in the Los Angeles basin, we were unable to disentangle ozone regulatory impacts from other pollution control measures in that region.

nated as nonattainment. The new classifications were not distributed as they were in the 1990s. Instead, they tended to be concentrated in the least-stringent categories. Consequently, we find that failure to account for heterogeneous treatment could lead to an over-prediction of employment effects for new, tighter standards.

The remainder of the paper is organized as follows. Section I describes the historical policy context and institutional setting for ozone NAAQS regulation. In Section II we present a simple conceptual framework to identify pathways through which regulation may affect plant-level output and employment decisions. We describe the data in Section III and develop the empirical methodology in Section IV. Results are presented in Section V, and Section VI concludes.

I. Ozone regulation under the Clean Air Act

The 1970 CAAAs introduced NAAQS for a set of criteria air pollutants. Today these include ground level ozone, carbon monoxide, lead, nitrogen dioxide, coarse and fine particulate matter, and sulfur dioxide.[6] Under the 1970 amendments the EPA was responsible for setting the NAAQS, but implementation was left to the states. After a lack of progress in achieving these standards, Congress enacted the 1977 CAAAs. The 1977 CAAAs introduced federal requirements based on an area's designation as in or out of attainment with the NAAQS. The amendments also gave the EPA authority to sanction states that do not comply with their responsibilities. Sanctions include taking over implementation via Federal Implementation Plans, banning new construction, and withholding grant money and highway funding, among other things.

States were responsible for monitoring ambient pollution in their air quality regions, and for submitting changes in attainment status to the EPA. New and modified major stationary sources (those emitting more than 100 tons per year

[6]Particulate matter was originally defined as Total Suspended Particulates (TSP) comprising particles smaller than 40 microns. In 1987, the EPA revised the standard to cover only particles smaller than 10 microns, PM_{10} (52 FR 24634). In 1997, the EPA preserved the PM_{10} standard, and added a stricter standard for particles smaller than 2.5 microns, $PM_{2.5}$ (62 FR 38652).

of any regulated pollutant) in attainment areas were governed under Prevention of Significant Deterioration (PSD) New Source Review (NSR) requirements. Under PSD, these sources must demonstrate that they will not significantly impair ambient air quality and must install best available control technology (BACT). Control costs are a factor in determining BACT.

Under the 1977 CAAAs ozone nonattainment designation affected sources of volatile organic compounds (VOCs). New or modified major stationary sources (emitting more than 100 tons of VOCs per year) were subject to stricter nonattainment NSR requirements. Among other things, nonattainment NSR imposed two requirements on plants. First, these sources were required to install "lowest achievable emission rate" controls regardless of cost. Second, they were required to offset emission increases ton for ton with reductions elsewhere in the area. Existing major sources faced the less stringent requirement of retrofitting with reasonably available control technology (RACT), for which cost affects the definition of "reasonable." Due to the lack of cost effective VOC control technology, during this period RACT had little impact on power plants.

The 1990 CAAAs preserved these requirements in Subpart 1 of Title I of the Act. In addition to Subpart 1, ozone was governed under stricter requirements set forth in Subpart 2.[7] Subpart 2 extended ozone regulations to cover sources of NOx as well as VOCs.[8] This revision is important for fossil fuel burning power plants since, unlike for VOCs, several cost effective NOx control strategies exist for power plants.[9]

Subpart 2 also divided ozone nonattainment into several new classifications Marginal, Moderate, Serious, Severe, and Extreme.[10] In addition, Submarginal and Transitional areas were regulated under the old Subpart 1.

[7]The Act did not change the standard itself, which the EPA set in 1979. The 1979 standard was defined as one day or less per calendar year expected to have a maximum hourly average concentration exceeding 0.12 ppm (44 FR 8202).

[8]Ground level ozone is created by a photochemical reaction to which both VOCs and NOx are precursors.

[9]`http://www.epa.gov/groundlevelozone/SIPToolkit/ctgs.html`

[10]Serious was subdivided into two categories, 15 and 17, referring to the number of years allowed for the area to come into attainment.

As illustrated in Figure 1, the classifications imposed increasingly strict requirements based on an area's ambient pollution concentration. These requirements are cumulative. Marginal areas, for example, must comply with all requirements of areas regulated under Subpart 1, and Extreme areas must satisfy the requirements of all other classifications.

With respect to stationary sources such as power plants, the classifications imposed the following requirements. The threshold for defining a major source gradually falls from 100 tons per year for Marginal areas to 10 tons per year for Extreme areas. This requirement is unlikely to have an impact on our analysis since all plants in our sample are major sources. NSR offset requirements are gradually increased from ratios of 1.1:1, to 1.5:1. RACT requirements become more strict for Moderate and above areas. This provision is potentially important since NOx RACT only applied to plants in Moderate and above nonattainment areas. The threshold for what qualifies as a significant modification for NSR purposes is lowered from 40 to 25 additional tons per year in Serious and Severe areas and eliminated for Extreme areas.[11] In addition to stationary source requirements, areas may be required to undertake vehicle inspection and maintenance programs, submitting an emissions inventory, demonstrating reasonable further progress in area-wide emissions reductions, etc.[12]

The 1990 CAAAs created the Ozone Transport Region comprising Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Maryland, Delaware, the District of Columbia, and the northern counties of Virginia in the Washington, DC Consolidated MSA (42 USC §7511c(a)). Fossil fuel fired power plants in the OTR are regulated at least as

[11]Other major stationary source requirements include annual emissions statements (Moderate and above), an emissions fee for missing deadlines (Serious and Extreme), and clean fuel, or advanced control technologies for all boilers emitting more than 25 tons per year of NOx (Extreme).

[12]Subparts 3 and 4 of the 1990 CAAAs introduced two classifications (Moderate and Serious) for carbon monoxide and PM_{10} nonattainment areas. In contrast to ozone, the burden of the new requirements (e.g., emissions inventories, attainment demonstrations, and mobile source requirements) fell almost exclusively on states, rather than individual stationary sources. The only stationary source requirement was lowering the major source threshold from 100 tons per year to 50 tons per year for Serious carbon monoxide nonattainment areas and 70 tons per year for Serious PM_{10} nonattainment areas.

Classification	Cumulative Requirements	Major Source Threshold* (tons/year)	NSR Offset* (ratio)	Attainment Deadline (years)
Extreme	NSR triggered by any modification* Traffic Controls; Clean Fuels for Boilers*	10	1.5:1	20
Severe	VMT Growth Offset Low VOC Reformulated Gasoline Penalty Fee Program for Major Sources*	25	1.3:1	15 or 17
Serious	Vehicle Miles Travelled (VMT) Demonstration Milestone Contingency Measures for RFP Modeled Attainment Demonstration; Enhanced Vehicle I/M Clean Fuels Program; NSR triggered by smaller modification* Average 3% RFP per year after year 6; Enhanced Monitoring Plan	50	1.2:1	9
Moderate	Vehicle Inspection/Maintenance (I/M) 15% RFP Over 6 Years; Stage II Gasoline Vapor Recovery Enhanced RACT*; Attainment Demonstration; Contingency Measures	100	1.15:1	6
Marginal	NOx Requirements*; Periodic EI Updates; Major Source Emission Statements*	100	1.1:1	3
Transitional (VOC only)	Reasonable Further Progress (RFP); Reasonably Available Control Measures Reasonably Available Control Technology (RACT) for some existing major sources* New Source Review (NSR) Program: Lowest Achievable Emission Rate and Offsets* Transportation Conformity; Emission Inventory (EI); Emission Growth Projection	100	1:1	5

Figure 1. 1990 Clean Air Act Requirements for Ozone Nonattainment Areas

Note: Requirements for each classification include those of all lower classifications. See Clean Air Act Title I, Part D, Subparts 1 and 2 for more details, including possible exemptions and waivers. *Requirement applies to individual major stationary sources.
Source: Authors, adapted from EPA, based on information from Wooley and Morss (2012).

Moderate nonattainment, regardless of local air quality. The CFR does not, however, identify OTR attainment areas as "nonattainment." Since they are regulated like other nonattainment counties, our main specification treats counties in the OTR as if the CFR listed them as nonattainment.

II. Conceptual Model

The directional impact of environmental regulations on labor demand is ambiguous *a priori* (Berman and Bui, 2001; Morgenstern, Pizer and Shih, 2002). Compliance actions may require more workers (e.g., to install and operate pollution control equipment), holding output constant. By increasing marginal production costs, however, compliance with environmental regulations may cause output to fall, with a corresponding drop in labor demand.

In the context of NAAQS, regulations for electricity generation units are generally written in the form of rate-based performance standards (e.g., tons of NOx emitted per unit of output). An existing source can comply with a standard by retrofitting the plant with pollution control devices and/or changing production processes. These compliance actions could have a positive or negative impact on employment depending on how changes in technology affect the labor intensity of the production process.

Referring to Figure 1 the following requirements applied directly to existing major power plants. In theory VOC RACT applied to all ozone nonattainment areas and NOx RACT commenced with Marginal Areas. In practice, however, states were required to make RACT determinations based on controls described in EPA guidance *prior to* 1990 (42 USC §7511a(a)(2)(A)). For power plants no such guidance existed (for NOx or VOCs).[13] Thus, the NOx and VOC RACT requirement had no practical effect for these sources. For Moderate areas, "enhanced" RACT for NOx applied to power plants. This provision mandated states to impose RACT controls described by EPA guidance *after* 1990 (42 USC §7511a(b)(2)). The EPA issued guidance for NOx controls for fossil-fuel burning utility boilers in early 1994 (US EPA, 1994).

RACT did not impose a particular technology on all affected sources, rather determinations were made on a case-by-case basis depending on boiler characteristics (e.g., tangentially-fired, single and opposed wall-fired, cell burner, cyclone, stoker, and fluidized bed composition), operation, and control technology. Broadly, there are two methods to control NOx emissions from utility boilers: combustion controls that reduce NOx formation, and post-combustion controls that remove NOx from flue gas. Combustion controls included operational modifications, overfire air, and low-NOx burners. Post-combustion controls included selective noncatalytic reduction (SNCR) and selective catalytic reduction (SCR).[14]

Berman and Bui (2001) discuss relative labor intensities of two general cate-

[13] `http://www.epa.gov/groundlevelozone/SIPToolkit/ctgs.html`
[14] For more details, see US EPA (1994).

gories of methods to reduce pollutant emissions: process changes and end-of-pipe technologies. End-of-pipe technologies, such as SNCR or SCR, remove pollutants at the end of the production process, and likely are complementary to labor. On the other hand, "improvements in production process, such as the installation of more efficient boilers which operate at lower levels of emissions, often reduce demand for production workers due to a general skill-bias of technological change" (Berman and Bui, 2001, p. 275). If compliance with the ozone NAAQS for fossil-fuel utility boilers took the form of primarily end-of-pipe compliance approaches, such as installations of SNCR or SCR, which require labor for installation, operation, and maintenance, one might expect a positive impact on labor demand. On the other hand, if compliance focused more on efficiency-enhancing process changes one might anticipate a decrease in labor demand.

During the 1990s, electricity generation mostly consisted of local monopolies whose price and output decisions were regulated by public utility commissions. There was more scope for competitive output decisions in those parts of the country with restructured retail or wholesale electricity makets. Even in those areas however, many plants served as baseload generators. Output for monopolies and baseload plants is thus likely to be exogenous, at least in the short run (Nerlove, 1961). As a result, the impact of environmental regulation on employment is most likely to operate through the channel of how compliance actions affect the labor intensity of the generation technology.

This impact could be either positive or negative. Labor required to install pollution control equipment may not appear in our data if the work was performed by external contractors. If operation of the equipment requires additional workers, however, environmental regulation may positively affect employment. Compliance with regulations may reduce employment, however, if plants respond by altering the production process to become less labor intensive.

For the sample as a whole, workers per unit of output declined by about 40 percent from 1987 to 1998, suggesting a general trend of labor-saving technological change. Environmental compliance could have accelerated this process. Plant managers may have taken advantage of the shutdown time, engineering studies, equipment purchases, etc. required for pollution control retrofits to undertake other efficiency-enhancing capital improvements that would not have been otherwise economical at the time.

During this period wholesale markets were being liberalized (Fabrizio, Rose and Wolfram, 2007). For non-baseload plants participating in these markets, environmental regulation could potentially affect employment through the output channel. Again, the impact could go in either direction. Environmental regulation might increase marginal production costs, placing regulated firms at a competitive disadvantage in wholesale markets, and causing a drop in generation. To the extent that decreased generation causes a reduction in labor demand, employment would also decline. Plant managers may, however, have been able to take advantage of the compliance process to invest in other efficiency-enhancing capital upgrades. Generation could possibly increase for plants with environmental regulation if the net effect was to decrease marginal generation costs.

Using this conceptual framework we empirically test variations of the following hypotheses. Do plants facing more stringent environmental regulation use fewer workers than their peers, and how does this effect vary over time? How sensitive are these results to ownership and changes in market structure implied by anticipated deregulation of retail electricity markets? Finally, we explore possible mechanisms by which regulations might affect labor use. For example, if there is an employment effect of environmental regulation does it operate through the output channel; i.e., does environmental regulation significantly affect generation?

This analysis sheds light on where one might expect future environmental regulations to have the strongest impact, as well as the mechanism by which the impact operates. Suppose, for example, generation and employment were to fall in plants facing stricter environmental regulations. This outcome would suggest that regulations cause a net increase in marginal costs. If these plants participate in regional wholesale markets, there could potentially be increases in electricity prices for customers in distant attainment areas. Alternatively, if generation were to increase and employment to decline for regulated plants it would suggest that technological changes associated with compliance save labor and possibly reduce marginal generation costs. In the next sections we describe our strategy for using data on plant characteristics and regulatory status to answer these questions.

III. Data

Plant-level characteristics come from data collected by Fabrizio, Rose and Wolfram (2007).[15] The Fabrizio, Rose and Wolfram (2007) data set uses plant operating characteristics from Federal Energy Regulatory Commission (FERC) Form 1 (investor-owned plants), Energy Information Agency (EIA) Forms 412 and 767 (municipally owned plants), and Rural Utilities Service (RUS) Forms 7 and 12 (rural electric cooperatives) as compiled in the Utility Data Institute (UDI) O & M Production Cost Database. Variables include employees, net MWh generation, installed MW capacity, plant age, NERC region and dummies for primary fuel source (coal, gas, or oil).[16] Utility ownership type (public or investor owned) is from UDI's 1997 Datapak Book, utility wages, fuel expenses per BTU, and state restructuring status were compiled by Fabrizio, Rose and Wolfram (2007).

To these data we add county-level NAAQS attainment status. The EPA's Green Book records county attainment status for each criteria pollutant.[17] We manually coded county-level ozone classifications in 1993 based on 40 CFR 81.[18] This source does not include information on the OTR. Instead, we use the relevant section of the statute, 42 USC §7511c(a), to account for the regulatory status implied by

[15] This data set, `frw1extract_enf2.dta`, and a detailed description, `readme_FRW_PubArchive.pdf`, are available at `https://www.aeaweb.org/articles.php?doi=10.1257/aer.97.4`.

[16] A small number of plant-years reported separate entries for different boilers. When this occurred we combined boiler data to create a single observation.

[17] Files `phistory.xls` and `phisttsp.xls` are available from `www.epa.gov/airquality/greenbook/data_download.html`.

[18] Subpart 1 refers to all areas regulated under the pre-1990 ozone rules. The statute lists these areas as Transitional, Sub-Marginal, and Incomplete Data. The 1990 CAAAs designated most areas, but states had time to challenge some designations and submit area boundary adjustments. Almost all these issues were resolved by 1993.

the OTR (i.e., plants in attainment, Subpart 1, and Marginal areas in the OTR are coded as Moderate nonattainment). Figure 2 illustrates location and ozone nonattainment status for plants in 1988 and 1993.[19]

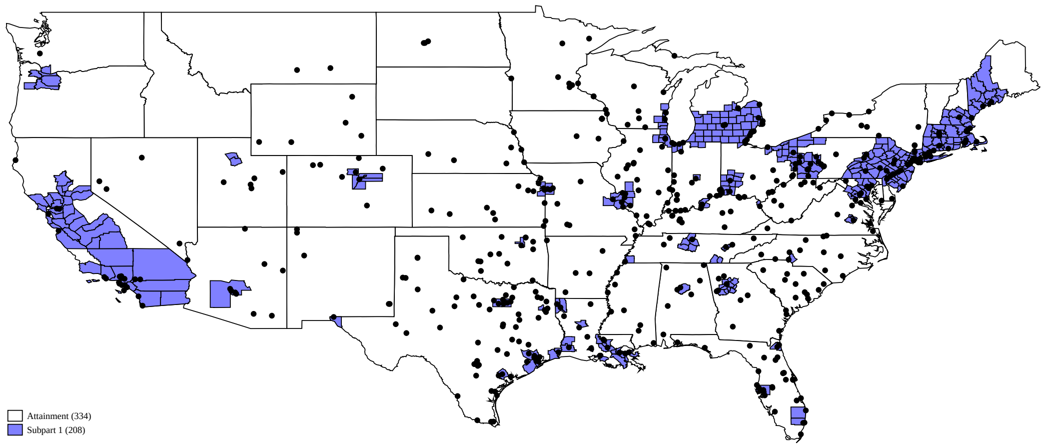
In addition to ozone provisions, beginning in 1996 the 1990 CAAAs imposed NOx performance standards on a set of coal-fired power plants as part of Phase I of the Title IV Acid Rain program. These NOx provisions were technology-based and did not allow emissions trading. Instead, plants needed to attain a standard which could typically be achieved through the installation of low-NOx burners. To control for this program, using US EPA (1997) we coded dummies for plant-years affected by these Title IV NOx provisions.

Table 1 presents summary statistics for 1989. The first column contains means and standard deviations for our preferred specification's control plants, those in attainment areas for the ozone NAAQS in 1993. The second column has values for plants that were regulated under ozone nonattainment provisions in 1993. The values are of similar magnitudes for employment, generation, and capacity.

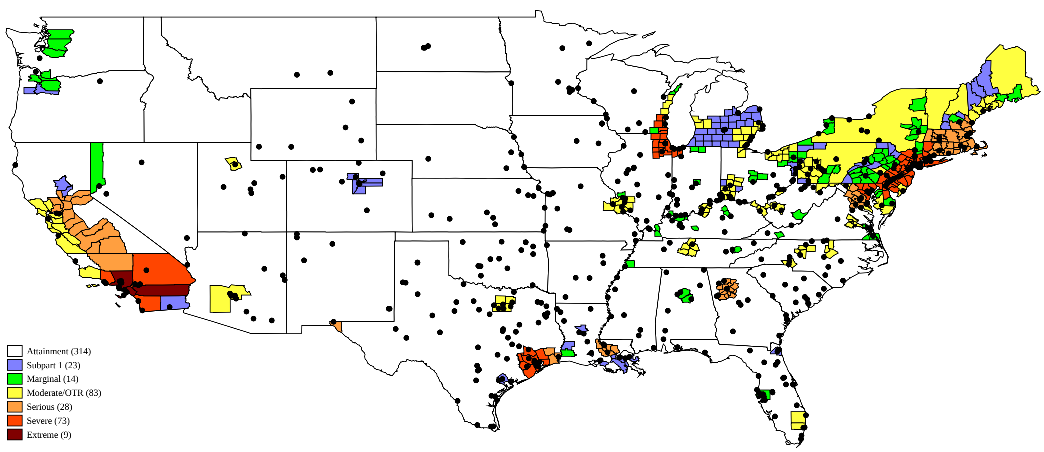
Table 2 breaks down summary statistics for plants in ozone nonattainment areas by classification. Plants in Extreme areas differ from the others. These are a small number of older gas-fired plants that, in addition to being in the nation's only NO_2 nonattainment area, are also out of attainment for the PM_{10} and SO_2 NAAQS. This area is also part of California's South Coast Air Quality Management District, and subject to relatively strict local environmental regulations. Consequently, our analysis cannot disentangle Extreme ozone nonattainment impacts from these other factors.

Referring to Table 1, significant differences exist between attainment and nonattainment plants with respect to ownership status, location in states that eventually restructured their electricity markets, fuel type, attainment status for other NAAQS criteria pollutants that require power plant pollution controls (SO_2 and

[19]To construct the maps, we geocode plants using EPA's Emissions and Generation Resource Integrated Database (eGRID), available at `http://www.epa.gov/cleanenergy/energy-resources/egrid/`. We merge almost all plants based on plant identification numbers. For the remainder we manually match plants based on name and address.



(a) 1988



(b) 1993

FIGURE 2. SAMPLE PLANTS BY COUNTY OZONE ATTAINMENT STATUS

Note: Dots depict power plants. OTR/Moderate includes plants in Attainment, Subpart 1 and Marginal areas within the Ozone Transport Region. Parentheses indicate number of plants in classification.
Source: Authors, based on 40 CFR 81, 42 USC §7511c(a).

TABLE 1— PLANT CHARACTERISTICS BY 1993 OZONE NAAQS DESIGNATION

	1989 Means			1987-89 Differences		
	Attainment	Nonattainment	Difference	Attainment	Nonattainment	Difference
Log employment	4.774	4.884	−0.111	-0.024	-0.017	−0.007
	(0.847)	(0.768)	(−1.584)	(0.097)	(0.123)	(−0.702)
Log generation (MWh)	14.427	14.306	0.120	0.074	0.099	−0.024
	(1.372)	(1.416)	(0.987)	(0.406)	(0.455)	(−0.631)
Log capacity (MW)	6.330	6.362	−0.031	0.003	0.002	0.001
	(0.868)	(0.856)	(−0.416)	(0.051)	(0.039)	(0.177)
Oldest unit (years)	24.655	30.969	-6.314^{***}	1.924	2.406	−0.482
	(12.327)	(10.607)	(−6.375)	(2.141)	(3.690)	(−1.726)
Muni	0.259	0.156	0.104^{**}			
	(0.439)	(0.363)	(3.005)			
IOU × Restructure	0.278	0.662	-0.384^{***}			
	(0.449)	(0.474)	(−9.486)			
Coal	0.741	0.476	0.265^{***}			
	(0.439)	(0.501)	(6.382)			
Gas	0.237	0.329	-0.092^{*}			
	(0.426)	(0.471)	(−2.318)			
Other nonattainment	0.082	0.240	-0.158^{***}			
	(0.275)	(0.428)	(−4.858)			
Title IV	0.443	0.280	0.163^{***}			
	(0.498)	(0.450)	(3.974)			
Plants	316	225		302	217	

Note: First two columns are sample means (standard deviations below). The third column is difference in means (t-statistic below). Fourth and fifth columns are changes in mean values between 1987 and 1989 (standard deviations below). The sixth column is the difference in changes between groups (t-statistic below). *, **, and *** indicate P-values of 10, 5, and 1 percent. Attainment areas in the OTR classified as nonattainment. Muni is proportion of plants not privately held. Restructure is proportion of privately held plants in areas that initiated electricity market deregulation hearings between 1993 and 1998 and eventually restructured. Coal and Gas are the proportion of plants that reported each as their primary fuel, the remainder were oil. Other nonattainment is the proportion of plants located in a county designated nonattainment for either PM_{10} or SO_2. Title IV is the proportion of plants affected by the Acid Rain Program's 1996 NOx provisions.

PM_{10}), and age. The main analysis uses several types of controls to avoid potentially mis-attributing the impact of these observable differences to ozone attainment status. We also conduct several robustness checks detailed in Section V.C to ensure our main results are not sensitive to alternative specifications.

If plants using different fuels followed different time trends independent of regulatory status, this trend could bias our estimates for regulatory impact. As illustrated in Appendix Figure A1 the continental U.S. wholesale electricity market was divided into ten North American Electric Reliability Corporation (NERC) regions tasked with managing local markets for reliability purposes. Interacting a dummy for fuel type with region and time period flexibly controls for trends that may be influenced by unobserved local factors such as input prices, fuel

TABLE 2— 1989 PLANT CHARACTERISTICS BY 1993 OZONE NAAQS CLASSIFICATION

	Subpart 1	Marginal	Moderate	Serious	Severe	Extreme
Log employment	4.505	5.031	4.874	4.883	4.710	4.595
	(0.948)	(0.783)	(0.728)	(0.632)	(0.797)	(0.393)
Log generation (MWh)	14.007	14.713	14.373	14.152	13.700	13.778
	(1.579)	(1.340)	(1.414)	(1.475)	(1.688)	(1.465)
Log capacity (MW)	6.244	6.514	6.455	6.413	6.277	6.685
	(0.965)	(0.918)	(0.861)	(0.890)	(0.836)	(0.849)
Oldest unit (years)	32.522	34.500	35.072	32.000	34.082	35.222
	(10.220)	(9.362)	(12.380)	(9.941)	(11.584)	(7.855)
Muni	0.391	0.143	0.084	0.179	0.068	0.444
	(0.499)	(0.363)	(0.280)	(0.390)	(0.254)	(0.527)
IOU × Restructure	0.217	0.286	0.687	0.750	0.795	0.556
	(0.422)	(0.469)	(0.467)	(0.441)	(0.407)	(0.527)
Coal	0.435	0.714	0.651	0.429	0.356	0.000
	(0.507)	(0.469)	(0.480)	(0.504)	(0.482)	(0.000)
Gas	0.478	0.071	0.265	0.286	0.425	1.000
	(0.511)	(0.267)	(0.444)	(0.460)	(0.498)	(0.000)
Other nonattainment	0.304	0.071	0.181	0.107	0.288	1.000
	(0.470)	(0.267)	(0.387)	(0.315)	(0.456)	(0.000)
Title IV	0.217	0.429	0.410	0.250	0.192	0.000
	(0.422)	(0.514)	(0.495)	(0.441)	(0.396)	(0.000)
Plants	23	14	83	28	73	9

Note: Sample means with standard deviations below in parentheses. Attainment, Subpart 1, and Marginal areas in the OTR classified as Moderate. Muni is proportion of plants not privately held. Restructure is proportion of privately held plants in areas that initiated electricity market deregulation hearings between 1993 and 1998 and eventually restructured. Coal and Gas are the proportion of plants that reported each as their primary fuel, the remainder were oil. Other nonattainment is the proportion of plants located in a county that was designated nonattainment for either PM_{10} or SO_2. Title IV is the proportion of plants affected by the Acid Rain Program's 1996 NOx provisions.

transportation costs, and other time-varying demand or supply shocks.

Plants subject to other NAAQs affecting electricity generators (SO_2 and PM_{10}) may behave differently over time from those that do not. To control for this effect we interact "Alt. NAAQS" (a dummy for plants in a county that was in nonattainment with either of these pollutants in 1993) with time period.

To the extent they face different incentives, investor-owned utilities (IOUs) may have a different time trend than publicly owned utilities (Fabrizio, Rose and Wolfram, 2007). We interact ownership status ("Muni" for non-IOUs) with time to control for this potential trend. Moreover, Fabrizio, Rose and Wolfram (2007) find IOUs in restructuring states had a significant drop in labor use per unit of output. We control for this potential impact with a time-varying dummy "Restructured" for IOUs in states that restructure their electricity market. Following

Fabrizio, Rose and Wolfram (2007), this dummy takes a value of unity after the initiation of public hearings on restructuring.

A further complication arises from missing data. Fabrizio, Rose and Wolfram (2007) attribute most of the missing data to different reporting requirements for plants that were divested from utilities. Missing data could also arise due to simple measurement error. If missing data is due to plant entry or exit and these are caused by environmental regulations, our estimates may underestimate negative employment impacts by replacing zero employment with missing values.[20]

Our main results drop missing plant-years from the regression. As discussed in Section V.C, however, we conduct sensitivity analysis to examine the potential for plant entry and exit to affect our results. To do so, we impute a value of 1 employee for missing years for plants that might be late entrants or early exits.[21]

For possible exits, we identify plants with missing data in years consecutive to 1998. We match these missing plant-years with net generation from EPA's eGRID database.[22] We classify a plant as a "potential exit" if it has zero, negative, or missing net generation in eGRID for the years missing from the Fabrizio, Rose and Wolfram (2007) data and 1999. Only 2 plants fall into this category, one in a Moderate and one in a Severe area, comprising a total of 12 missing plant years.

Missing values might also correspond to new plants entering the sample after 1987. We define "potential entrants" as plants with missing values consecutive to 1987 for which the first non-missing value reports plant age as being zero or one. Over the 12-year panel, 11 plants (64 missing plant-years) are entrants. We do not observe how many workers were used to construct or maintain a plant prior to entry. Table 3 summarizes potential plant entry and exit.

In summary, our main regressions control for the following factors. Plant fixed effects control for unobserved time-invariant plant heterogeneity. We control for unobserved time-varying factors affecting all plants of a fuel type in a NERC

[20]Missing data may also arise due to temporary plant shutdowns.

[21]It is unclear what the actual employment was in these plants since some workers may have been used to maintain a facility while it was out of use either prior to entry or post exit.

[22]This database begins in 1996 and does not contain employment data.

Table 3— Potential plant entry and exit by year and ozone attainment designation

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Potential entries										
Attainment	1	0	0	2	0	1	0	0	2	2
Nonattainment	1	0	0	1	0	0	1	0	0	0
Potential exits										
Attainment	0	0	0	0	0	0	0	0	0	0
Nonattainment	0	0	0	0	1	0	1	0	0	0

Note: Potential entries are number of plants that first appear in the Fabrizio, Rose and Wolfram (2007) data in a given year and whose plant age is either zero or one. Potential exits are number of plants that are first missing from this data set in a given year, are missing from the data set for all subsequent years, and have nonpositive generation reported in eGRID from 1996-1999. Nonattainment status is for 1993 and includes the OTR.

region with fuel×region×year effects. We control for unobserved time-varying factors correlated with ownerhip structure by interacting an ownership dummy with year. We control for time-varying factors affecting privately held plants in restructuring markets by further interacting an IOU dummy with restructuring status. We control for time-varying impacts of other NAAQS by interacting a dummy for other nonattainment with year. We control for the Title IV NOx program by including a dummy for affected plant-years.

IV. Empirical Methodology

Our main results employ a difference-in-difference approach in which the treatment is defined as being regulated under the ozone nonattainment NAAQS provisions in 1993.[23] The goal is to estimate reduced form equations to identify how performance of treated plants differed from that of controls.[24]

The treatment variable D_{ip} takes a value of 1 if plant i is located in a county

[23] Although the CAAAs became law in 1990, they did not regulate emissions sources directly. They set a statutory framework for nonattainment designation. The EPA promulgated regulations with most official designations in November of 1991. Due to border adjustments some areas were not officially designated until 1993. We base our treatment on plant county status as of this date.

[24] Some studies estimate a third difference by distinguishing between polluting and and non-polluting manufacturers in the same county. Unfortunately, this distinction cannot be made precisely. Using an industrial classification's pollution intensity (e.g., Becker and Henderson, 2000; Greenstone, 2002) can result in mischaracterization of large individual polluters in low emission sectors and vice versa. Using the EPA's Air Facility Subsystem (AFS) permit database (e.g., Walker, 2011, 2013) runs into similar issues since several states have Federally Enforceable State Operating Permitting programs that do not appear in AFS (See `http://www.epa.gov/reg5oair/permits/oper.html`). Here, we gain precision in the definition of treated plants at the expense of being unable to estimate a third difference.

with ozone nonattainment classification p, and a value of zero otherwise. Let $Y_{it}(1)$ and $Y_{it}(0)$ denote the (log-transformed) outcome variable for plant i in time period t, conditional on being treated or not. We estimate the average treatment effect on the treated (ATT) relative to a base period:

$$ATT_{pt} = E\left[[Y_{it}(1) - Y_{it_0}(1)] - [Y_{it}(0) - Y_{it_0}(0)] | D_{ip} = 1\right]. \tag{1}$$

ATT_{pt} represents average difference between period t and base period t_0 for plants treated with classification p in 1993, relative to the difference in outcomes for the counterfactual case in which they were untreated. Since we cannot observe $E[Y_{it}(0) - Y_{it_0}(0)|D_{ip} = 1]$, we use outcomes for plants in 1993 attainment areas, assuming

$$E[Y_{it}(0) - Y_{it_0}(0)|D_{ip} = 1] = E[Y_{it}(0) - Y_{it_0}(0)|D_{ip} = 0] = \alpha \mathbf{z}_{it}, \tag{2}$$

where $\mathbf{z}_{it}$ is the vector of controls described in Section III.

We implement this model using variations of the estimator

$$Y_{it} = \sum_{p=1}^{P} \sum_{\tau=1,\tau\neq t_0}^{T} \beta_{p\tau}[D_{ip} \times 1(t = \tau)] + \alpha \mathbf{z}_{it} + \gamma_i + \epsilon_{it}, \tag{3}$$

in which γ_i is a plant fixed effect and ϵ_{it} is an error term. The variable D_{ip} equals unity if plant i has classification p in 1993, and a value of zero otherwise, with P equal to the total number of classifications. We cluster standard errors by state-classification to ensure robustness to arbitrary correlation in these groups.

We use three different specifications for ozone classification status. To highlight the importance of allowing regulatory intensity to vary we first set $P = 1$, collapsing the ozone classifications into a single nonattainment designation. We then set $P = 6$, allowing the impact to vary by ozone classification. Finally, based on the results of this second specification, we set $P = 3$, grouping classifications into categories with qualitatively similar results. The first category contains Subpart 1 and Marginal areas. The second contains Moderate, Serious, and Severe areas, and the third contains Extreme areas.

We employ two different specifications for time periods. First, $T = 12$ with t representing years 1987-1998, setting the base year t_0 to 1989. Our second specification uses sets $T = 3$, with t_0 being the base period 1987-1989, before the 1990 CAAAs became law.[25] The second period, 1990-1992, is the years between enactment and the first SIP submittal deadline, and the final period is 1993-1998.[26] County regulatory status is interacted with an indicator variable equal to unity if τ is period t, omitting the base period t_0. This interaction allows us to flexibly identify time-varying effects of 1993 regulatory status (arising from either anticipatory actions or lags in implementation, for example).[27]

Eqs. (1)-(3) together imply $ATT_{pt} = \beta_{pt}$. These parameters measure the approximate percent impact relative to the control group of being out of attainment for each classification in 1993 for each period, relative to t_0. In the nonattainment designation model, for example, a value of 0.03 would indicate that the difference in outcomes between periods t and t_0 was approximately three percentage points higher for a plant in a non-attainment area in 1993 than the difference corresponding to a plant in an attainment area.[28]

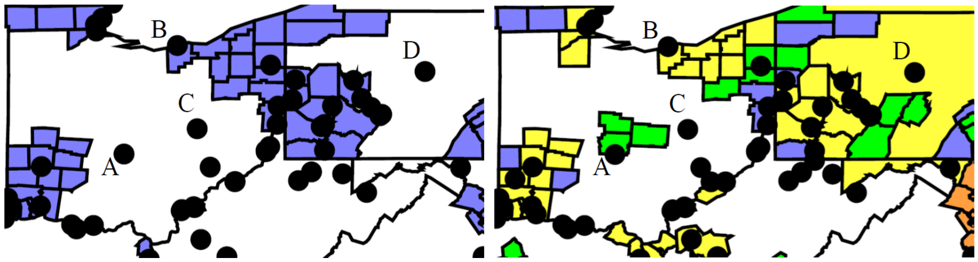
In addition to dividing ozone nonattainment into heterogeneous classifications, there are two key differences between our Eq. (3) and earlier approaches: we categorize plants in nonattainment areas that do not switch status as being treated; and we code plants in attainment, Subpart 1, and Marginal areas in the OTR as Moderate nonattainment.

[25]We test whether the parallel trends assumption is met in the pre-treatment period by running our preferred specification for the years 1987-1989 only, and including a false treatment for 1989. Results in Table 5 indicate that the false treatment is not significant.

[26]Our preferred specification uses three nonattainment categories and three time periods, gaining degrees of freedom by reducing the number of these interaction terms from 66 to 6.

[27]Note that although the P regulatory status terms D_{ip} for each plant are not time varying, the interaction with indicator $1(t = \tau)$ prevents them from being absorbed by plant-level fixed effect γ_i.

[28]Since the outcome uses a log transformation, we use $[e^x - 1] * 100$ to approximate the percent impact implied by parameter value x.



(a) 1988 (b) 1993

FIGURE 3. PLANT CATEGORIES OF PLANTS BASED ON CHANGE IN REGULATORY STATUS

Note: Shaded areas are regulated as ozone nonattainment. Plant A switches from attainment to nonattainment. Plant B is always in nonattainment. Plant C is always in attainment. Plant D is always in attainment, but regulatory regime changes due to Pennsylvania's participation in the OTR.
Source: Authors, based on 40 CFR 81, 42 USC §7511c(a).

The four categories of plants based on changes in regulatory status before and after the 1990 CAAAs are illustrated in the maps in Figure 3. Plant A is "new nonattainment," switching status from attainment to nonattainment. There are 13 plants of this type in the sample. Plant B (224 plants) is always in nonattainment, and Plant C (346 plants) is always in attainment. Plant D (13 plants) is always in attainment. Since it is in an OTR state (Pennsylvania), however, it is regulated as if it were in a Moderate ozone nonattainment area. A standard fixed effect difference-in-differences framework using attainment status from the CFR would place plant A in the treatment group and the others in the control group. Our preferred specification places plants A, B, and D in the treatment group.

The main justification for these changes is that plants in these categories experienced a change in regulation, particularly with respect to NOx emissions, despite a constant nominal designation in 40 CFR 81.[29] Figure 4 illustrates why regression results may be sensitive to how these plants are coded. The solid line represents average log employment for plants in a "pure" less-stringently regulated control group: those outside the OTR designated as in attainment with the ozone NAAQS throughout the period of study (Plant C in Figure 3). The trend

[29] Ozone regulations initially applied to sources of VOCs. It was only after the 1990 CAAAs that they applied to NOx sources as well.

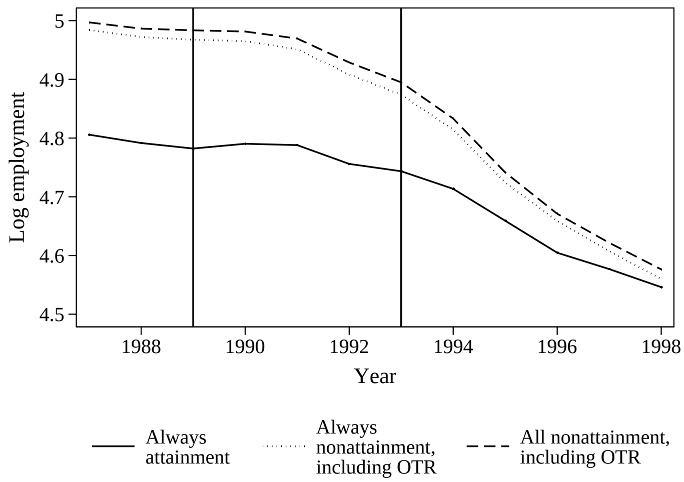


Figure 4. Mean employment trends by ozone regulatory status

Note: "Always attainment" includes plants in ozone attainment areas outside the OTR from 1987-1998. "Always nonattainment, including OTR" includes plants in nonattainment areas from 1987-1998 and plants in OTR attainment areas. "All nonattainment, including OTR" includes all plants in nonattainment areas after 1993 and all plants in the OTR. Series depict plants from balanced panel.

for these plants is slightly downward until 1992, when it begins a steeper decline. The dotted line represents average log employment for the more-stringently regulated plants that a standard fixed effect approach would include in the control group: plants always in ozone nonattainment areas (Plant B) and plants in ozone attainment areas in the OTR (Plant D). These plants have a trend similar to attainment plants until about 1993, when they begin a markedly steeper decline. The dashed line represents our preferred treatment group including all plants in areas potentially affected by ozone regulations: all plants in 1993 nonattainment areas and the OTR (A, B, and D). This group has slightly higher employment but otherwise mimics the trend of the dotted line.

These trends suggest that the 1990 CAAAs may have impacted not just the plants typically in the treatment group (plant A) but also plants that do not change status according to the CFR (plants B and D). If these plants contaminate the control group, they may mask impacts of the change in ozone regulation.

As noted by Walker (2013), Chay and Greenstone (2003), List et al. (2003), and others, the likely correlation of pollution with unobserved economic activity may pose a problem for identifying effects of environmental regulation. If local economic growth causes a county to become more highly regulated (e.g., by a switch in attainment status) and local economic growth also causes an increase in power plant employment, one risks falsely attributing increased employment to environmental regulation.

This issue is unlikely to be a concern in the context of our study, however. Statutory changes in the 1990 CAAAs, not changes in air quality monitoring data, caused plants to be subject to more stringent regulation. As illustrated in Figure 3, there are three categories of nonattainment plants in our sample: plants outside the OTR newly (after 1990) designated as nonattainment (type A), plants in nonattainment areas since before the 1990 CAAAs (type B), and plants in OTR attainment areas (type D). They experienced a change in regulatory regime due to the fact that it was only after 1990 that the stricter Subpart 2 ozone NAAQS requirements (the applicability to NOx emissions and the more stringent classifications) became law. Since it was determined by statute at the national level, this change in regulatory regime is arguably independent of contemporaneous changes in local economic activity.

There may also be a concern that unobserved economic shocks that determined historic air quality monitor values could have had persistent impacts on power plant employment decisions. For attainment area plants in the OTR this is not likely to be an issue, nor for plants in "clean" counties that changed status due to their location in the same MSA as a Serious, Severe, or Extreme county. Other new nonattainment designations were based on pre-treatment 1987-1989 monitoring data.[30] All "always" nonattainment areas had been designated as such

[30] Although they were made based on air quality monitoring data from 1987-89, new designations did not necessarily reflect a change in air quality during that period since a state may not have submitted a nonattainment designation for all areas with monitor data exceeding the standard.

since at least 1979. Although we cannot address this possibility directly, the fact that employment, generation, and capacity levels and trends in the 1987-89 pre-treatment period are not statistically different based on plants post-1990 nonattainment designations (see Table 1), reduces the concern that such shocks would have a significant impact up to a decade later.

V. Results

We have three main sets of results. The first shows the importance of accounting for changes in regulatory status over time and space. The second shows the importance of differentiating the treatment by regulatory stringency, i.e., ozone classification. The third explores mechanisms by which the ozone NAAQS may have impacted employment decisions at EGUs during this period.

Including plants whose regulatory regime changed over time in the control group masks regulatory impacts, suggesting the 1990 change in ozone regulations had no significant impacts on the power sector. In contrast, including these plants in the treated group suggests environmental regulations caused a significant downward shift in employment in nonattainment relative to attainment areas.

Second, we show the importance of specifying a heterogeneous treatment effect. A significant shift in employment only occurred at relatively stringent classifications. We show the relevance of this distinction in the context of using historical results to evaluate future regulations.

Third, we examine mechanisms by which environmental regulations impacted EGU employment decisions. One hypothesis is that regulations increased marginal costs, making affected sources less competitive than their less-regulated rivals. If that were the case, we would expect generation to be impacted as well as employment. We find, however, that generation impacts are small and insignificant.

This result has two implications. First, it reduces the concern that geographic spillovers are inflating the employment impacts. If employment impacts were driven by generation decisions, and environmental regulation causes generation to shift from nonattainment to attainment areas, this shift could bias net national employment estimates upwards in absolute value. Secondly, it suggests that environmental regulations induced technological change that increased labor-efficiency. We test this last effect using an instrumental variables approach similar to that employed by Fabrizio, Rose and Wolfram (2007).

A. Control group composition

Our main results identify the impact of ozone regulations relative to plants outside the OTR that are always in ozone attainment areas. To illustrate the importance of this distinction, we estimate two versions of Eq. (3) using the binary ozone attainment/nonattainment designation. The first defines $D_{ip} = 1$ only plants in new nonattainment counties according to 40 CFR 81 (plant A in Figure 3). The second specification moves plants in OTR attainment areas (plant D) to the treated group, and the third specification includes all plants in nonattainment or OTR counties to the treated group (plants A, B, and D).

Figure 5 illustrates $\beta_{p\tau}$ parameter trends using annual time interactions relative to a base year of 1989.[31] The standard specification, Model (1), masks the impact of the regulations, showing no significant impact. As shown in Model (2) plants in the OTR attainment areas are not driving this result (perhaps due to the fact that there are only 13 of them). If the control group is composed only of plants in attainment areas, as in Model (3), the interpretation changes. There is a statistically significant downward trend in relative employment, particularly after the 1993 SIP submittal deadline. There is weak evidence that the employment decline began after the 1990 Act in anticipation of the 1993 deadline.

Specifying year effects affords flexibility in identifying time trends, but has a cost in degrees of freedom. Given the shape of the overall trends and the fact that 1993 represents the deadline for SIP submittals, we divide the period of study into three intervals: the pre-statutory base period of 1987-1989, the period from

[31]Numerical results are in Appendix Table A1.

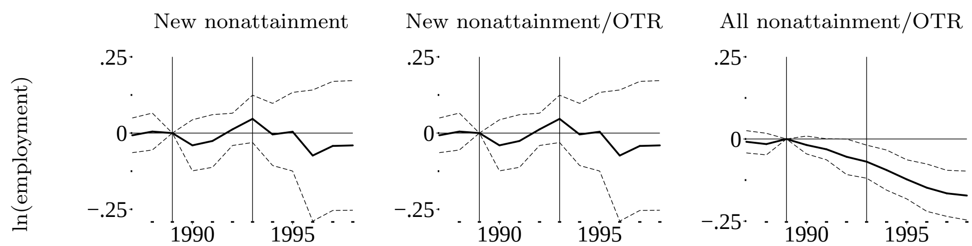


FIGURE 5. IMPACT OF 1993 OZONE NONATTAINMENT DESIGNATION OVER TIME, BY TREATMENT GROUP

Note: Plotted values are coefficients from Table A1 for the interaction between being in ozone nonattainment in 1993 and log employment. Dashed lines indicate 95 percent confidence intervals. There are two regression specifications of the treatment group. "New nonattainment" indicates only plants located in counties that switched from attainment to nonattainment between 1989 and 1993 are treated. "New nonattainment/OTR" indicates plants in attainment areas in the OTR are also treated. "All nonattainment/OTR" indicates plants always in nonattainment are also treated.

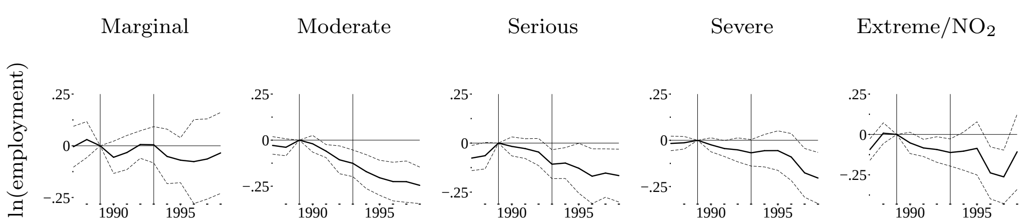


FIGURE 6. IMPACT OF 1993 OZONE CLASSIFICATION OVER TIME

Note: Plotted values are coefficients from Table A1 for the interaction between being in ozone nonattainment with a given classification in 1993 and each year for the two outcomes, measured in log employment. Dashed lines indicate 95 percent confidence intervals. Moderate includes plants in attainment, Subpart 1, and Marginal areas in the OTR. Control group is plants in ozone attainment areas outside the OTR in 1993.

1990-1992 between enactment of the 1990 CAAAs and the SIP deadline, and the years subsequent to the 1993 deadline.

Results, summarized in columns (1) - (3) of Table 4 are consistent with Figure 5. Whereas including all non-switching plants in the control group suggests no significant employment impact, purging regulated plants from the control group reveals a decline of almost 12 percent after 1993, which is statistically significant at the 1 percent level.[32] The data may not include workers contracted to install pollution control equipment, however, so this potential positive impact of the regulation cannot be ruled out.

B. Regulatory stringency

Results presented in Figure 5 do not distinguish differences in regulatory stringency among ozone classifications. Figure 6 presents results with annual time effects for a specification of Eq. (3) in which the ozone nonattainment designation is divided into classifications, with the control group being plants in ozone attainment areas outside the OTR.[33]

Plants in Marginal areas do not have a statistically significant employment trend throughout the period. Plants in Moderate and Serious areas, in contrast, exhibit significant declines in employment, particularly after 1993. Severe areas show a similar pattern, albeit at a weaker level of significance. Taken together, this evidence presents a nuanced relationship between regulatory stringency and employment; only plants in Moderate, Serious, and Severe areas appear to respond to increasing stringency by reducing employment.[34]

Column (4) in Table 4 presents the three-period model in which Subpart 1 and Marginal classifications are combined into a single S1M category, and Mod-

[32]These changes are relative to corresponding changes in attainment areas with respect to the 1987-1989 baseline period.

[33]For numerical results refer to Appendix Table A1.

[34]Interpretation of Extreme areas is complicated by the fact that there were only 11 such plants (all in the Los Angeles area) and they were also the only ones to be in an NO_2 nonattainment area. As such, they were also the only plants to be federally regulated under the NAAQS for NOx emissions prior to 1990, and it is not possible to disentangle these effects. We therefore control for plants in Extreme areas, but do not emphasize the results.

Table 4— Ozone classification impact on employment

	Dependent Variable: Log employment			
	(1)	(2)	(3)	(4)
O3 NAAQS × 90-92	−0.017	−0.007	−0.027	
	(0.028)	(0.024)	(0.018)	
O3 NAAQS × 93-98	−0.017	−0.014	-0.120^{***}	
	(0.070)	(0.074)	(0.030)	
S1M × 90-92				−0.018
				(0.019)
S1M × 93-98				-0.072^{*}
				(0.043)
MSS × 90-92				−0.030
				(0.022)
MSS × 93-98				-0.141^{***}
				(0.037)
Extreme × 90-92				−0.046
				(0.038)
Extreme × 93-98				-0.129^{*}
				(0.076)
Alt. NAAQS × 90-92	−0.023	−0.023	−0.016	−0.015
	(0.017)	(0.018)	(0.019)	(0.020)
Alt. NAAQS × 93-98	−0.035	−0.035	−0.006	−0.005
	(0.042)	(0.042)	(0.042)	(0.041)
Restructured	-0.069^{**}	-0.069^{**}	-0.061^{*}	-0.060^{*}
	(0.033)	(0.033)	(0.034)	(0.034)
Muni × 90-92	0.071^{***}	0.071^{***}	0.069^{***}	0.069^{***}
	(0.016)	(0.016)	(0.016)	(0.016)
Muni × 93-98	0.080^{***}	0.080^{***}	0.079^{***}	0.076^{***}
	(0.023)	(0.023)	(0.022)	(0.022)
Title IV	−0.020	−0.020	−0.019	−0.018
	(0.021)	(0.021)	(0.021)	(0.021)
Plant F.E.	Yes	Yes	Yes	Yes
Region × Year × Fuel F.E.	Yes	Yes	Yes	Yes
Always nonattainment	Control	Control	Treated	Treated
OTR attainment	Control	Treated	Treated	Treated
R^2	0.477	0.477	0.487	0.488
Plant-years	6439	6439	6439	6439
Plants	596	596	596	596

Note: Impacts are relative to plants in ozone attainment areas in the 1987-1989 base period. O3 NAAQS refers to plants in counties out of attainment with the ozone standard as of 1993. S1M combines Subpart 1 and Moderate ozone nonattainment classifications. MSS combines Moderate, Serious, and Severe classifications. There are 11 plants in the Extreme classification which is also the country's only NO_2 nonattainment area. Alt. NAAQS is a dummy for areas out of attainment with PM_{10} and SO_2 NAAQS. Restructured is a dummy for IOUs in states that restructured electricity markets; it takes a value of unity after initiation of public hearings. Muni is a dummy for plants that are not investor-owned. Always nonattainment refers to plants in nonattainment counties that do not change status. OTR attainment refers to plants in attainment counties within the OTR. Standard errors in parentheses clustered by state-by-ozone-classification. *, **, and *** indicate P-values of 10, 5, and 1 percent.

erate, Serious, and Severe classifications are collapsed into MSS. Results for all three specifications are consistent with the graphical results for the 12-period model. Plants in relatively lightly regulated Subpart 1 and Marginal areas have

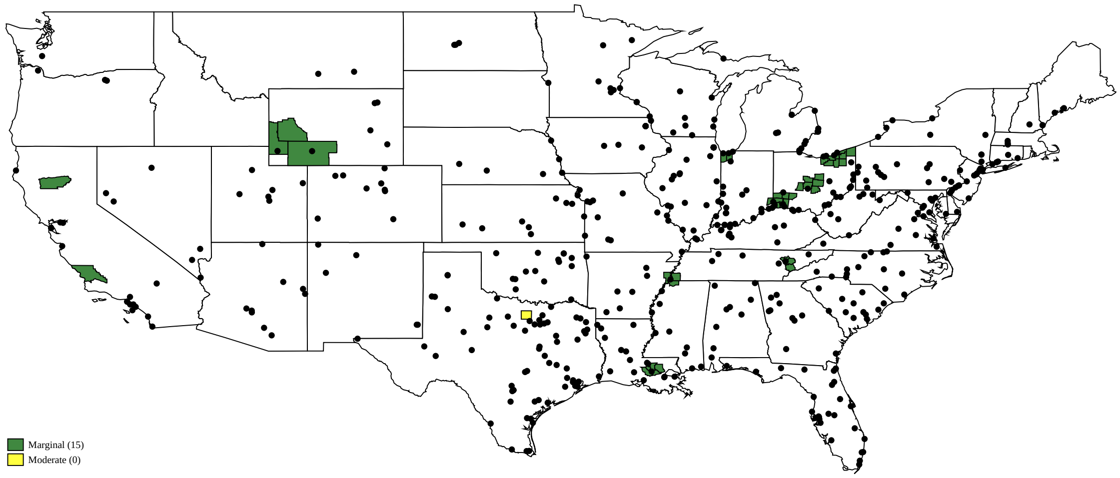


Figure 7. Plants and counties newly designated as nonattainment with 2008 ozone NAAQS

Note: Excludes newly designated marginal or moderate nonattainment areas within the OTR. Parentheses indicate plants in counties newly designated with the given classification.
Source: Authors, based on 40 CFR 81, 42 USC §7511c(a), and US EPA (2003).

small employment impacts that are only weakly significant after 1993. Those in Moderate, Serious and Severe classifications have highly significant negative employment impacts, particularly after 1993.

To illustrate the importance of accounting for differences in stringency we conduct an exercise predicting the impact of a change in designations on our sample. The ozone NAAQS has been revised twice after 1998. The most recent revision, in 2008, tightened the previous standard promulgated in 1997.[35] Designations under the 2008 standard were finalized in 2012. 48 counties previously in attainment were newly designated as nonattainment. Of these 46 were classified as Marginal and 2 were classified as Moderate. As illustrated in Figure 7, 15 of the EGUs in our sample were located in these newly designated areas, all Marginal.

Figure 8 presents two back of the envelope predictions of the new designations' employment impact. Panel (a) uses estimates from Model (2) in Table A1 that do not distinguish between ozone classifications. They predict a significant relative

[35]Designations for the 1997 ozone standard did not take place until 2002.

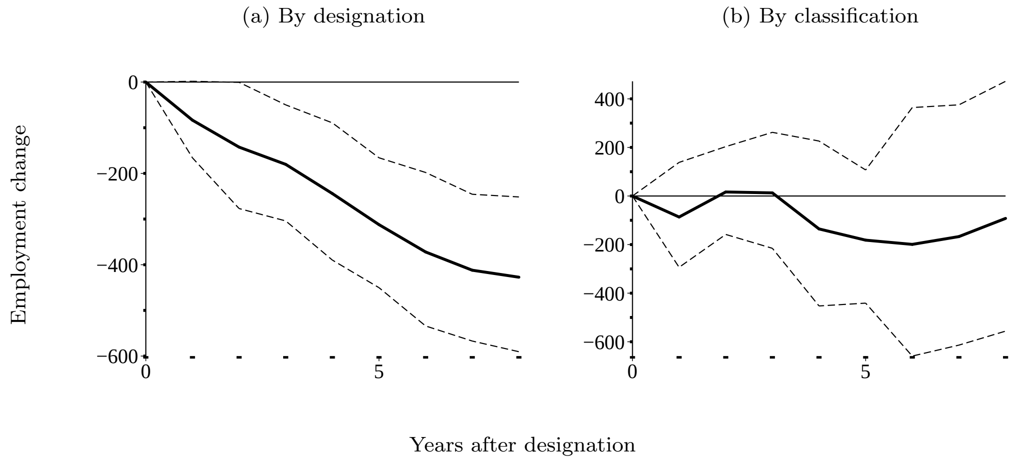


FIGURE 8. PREDICTED EMPLOYMENT IMPACT OF 2008 OZONE NAAQS

Note: Plotted values are predicted change in labor demand relative to plants in attainment counties over time plants in counties newly designated as nonattainment with the 2008 Ozone NAAQS. Dashed lines indicate 95 percent confidence intervals. Panel (a), using parameter estimates from Model (2) of Table A1, does not distinguish among nonattainment classifications. Panel (b), using parameter estimates from Model (3) in Table A1, uses the parameter estimate appropriate to each plant's county classification.

decline in employment reaching about 400 employees eight years after finalizing the standard. In contrast Panel (b), using coefficients for the Marginal classification in Model (3) of Table A1, shows no significant impact.

These results illustrate how prospective employment analysis can be sensitive to modeling regulatory stringency. The estimated impact for nonattainment designation should roughly correspond to the average impact across the various ozone classifications for the years in the sample. However, using the nonattainment designation parameter to evaluate a rulemaking that causes a different distribution of ozone classifications than those in the 1990s can introduce substantial bias. For the case of the 2008 ozone NAAQS considered here, using the binary nonattainment designation parameter rather than the classification parameters would result in a significant over-estimate of job loss since none of the affected plants were in Moderate, Serious, or Severe classifications.

C. Robustness Checks

Summary statistics in Table 1 reveal significant differences between attainment and nonattainment areas for several covariates. This lack of balance has the potential to cause a misattribution of ozone regulation impacts.

Fabrizio, Rose and Wolfram (2007) and Fowlie (2010), for example, find evidence suggesting IOUs in states facing market restructuring had different incentives regarding input use. Of particular concern is the fact that Fabrizio, Rose and Wolfram (2007) find IOUs in restructuring states had a significant drop in labor use conditional on output. Figure A2 depicts states that initiated restructuring hearings between 1993 and 1998 and eventually restructured their markets.[36] Comparing this map with panel (b) of Figure 2 shows the overlap between market restructuring and ozone regulation during this period. From Table 1, plants in ozone nonattainment areas were over twice as likely to be IOUs in restructuring states than plants in attainment areas.[37] It is possible that the estimated employment impact for nonattainment is driven by plants in nonattainment areas that are affected by restructuring or other observable factors. We address this type of concern in several ways.

Difference-in-differences estimation is most appropriate when treatment–in our case being designated as in nonattainment with respect to ozone NAAQS–is random. Areas are not randomly designated as ozone nonattainment, however. Since the control group is not similar to the treated plants based on average observable characteristics, our main difference-in-differences results in Model (4) of Table 4 may be biased. Fortunately, we can approximate a randomized experiment by selecting a properly matched control group to eliminate or reduce this potential bias Rubin (2008). To get approximately unbiased estimates we need a control group that is not systematically different from the plants in ozone nonattainment areas in our sample (Stuart and Rubin, 2008). We use propensity score matching (as de-

[36]The earliest hearings recorded in the Fabrizio, Rose and Wolfram (2007) data began in 1993.
[37]This difference is statistically significant at the 99 percent level.

velped by Rosenbaum and Rubin, 1983) based on pre-1990 attributes–excluding the outcome variable–to select a statistically similar control group from non-treated plants.[38] We use difference-in-differences estimation to investigate how the ozone NAAQS affected employment relative to this matched control group.

We use nearest neighbor matching with replacement.[39] At the potential cost of losing precision in coefficient estimation due to dropped observations (included plants drop from 596 to 340), this approach reduces potential bias arising from selection on observables by generating close matches between treated and control plants (based on pre-policy characteristics) (Stuart and Rubin, 2008). Matched regression estimates and standard errors, reported in Model (1) in Table 5, are close to main estimates, suggesting selection on observables is not driving results.

Next we consider the potential for market structure to affect the results. Model (2) interacts non-IOU ("Muni") plant ownership with ozone classification and period. If ownership were driving results we would expect this interaction term to be significant. Model (3) is a similar specification with the interaction term being IOU $\times$ restructuring state after hearings began $\times$ classification $\times$ period.[40] For both models, the interaction terms are not significantly different from zero. Moreover the point estimates and standard errors of the ozone classification parameters without the interaction terms are close to those of our main results in Model (4) of Table 4. It is therefore unlikely that either of these factors unduly affects the main results.

Model (4) of Table 5 presents a similar exercise to examine whether the labor impact is driven by plants in nonattainment with other NAAQS. The interaction terms are not significant and the estimates and standard errors for the ozone classification are similar to the main results.

In theory input prices may impact plant labor decisions. Due to lack of high-

[38]We also require plants in our chosen control group to have common support, such that areas of the covariate space include both treated and control units. Only performing regression analyses in areas with common support will result in more robust statistical inference (Stuart and Rubin, 2008).

[39]We match treatment and control plants using `psmatch2` (Leuven and Sianesi, 2003) in Stata.

[40]The earliest restructuring hearings took place in 1993.

Table 5— Ozone classification impact on employment: Alternative specifications

	Dependent Variable: Log employment							
	(1) Matched Sample[a]	(2) Plant Owner[b]	(3) Electricity Market[c]	(4) Alternate NAAQS[d]	(5) Input Prices[e]	(6) Entry/ Exit[f]	(7) Balanced Panel[g]	(8) Falsification Test[h]
S1M × 89								−0.014
								(0.011)
MSS × 89								0.004
								(0.013)
Muni × 89								0.037***
								(0.008)
S1M × 90-92	−0.007	−0.004	−0.018	−0.027	−0.018	−0.017	−0.006	
	(0.020)	(0.017)	(0.019)	(0.020)	(0.019)	(0.019)	(0.018)	
S1M × 93-98	−0.046	−0.055	−0.068	−0.100**	−0.067	−0.078*	−0.026	
	(0.047)	(0.061)	(0.042)	(0.041)	(0.042)	(0.043)	(0.060)	
MSS × 90-92	−0.022	−0.024	−0.030	−0.014	−0.035*	−0.030	−0.024**	
	(0.023)	(0.024)	(0.022)	(0.025)	(0.021)	(0.022)	(0.012)	
MSS × 93-98	−0.115***	−0.129***	−0.140***	−0.141***	−0.143***	−0.143***	−0.118***	
	(0.039)	(0.042)	(0.039)	(0.041)	(0.037)	(0.036)	(0.031)	
S1M × 90-92 × Variable		−0.045		0.023				
		(0.049)		(0.043)				
S1M × 93-98 × Variable		−0.057	−0.024	0.137				
		(0.089)	(0.118)	(0.116)				
MSS × 90-92 × Variable		−0.046		−0.077**				
		(0.055)		(0.039)				
MSS × 93-98 × Variable		−0.044	−0.003	0.011				
		(0.086)	(0.059)	(0.081)				
Restructured	−0.044	−0.062*	−0.056	−0.057*	−0.061*	−0.059	−0.069*	
	(0.035)	(0.035)	(0.046)	(0.034)	(0.036)	(0.036)	(0.035)	
Muni × 90-92	0.070***	0.066***	0.069***	0.071***	0.071***	0.069***	0.082***	
	(0.023)	(0.018)	(0.016)	(0.016)	(0.016)	(0.016)	(0.019)	
Muni × 93-98	0.094**	0.076***	0.075***	0.077***	0.079***	0.072***	0.093***	
	(0.042)	(0.023)	(0.023)	(0.022)	(0.025)	(0.022)	(0.030)	
Title IV	−0.002	−0.018	−0.018	−0.019	−0.020	−0.030	−0.022	
	(0.027)	(0.021)	(0.021)	(0.021)	(0.021)	(0.024)	(0.021)	
Interaction variable	None	Muni	Restructured	Alt. NAAQS	None	None	None	None
Plant F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region × Year × Fuel F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.537	0.493	0.488	0.490	0.491	0.489	0.536	0.125
Plant-years	3818	6439	6439	6439	6322	6439	4872	1618
Plants	340	596	596	596	588	596	406	559

Note: Impacts are relative to plants in ozone attainment areas in the 1987-1989 base period, except for model (9) which is relative to 1987-1988. S1M combines Subpart 1 and Moderate ozone nonattainment classifications. MSS combines Moderate, Serious, and Severe classifications. "Variable" signifies that the term is interacted with the "Interaction variable" listed at the bottom of the table. Unless otherwise noted, other controls include log wages, log input prices, Alternate NAAQs nonattainment by period, and Extreme ozone nonattainment by period. Standard errors in parentheses clustered by state-by-ozone-classification. [a]Nearest neighbor with replacement. [b]Dummy for non-privately owned plants. [c]Dummy for investor-owned plants in restructuring states after initiation of public hearings. [d]Dummy for plants in counties out of attainment for either PM_{10} or SO_2 NAAQS. [e]Does not control for input prices.[f]Does not control for input prices. One employee imputed to missing years for entering and exiting plants and plants reporting non-positive net generation in eGRID.[g]Includes only plants with no missing years. [h]Only includes data for 1987-1990. *, **, and *** indicate P-values of 10, 5, and 1 percent.

quality input price data for all plants in our sample, we do not directly control for plant-specific input prices in our main specification.[41] In Model (5) we use state utility proxy wage data from Fabrizio, Rose and Wolfram (2007) and expenditures per heat input from Fabrizio, Rose and Wolfram (2007) and the EIA to control for prices. In doing so, we lose 117 plant-year observations, but point estimates and standard errors remain largely unaffected.

The next two models explore how missing data might affect the results. The main results drop missing plant-years from the regression. This approach may understate (in absolute value) labor impacts if regulations cause plant exit. As a conservative approach, Model (6) imputes a single worker for each missing plant-year corresponding to entry and exit (as defined in Section III) or that reports non-positive net generation in eGRID. To evaluate the degree to which (apart from entry or exit) plants with missing data may be driving results, Model (7) includes only those 406 plants with no missing observations. Results are similar in magnitude and precision to those estimated by the other models.

The last specification examines the plausibility of the common trends assumption implicitly underlying the difference in difference approach. We cannot test the hypothesis that trends for treated and control plants would have been the same for the counterfactual in which no plants were treated. Model (8), however, tests the hypothesis that the two groups had similar trends in the pre-treatment period. This model uses data for the period before the 1990 CAAAs were signed into law (1987-1989). If plants in 1993 ozone nonattainment counties had a different pre-treatment trend from those in attainment counties, then the interaction terms S1M$\times$89 and MSS$\times$89 should be different from zero, whereas the estimates are small and insignificant.

In sum, evidence from the eight robustness checks presented in Table (5) does not support the hypothesis that the main impacts of ozone classification on employment reported in Model (4) of Table 4 are caused by selection on observ-

[41] Fuel$\times$region$\times$year fixed effects should absorb common input price shocks at the NERC-region level.

ables, plant ownership type, electricity market restructuring, nonattainment with NAAQS of other pollutants, plant entry and exit, missing data, or diverging pre-treatment trends. Moreover, point estimates for classification-by-time treatments are consistent across specifications: S1M plants range from -0.02 to 0 in the 1990-92 period (compared to the main estimate of -0.02) and from -0.09 to -0.03 from 1993-98 (compared with -0.07). MSS plants have a range of -0.04 to -0.02 in the 1990-92 period (compared with -0.03) and a highly significant range of -0.15 to -0.12 from 1993-98 (compared with -0.14).

D. Possible mechanisms

Referring to Figure 1, there are two likely avenues by which a more stringent classification could affect plant outcomes. Plants in our sample are all major sources, so tightening the major source threshold is not likely to be relevant. The penalty fee program has rarely been implemented, and emissions statements are a paperwork exercise, so these factors are also unlikely to be important. This leaves the NSR offset ratio (increasing for each classification), the applicability of requirements to NOx in addition to VOCs (applicable to Marginal and above), and enhanced RACT requirements (applicable to Moderate and above) as likely candidates. The fact that there does not appear to be a difference in performance between Moderate, Serious, and Severe undermines the case for NSR offsets being a driving mechanism. This leaves the NOx and enhanced RACT requirements.

For sources triggering NSR, the main difference between these two requirements is the Lowest Achievable Emission Rate (LAER). New or modified sources in a Subpart 1 area would not be required to install LAER NOx controls, whereas those in Marginal and above areas would. The lack of significant impact in Marginal areas, however, reduces the plausibility of this potential channel.

For utility boilers that do not trigger NSR, the Marginal area NOx requirements were not binding. For these areas, states were required to impose RACT controls described in EPA guidance *prior to* 1990 (42 USC §7511a(a)(2)(A)). For power plants, however, no such guidance existed (for NOx or VOCs).[42] Thus, the NOx and VOC RACT requirement had no practical effect for these sources. In contrast, the "enhanced" RACT requirement for Moderate and above classifications mandated states to impose RACT controls described by EPA guidance *after* 1990 (42 USC §7511a(b)(2)). The EPA issued guidance for NOx controls for fossil-fuel burning utility boilers in early 1994 (US EPA, 1994). The similarity in performance for plants in counties with Moderate, Serious, or Extreme classifications might be explained by the common enhanced RACT requirement.

Results in Section V.B suggest that the increased environmental regulation in Moderate, Serious, and Severe ozone nonattainment areas generally caused a decline in plant employment relative to attainment areas. In principle, the reduction in employment could occur through two channels. Requirements such as enhanced RACT could increase marginal costs. During the mid-1990s electricity markets were being restructured in many states, opening them to increased competition. An increase in marginal costs could cause a nonattainment plant to drop in the dispatch order causing a reduction in generation and employment. Alternatively, plants may have upgraded technology while installing NOx controls, reducing both emissions and labor requirements per MWh generation.[43] If they did, that might explain the relatively high labor impacts in spite of the low cost of typical controls like low-NOx burners.

If generation displacement occurred from nonattainment plants to attainment plants, and plant employment were positively correlated with generation, then estimates from the previous sections could exaggerate net national employment impacts of environmental regulation. In such a case, control plants would produce more electricity if regulated plants were treated than if they were not. If total generation remained unchanged then the decrease in generation in nonattainment

[42] See `http://www.epa.gov/groundlevelozone/SIPToolkit/ctgs.html`.

[43] Swift (2001) provides anecdotal evidence that power plants may have responded to the Title IV NOx requirements by introducing efficiency-enhancing process changes. Unfortunately neither the Pollution Abatement Cost Expenditures Survey nor eGRID database contain either pollution control or emissions data over a time period that would allow us to evaluate this mechanism empirically.

plants, and any associated labor differential, would effectively be counted twice.

To consider the question of how environmental regulation affected employment, we run the previous regressions using net generation (log MWh) as a dependent variable. Results reported in Table 6 suggest that such spillovers are unlikely to be driving employment results. In none of the specifications does generation appear to be significantly affected by ozone regulations.

This disconnect between generation and employment reduces concerns that spillovers in electricity markets bias estimated employment impacts. It suggests environmental regulation may have affected employment not by reducing output, but perhaps by inducing firms to change their production technology in a way affecting labor intensity.

Pollution control retrofits may involve engineering studies and plant shutdowns. One mechanism by which this factor substitution effect might occur would be if plant managers took advantage of these sunk engineering and shutdown costs to design and install upgrades that would not have otherwise been economical. If these upgrades lowered labor intensity (e.g., through reduced maintenance) they may have led to reduced employment relative to unregulated plants.[44]

Given the general pattern of increasing generation and reduced employment during the 1990s (Figure 4) it is possible that environmental regulation affected employment by accelerating the trend of reduced labor intensity that was taking place across the sector. To explore this mechanism, we modify our previous labor regressions to control for changes in output. This analysis follows Fabrizio, Rose and Wolfram (2007), including net generation as an explanatory variable for labor use. Recognizing its endogeneity as a choice variable, we use their strategy of instrumenting it with state-level electricity demand. We also adopt their method of using by plant-epoch fixed effects to control for changes in plant capacity.[45]

Models reported in Table 7 estimate changes in labor efficiency rather than

[44]Gray and Shadbegian (1998) identify a similar phenomenon in the pulp and paper sector, finding a significant relationship between productive (non-abatement) investment and the amount and timing of pollution control investment.

[45]A plant epoch is contiguous years over which capacity changes are less than 40 MW or 15 percent.

Table 6— Ozone classification impact on net generation

	Dependent variable: Log MWh			
	(1)	(2)	(3)	(4)
O3 NAAQS × 90-92	−0.048	0.036	−0.032	
	(0.088)	(0.068)	(0.040)	
O3 NAAQS × 93-98	−0.090	−0.138	−0.046	
	(0.067)	(0.107)	(0.052)	
S1M × 90-92				−0.075
				(0.058)
S1M × 93-98				−0.090
				(0.081)
MSS × 90-92				−0.011
				(0.042)
MSS × 93-98				−0.025
				(0.055)
Extreme × 90-92				−0.231**
				(0.091)
Extreme × 93-98				−0.189*
				(0.113)
Alt. NAAQS × 90-92	0.019	0.022	0.027	0.044
	(0.032)	(0.032)	(0.035)	(0.032)
Alt. NAAQS × 93-98	0.029	0.026	0.043	0.054
	(0.054)	(0.054)	(0.050)	(0.055)
Restructured	−0.036	−0.032	−0.035	−0.037
	(0.044)	(0.045)	(0.045)	(0.046)
Muni × 90-92	−0.020	−0.018	−0.021	−0.011
	(0.053)	(0.052)	(0.053)	(0.054)
Muni × 93-98	−0.090	−0.089	−0.091	−0.083
	(0.067)	(0.067)	(0.067)	(0.069)
Title IV	−0.015	−0.012	−0.014	−0.014
	(0.026)	(0.026)	(0.026)	(0.026)
Plant F.E.	Yes	Yes	Yes	Yes
Region × Year × Fuel F.E.	Yes	Yes	Yes	Yes
Always nonattainment	Control	Control	Treated	Treated
OTR attainment	Control	Treated	Treated	Treated
R^2	0.293	0.294	0.293	0.294
Plant-years	6439	6439	6439	6439
Plants	596	596	596	596

Note: Impacts are relative to plants in ozone attainment areas in the 1987-1989 base period. O3 NAAQS refers to plants in counties out of attainment with the ozone standard as of 1993. S1M combines Subpart 1 and Moderate ozone nonattainment classifications. MSS combines Moderate, Serious, and Severe classifications. There are 11 plants in the Extreme classification which is also the country's only NO_2 nonattainment area. Alt. NAAQS is a dummy for areas out of attainment with PM_{10} and SO_2 NAAQS. Restructured is a dummy for IOUs in states that restructured electricity markets; it takes a value of unity after initiation of public hearings. Muni is a dummy for plants that are not investor-owned. Always nonattainment refers to plants in nonattainment counties that do not change status. OTR attainment refers to plants in attainment counties within the OTR. Standard errors in parentheses clustered by state-by-ozone-classification. *, **, and *** indicate P-values of 10, 5, and 1 percent.

overall labor demand. Model (1) presents OLS results, while Models (2) and (3) use state sales as an instrument for net generation.[46] Model (2) employs the

[46]First-stage regression results with natural log net generation as dependent variable are presented in Appendix Table A2. In the first stage, the excluded instrument, annual state electricity sales, has the

approach used in our main results in Table 4. Model (3) introduces an interaction term between restructuring and ozone classifications to identify whether efficiency impacts are driven by nonattainment plants in restructuring areas. Overall results are consistent with the hypothesis that environmental regulation reduced labor use operating through the channel of increased efficiency. All models report a statistically significant reduction in labor use (controlling for output and capacity) ranging from approximately 13 to 15 percent for plants in Moderate, Serious, and Severe ozone nonattainment areas after 1993, and the interaction terms between restructuring and ozone classifications are not significant.

VI. Conclusion

We examine three aspects of the Clean Air Act that may affect inference regarding impacts of environmental regulations: geographic coverage of federal requirements, how requirements change over time, and intensity of requirements. Specifically, we analyze the impacts of the 1990 change in ozone NAAQS regulations on employment and electricity generation in the U.S. fossil-fuel burning electric power sector. In periods of low economic growth policy makers and the general public are interested in the potential impact of environmental regulation on output and employment. Due to its role as a major source of pollutants and in providing an essential input to other industrial sectors, impacts on the electricity sector are of particular importance.

Results suggest that identifying impacts only off plants that switch attainment status (i.e., including non-switching nonattainment plants in the control group) generates estimates of no significant impact of ozone regulation on employment or generation. In contrast, allowing for time-varying impacts of regulation permits us to identify impacts on all nonattainment plants, suggesting that ozone rules reduced employment in nonattainment relative to attainment areas.

Breaking down nonattainment areas into classifications yields more nuanced

expected statistically significant positive effect on plant-level net generation.

Table 7— Ozone classification impact on labor efficiency

	Dependent Variable: Log employment		
	(1)	(2)	(3)
S1M × 90-92	−0.009	0.022	0.024
	(0.014)	(0.031)	(0.032)
S1M × 93-98	−0.052	−0.023	−0.004
	(0.047)	(0.048)	(0.049)
MSS × 90-92	-0.040^{*}	−0.036	−0.036
	(0.022)	(0.024)	(0.025)
MSS × 93-98	-0.141^{***}	-0.127^{***}	-0.114^{**}
	(0.035)	(0.045)	(0.050)
Extreme × 90-92	−0.037	0.019	0.021
	(0.037)	(0.070)	(0.071)
Extreme × 93-98	-0.133^{*}	−0.082	−0.136
	(0.067)	(0.103)	(0.092)
Alt. NAAQS × 90-92	−0.011	−0.023	−0.023
	(0.021)	(0.026)	(0.027)
Alt. NAAQS × 93-98	0.005	−0.022	−0.025
	(0.039)	(0.047)	(0.048)
S1M × 93-98 × Restructured			−0.096
			(0.105)
MSS × 93-98 × Restructured			−0.051
			(0.057)
Extreme × 93-98 × Restructured			0.165
			(0.121)
Muni × 91-92	0.073^{***}	0.075^{***}	0.075^{***}
	(0.016)	(0.026)	(0.026)
Muni × 93-98	0.081^{***}	0.109^{***}	0.113^{***}
	(0.024)	(0.037)	(0.039)
ln(MWh)	0.063^{***}	0.440^{*}	0.457^{*}
	(0.012)	(0.229)	(0.238)
Restructured	−0.050	−0.042	−0.018
	(0.032)	(0.029)	(0.037)
Title IV	−0.014	−0.007	−0.006
	(0.021)	(0.024)	(0.024)
Plant F.E.	Yes	Yes	Yes
Plant-epoch F.E.	Yes	Yes	Yes
Region × Year × Fuel F.E.	Yes	Yes	Yes
IV	No	Yes	Yes
R^2	0.615	0.331	0.307
Plant-years	6439	6439	6439
Plant-epochs	716	716	716
Plants	596	596	596

Note: Impacts are relative to plants in ozone attainment areas in the 1987-1989 base period. S1M combines Subpart 1 and Moderate ozone nonattainment classifications. MSS combines Moderate, Serious, and Severe classifications. The Extreme ozone nonattainment area is also the country's only NO_2 nonattainment area. Alt. NAAQS is a dummy for areas out of attainment with PM_{10} and SO_2 NAAQS. Restructured is a dummy for IOUs in states that initiated retail electricity market deregulation. Muni is a dummy for plants that are not investor-owned. IV No indicates an OLS specification. IV Yes indicates that the log of state electricity sales is an instrument for ln(MWh). Standard errors in parentheses clustered by state-by-ozone-classification. *, **, and *** indicate P-values of 10, 5, and 1 percent.

effects. Significant negative employment impacts after 1993 are limited to areas (Moderate and above) subject to enhanced RACT requirements. Nonattainment areas lacking these requirements show no significant trends.

This latter set of results is important if one wishes to use historical experience with clean air regulation to analyze potential new policies. An analysis of the 2008 ozone NAAQS based on a binary attainment/nonattainment designation would lead to a significant over-estimate (in absolute value) of negative relative employment effects due to the fact that most newly designated areas for that rule had a Marginal classification.

Perhaps the most direct mechanism by which regulations might affect employment is by raising marginal production costs, inducing regulated plants to produce less output and therefore use fewer inputs, including labor. Instead, we find that employment declines without any significant decline in generation, even controlling for electricity market restructuring taking place during this period. Alternatively, plant managers may have undertaken efficiency-enhancing process changes to reduce emissions or taken advantage of the shutdown period and engineering evaluations necessary for retrofiting pollution controls to perform unrelated efficiency upgrades to the facility. Results from a labor efficiency model showing a drop in labor use conditional on generation are consistent with this channel.

REFERENCES

Auffhammer, Maximilian, Antonio M. Bento, and Scott E. Lowe. 2009. "Measuring the effects of the Clean Air Act Amendments on ambient PM_{10} concentrations: The critical importance of a spatially disaggregated analysis." *Journal of Environmental Economics and Management*, 58: 15–26.

Becker, R. 2005. "Air pollution abatement costs under the Clean Air Act: Evidence from the PACE survey." *Journal of Environmental Economics and Management*, 50: 144–169.

Becker, R, and J Henderson. 2000. "Effects of air quality regulation on polluting industries." *Journal of Political Economy*, 108: 379–421.

Berman, Eli, and Linda Bui. 2001. "Environmental regulation and labor demand: Evidence from the South Coast Air Basin." *Journal of Public Economics*, 79(2): 265–295.

Carr, D. 2011. "The Intergovernmental Fiscal Effects of the Clean Air Act." *Public Finance Review*, 39(6): 810–830.

Carr, D, and W Yan. 2012. "Federal Environmental Policy and Local Industrial Diversification: The Case of the Clean Air Act." *Regional Studies*, 46(5): 639–649.

Chay, Kenneth, and Michael Greenstone. 2003. "The Impact of Air Pollution on Infant Mortality: Evidence from Geographic Variation in Pollution Shocks Induced by a Recession." *Quarterly Journal of Economics*, 118: 1121–1167.

Chay, Kenneth, and Michael Greenstone. 2005. "Does Air Quality Matter? Evidence from the Housing Market." *Journal of Political Economy*, 113(2): 376–424.

Condliffe, S, and O Morgan. 2009. "The Effects of Air Quality Regulation Enforcement and the Firm Location Decision among U.S. Counties." *Journal of Regulatory Economics*, 36(1): 83–93.

Curtis, Mark. 2014. "Who Loses Under Power Plant Cap-and-Trade Programs?" *NBER Working Paper 20808.*

Fabrizio, Kira R., Nancy L. Rose, and Catherine D. Wolfram. 2007. "Do Markets Reduce Costs? Assessing the Impact of Regulatory Restructuring on US Electric Generation Efficiency." *American Economic Review*, 97: 1250–1277.

Ferris, Ann E., Ronald J. Shadbegian, and Ann Wolverton. 2014. "The Effect of Environmental Regulation on Power Sector Employment: Phase I of the Title IV SO_2 Trading Program." *Journal of the Association of Environmental and Resource Economists*, 1(4): 521–553.

Foster, John S., Earl Gjelde, William R. Graham, Robert J. Hermann, Henry M. Kluepfel, Richard L. Lawson, Gordon K. Soper, Jr. Lowell L. Wood, and Joan B. Woodard. 2008. "Critical National Infrastructures." Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack.

Fowlie, Meredith. 2010. "Emissions Trading, Electricity Industry Restructuring, and Investment in Pollution Control." *American Economic Review*, 100: 837–869.

Gray, Wayne, and Ron Shadbegian. 2014. "Do the job effects of regulation differ with the competitive environment?" In *Does Regulation Kill Jobs?*. , ed. Cary Coglianese, Adam Finkel and Chris Carrigan. University of Pennsylvania Press.

Gray, Wayne B., and Ronald J. Shadbegian. 1998. "Environmental Regulation, Investment Timing, and Technology Choice." *Journal of Industrial Economics*, 46(2): 235–256.

Gray, Wayne B, Ronald J Shadbegian, Chunbei Wang, and Merve Meral. 2014. "Do EPA regulations affect labor demand? Evidence from the pulp and paper industry." *Journal of Environmental Economics and Management*, 68(1): 188–202.

Greenstone, M. 2002. "The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufacturers." *Journal of Political Economy*, 110(6): 1175–1219.

Greenstone, Michael. 2003. "Estimating Regulation-Induced Substitution: The Effect of the Clean Air Act on Water and Ground Pollution." *American Economic Review Papers and Proceedings*, 93(2): 442–448.

Greenstone, Michael. 2004. "Did the Clean Air Act cause the remarkable decline in sulfur dioxide concentrations?" *Journal of Environmental Economics and Management*, 47(585-611).

Greenstone, Michael, J List, and Chad Syverson. 2012. "The Effects of Environmental Regulation on the Competitiveness of U.S. Manufacturing." NBER Working Paper 18392.

Henderson, J. 1996. "Effects of air quality regulation." *American Economic Review*, 86: 789–813.

Jacobson, Louis S, Robert J LaLonde, and Daniel G Sullivan. 1993. "Earnings losses of displaced workers." *American Economic Review*, 685–709.

Joskow, Paul L., and Richard Schmalensee. 1998. "The Political Economy of Market-Based Environmental Policy: the U.S. Acid Rain Program." *Journal of Law & Economics*, 41(1): 37–84.

Kahn, Matthew. 1997. "Particulate pollution trends in the United States." *Regional Science and Urban Economics*, 27: 87–107.

Kahn, Matthew, and Erin Mansur. 2013. "Do local energy prices and regulation affect the geographic concentration of employment?" *Journal of Public Economics*, 101: 105–114.

Leuven, E, and B Sianesi. 2003. "psmatch2: Stata module to perform full Mahalanobis and propensity score matching, common support graphing, and covariate imbalance testing." *http://ideas.repec.org/c/boc/bocode/s432001.htm.*

List, J, and W McHone. 2000. "Measuring the effects of air quality regulations on 'dirty' firm births: Evidence from the neo and mature-regulatory periods." *Papers in Regional Science*, 79: 177–190.

List, J, D Millimet, and W McHone. 2004. "The Unintended Disincentive in the Clean Air Act." *Advances in Economic Analysis & Policy*, 4(2): Art. 2.

List, J, D Millimet, P Fredriksson, and W McHone. 2003. "Effects of Environmental Regulations on Manufacturing Plant Births: Evidence from a Propensity Score Matching Estimator." *Review of Economics and Statistics*, 56: 944–952.

List, J, W McHone, and D Millimet. 2003. "Effects of air quality regulation on the destination choice of relocating plants." *Oxford Economic Papers*, 55: 657–678.

List, J, W McHone, and D Millimet. 2004. "Effects of environmental regulation on foreign and domestic plant births: Is there a home field advantage?" *Journal of Urban Economics*, 56: 303–326.

Morgan, O, and S Condliffe. 2009. "Spatial Heterogeneity in Environmental Regulation Enforcement and the Firm Location Decision among U.S. Counties." *The Review of Regional Studies*, 39(3): 239–252.

Morgenstern, Richard D., William A. Pizer, and Jhih-Shyang Shih. 2002. "Jobs Versus the Environment: An Industry-Level Perspective." *Journal of Environmental Economics and Management*, 43: 412–436.

Nerlove, Marc. 1961. *Returns to scale in electricity supply.* Institute for mathematical studies in the social sciences.

Rosenbaum, P, and D Rubin. 1983. "The central role of the propensity score in observational studies for causal effects." *Biometrika*, 70: 41–55.

Rubin, Donald. 2008. "For Objective Causal Inference, Design Trumps Analysis." *The Annals of Applied Statistics*, 2: 808–840.

Stuart, Elizabeth, and D Rubin. 2008. "Best practices in quasi-experimental designs: Matching methods for causal inference." In *Best Practices in Quantitative Methods.* , ed. Jason Osborne. Sage.

Sullivan, Daniel, and Till Von Wachter. 2009. "Job displacement and mortality: An analysis using administrative data." *Quarterly Journal of Economics*, 1265–1306.

Swift, Byron. 2001. "How Environmental Laws Work: An Analysis of the Utility Sector's Response to Regulation of Nitrogen Oxides and Sulfur Dioxide Under the Clean Air Act." *Tulane Environmental Law Journal*, 14: 309–424.

US EPA. 1994. "Alternative Control Techniques Document – NOx Emissions from Utility Boilers." Office of Air Quality Planning and Standards.

US EPA. 1997. "1996 Compliance Report: Acid Rain Program." Office of Air and Radiation.

US EPA. 2003. "eGRID2002 Version 2.1."

US EPA. 2008. "Final Ozone NAAQS Regulatory Impact Analysis." Office of Air Quality Planning and Standards, http://www.epa.gov/ttnecas1/regdata/RIAs/452_R_08_003.pdf.

Walker, W. 2011. "Environmental Regulation and Labor Reallocation: Evidence from the Clean Air Act." *American Economic Review Papers and Proceedings*, 101(3): 442–447.

Walker, W Reed. 2013. "The Transitional Costs of Sectoral Reallocation: Evidence from the Clean Air Act and the Workforce." *Quarterly Journal of Economics*, 1787–1835.

Wooley, David, and Elizabeth Morss. 2012. *Clean Air Act Handbook: A practical guide to compliance.* . 22nd ed., West.

Appendix

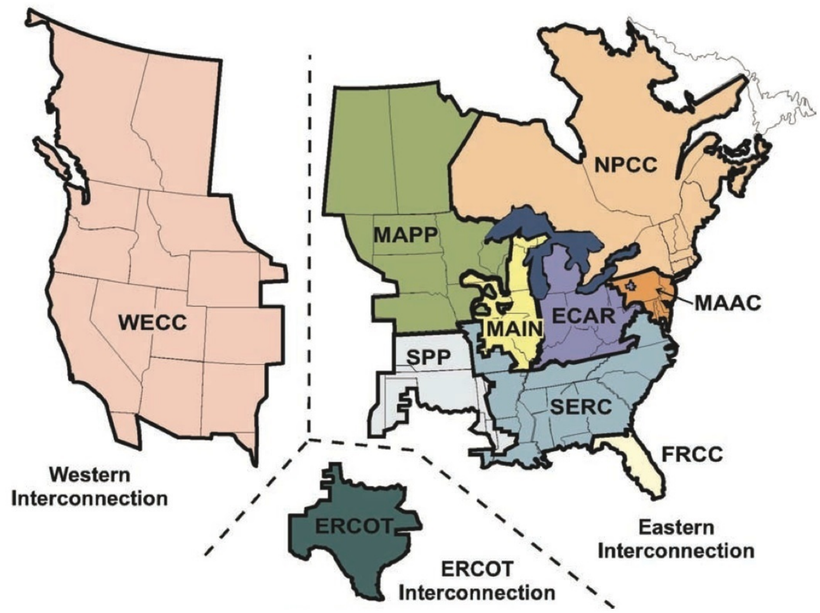


Figure A1. NERC Interconnections and Regions

Source: Foster et al. (2008).

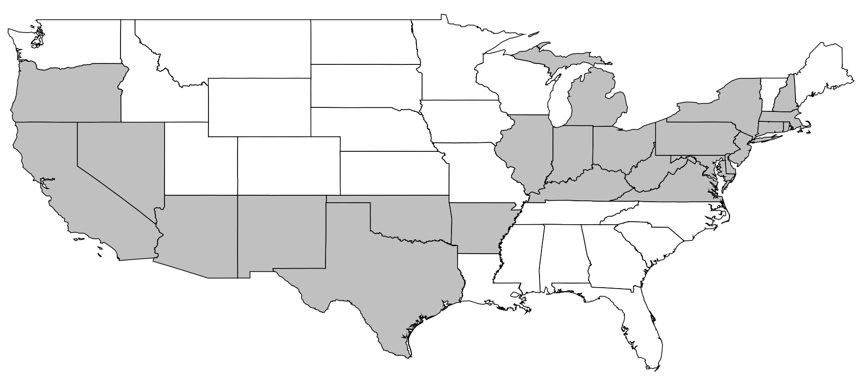


Figure A2. Electricity market restructuring in the 1990s.

Note: Shaded states restructured electricity markets by 2001. Restructuring hearings commenced after 1993.
Source: Authors, based on data from Fabrizio, Rose and Wolfram (2007).

Table A1— Ozone NAAQS annual impact on employment

	Dependent variable: log employment								
	(1)	(2)	(3)	(4)					
	O3 NAAQS	O3 NAAQS	O3 NAAQS	Subpart 1	Marginal	Moderate	Serious	Severe	Extreme
1987	−0.007	−0.007	−0.008	0.098**	−0.005	−0.029	−0.076**	−0.017	−0.093***
	(0.029)	(0.029)	(0.017)	(0.044)	(0.050)	(0.024)	(0.032)	(0.020)	(0.034)
1988	0.005	0.005	−0.015	0.040	0.030	−0.039*	−0.064*	−0.013	0.008
	(0.031)	(0.031)	(0.017)	(0.033)	(0.044)	(0.023)	(0.034)	(0.017)	(0.032)
1990	−0.040	−0.040	−0.018	0.033	−0.056	−0.020	−0.017	−0.024	−0.052
	(0.042)	(0.042)	(0.014)	(0.032)	(0.039)	(0.023)	(0.024)	(0.019)	(0.033)
1991	−0.026	−0.026	−0.031*	0.063	−0.033	−0.060***	−0.028	−0.044**	−0.084***
	(0.044)	(0.044)	(0.016)	(0.046)	(0.042)	(0.018)	(0.025)	(0.022)	(0.027)
1992	0.012	0.012	−0.054**	0.025	0.006	−0.107***	−0.046	−0.052	−0.093**
	(0.027)	(0.027)	(0.027)	(0.033)	(0.033)	(0.038)	(0.035)	(0.033)	(0.040)
1993	0.047	0.047	−0.069***	0.033	0.005	−0.126***	−0.108***	−0.068*	−0.112***
	(0.039)	(0.039)	(0.025)	(0.057)	(0.044)	(0.036)	(0.037)	(0.036)	(0.042)
1994	−0.005	−0.005	−0.095***	0.009	−0.051	−0.171***	−0.102**	−0.056	−0.103*
	(0.051)	(0.051)	(0.031)	(0.041)	(0.066)	(0.046)	(0.040)	(0.044)	(0.060)
1995	0.004	0.004	−0.123***	−0.052	−0.070	−0.204***	−0.128**	−0.056	−0.086
	(0.065)	(0.065)	(0.030)	(0.057)	(0.055)	(0.048)	(0.064)	(0.054)	(0.083)
1996	−0.074	−0.074	−0.148***	−0.074	−0.077	−0.225***	−0.169**	−0.090	−0.238***
	(0.108)	(0.108)	(0.036)	(0.070)	(0.102)	(0.053)	(0.070)	(0.064)	(0.081)
1997	−0.042	−0.042	−0.165***	−0.085	−0.064	−0.225***	−0.153**	−0.176***	−0.263***
	(0.107)	(0.107)	(0.035)	(0.090)	(0.098)	(0.056)	(0.062)	(0.066)	(0.083)
1998	−0.040	−0.040	−0.172***	−0.073	−0.035	−0.245***	−0.166**	−0.204***	−0.107
	(0.107)	(0.107)	(0.037)	(0.095)	(0.099)	(0.050)	(0.068)	(0.070)	(0.117)
OTR attainment	Control	Treated	Treated	Treated					
Always nonattainment	Control	Control	Treated	Treated					

Note: Each model number represents a single regression. Column headings are treatment variables. Parameter values and standard errors correspond to treatment × year. Impacts are relative to changes in plants in ozone attainment areas from 1989 base period. O3 NAAQS refers to plants in counties out of attainment with the ozone standard as of 1993. OTR attainment refers to plants in attainment counties within the OTR. Always nonattainment refers to plants in nonattainment counties that do not change status. Controls include a dummy for IOUs in states that restructured electricity markets that takes a value of unity after initiation of public hearings, plant fixed effects, NERC region × fuel × year effects and year × dummy interactions for areas out of attainment with PM_{10} and SO_2 NAAQS, and plants that are not investor-owned. Sample is 12-year panel of 596 EGUs with 6439 plant years. Standard errors in parentheses clustered by state-by-ozone-classification. *, **, and *** indicate P-values of 10, 5, and 1 percent.

Table A2— First Stage IV labor efficiency results

	Dependent Variable: Log MWh net generation	
	(1)	(2)
State sales	0.697**	0.680**
	(0.274)	(0.268)
S1M × 90-92	−0.070	−0.071
	(0.053)	(0.053)
S1M × 93-98	−0.069	−0.085
	(0.071)	(0.075)
MSS × 90-92	0.001	0.001
	(0.042)	(0.042)
MSS × 93-98	−0.023	−0.054
	(0.055)	(0.054)
Extreme × 90-92	−0.132	−0.130
	(0.103)	(0.103)
Extreme × 93-98	−0.065	0.099
	(0.156)	(0.154)
Alt. NAAQS × 90-92	0.035	0.034
	(0.037)	(0.037)
Alt. NAAQS × 93-98	0.077	0.077
	(0.058)	(0.056)
S1M × 93-98 × Restructured		0.096
		(0.071)
MSS × 93-98 × Restructured		0.111*
		(0.059)
Extreme × 93-98 × Restructured		−0.494***
		(0.059)
Restructured	−0.006	−0.047
	(0.041)	(0.047)
Muni × 91-92	−0.009	−0.008
	(0.053)	(0.053)
Muni × 93-98	−0.078	−0.086
	(0.067)	(0.067)
Title IV	−0.024	−0.024
	(0.025)	(0.025)
Plant F.E.	Yes	Yes
Plant-epoch F.E.	Yes	Yes
Region × Year × Fuel F.E.	Yes	Yes
R^2	0.404	0.407
Plant-years	6439	6439
Plant-epochs	716	716
Plants	596	596

Note: First-stage regression results for IV regression in Table 7. State sales is the excluded instrument: natural log of annual state electricity sales in million kWh. Impacts are relative to plants in ozone attainment areas in the 1987-1990 base period. S1M combines Subpart 1 and Moderate ozone nonattainment classifications. MSS combines Moderate, Serious, and Severe classifications. The Extreme ozone nonattainment area is also the country's only NO_2 nonattainment area. Alt. NAAQS is a dummy for areas out of attainment with PM_{10} and SO_2 NAAQS. Restructured is a dummy for IOUs in states that initiated retail electricity market deregulation. Muni is a dummy for plants that are not investor-owned. Standard errors in parentheses clustered by state-by-ozone-classification. *, **, and *** indicate P-values of 10, 5, and 1 percent.