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Air pollution abatement costs under the Clean Air Act: evidence from the PACE survey

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Abstract

This paper uses establishment-level data from the US Census Bureau's Pollution Abatement Costs and Expenditures (PACE) survey to investigate the effects of the Clean Air Act and its amendments on the air pollution abatement (APA) capital expenditures and operating costs of manufacturing plants from 1979 to 1988. Results, based on some 90,000 observations, show that heavy emitters of the "criteria" air pollutants that were subject to more stringent regulation (due to county non-attainment of national ambient air quality standards) generally had higher APA expenditures, with estimates that imply hundreds of thousands of dollars of additional annual costs for the abatement of a specific pollutant for the average affected plant. Establishment characteristics, such as the size of the facility, appear to affect the intensity of this regulation and enforcement. While this study validates the PACE data to a certain extent, potential limitations are also revealed. The findings of this paper support those of a number of recent studies.
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1. Introduction

The Clean Air Act (CAA) strictly prohibits the Environmental Protection Agency (EPA) from considering potential costs—in conjunction with benefits—when setting the national ambient air

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quality standards (NAAQS) that all areas of the country are required to meet.[1] Nonetheless, compliance costs are of significant interest,[2] and a compelling case has been made (e.g., [1]) for allowing cost-benefit analyses to be conducted here, as is required for other types of regulation. This paper examines some of the costs to manufacturing plants of the CAA (and its amendments) from 1979 to 1988, using establishment-level data on environmental expenditures from the Census Bureau's Pollution Abatement Costs and Expenditures (PACE) survey. The effects of air quality regulation, in terms of higher operating costs and additional capital expenditure for air pollution abatement (APA), are identified by using the variation in regulatory stringency, between counties that are in *non-attainment* versus *attainment* of federal air quality standards, for establishments that are and are not heavy emitters of the targeted pollutants. The analyses also control for location-specific effects as well as various establishment characteristics thought to be important determinants of plant-level environmental expenditures.

If no significant effects are found here, a number of possibilities might be implied. First, it might suggest that these regulations are not enforced or that it is relatively inexpensive to comply with them. This would counter mounting evidence of significant impacts of the CAA on manufacturing industries (e.g., [4,12,15,17]). Second, it could mean that the most noteworthy regulatory expenses are the ones that are not explicitly covered by the PACE survey. For example, no attempt is made to capture items such as taxes, fines, permits, pollution offsets, and the like, let alone lost or sacrificed output. Furthermore, arguably the most affected segment of the population—plants under construction—is not canvassed by the survey at all. Finally, it has been suggested that the PACE survey fails to measure all that it was designed to measure (e.g., [5,11,16]). In particular, respondents may face difficulty in separating out their firms' environmental costs from normal production costs and/or deciding on the relevant baseline with which to compare their expenditures. Given the frequent use of the published PACE data in proxies for regulatory stringency, knowing whether the underlying PACE responses actually correlate with precise measures of environmental regulation is of great significance. The analyses in this paper can be viewed as a test of whether these various claims can be refuted.

Results, based on some 90,000 observations, suggest that establishments subject to CAA regulation during this period generally did have higher APA capital expenditures and operating costs. Estimates imply hundreds of thousands of dollars of additional annual costs for the abatement of a specific pollutant for the average affected plant in this sample. In general, however, this reflects just a minority of the additional abatement costs incurred by such facilities.

[1]This matter was revisited in the recent Supreme Court case *American Trucking Associations Inc., et al. v. Administrator of Environmental Protection Agency, et al*. At issue here were the new, stricter ambient standards for ozone and particulates issued by the EPA in 1997 and the question of whether the CAA represents an unconstitutional delegation of legislative power to an executive branch agency. That is, if the EPA must *only* consider health benefits when setting these standards, and there are no truly safe levels of exposure to these pollutants (above zero), then Congress's CAA (arguably) provides EPA with no "intelligible principle" with which to set such non-zero standards. In the end, however, the Supreme Court ruled that the CAA does not unconstitutionally concede power to the EPA, and it upheld the lower court's decision requiring the EPA to ignore all factors other than health effects when setting the national ambient air quality standards.

[2]For example, Section 812 of the CAA requires the EPA to periodically submit to Congress reports of the retrospective and prospective benefits and costs of the Act (e.g., [25]). Furthermore, as did Executive Order 12291 before it, Executive Order 12866 requires federal agencies to assess the costs and benefits of any significant new regulatory proposals. This is true even for CAA-related rule changes, where costs are not to be considered (e.g., [26]).

Analyses also show that establishment characteristics, such as plant size, can have an impact on the intensity of CAA-related regulation and enforcement. In the end, while many of the results suggest significant regulatory enforcement and compliance costs associated with county non-attainment status—corroborating the findings of a number of recent studies and validating the PACE data to a certain extent—there is also evidence that the PACE survey may indeed have limitations that prevent the full costs of regulation from being captured.

The paper proceeds as follows. In Section 2, I offer some background discussion, including an overview of air quality regulation in the United States, a review of the recent literature, and the motivation for this current study. This is followed by Section 3, which describes data sources and empirical specifications. Section 4 contains my empirical results, and Section 5 offers some concluding remarks.

2. Background

In accordance with the CAA of 1970, the US EPA has set NAAQS for six pollutants that all areas of the country are required to meet. These so-called "criteria" air pollutants are: tropospheric ozone (O_3), total suspended particulates (TSP), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and lead (Pb). The standards set for each of these pollutants are science-based criteria designed to protect human health with "an adequate margin of safety" and essentially amount to maximum permissible ambient concentrations.

A stipulation of the 1977 amendments to the CAA is that, each year, every county in the United States be officially designated as being either in- or out-of-attainment of the federal standard for each of these air pollutants. States with counties that are in non-attainment of a standard are required by law to develop plans for bringing them into attainment within a specified time. Failure to submit and execute an acceptable State Implementation Plan (SIP) can potentially result in federal sanctions, including the withholding of federal grant monies (e.g., highway construction funds), direct EPA enforcement and control (through Federal Implementation Plans), bans on the construction of new establishments with the potential to pollute, and so forth.[3] Consequently, pollution sources in non-attainment areas—particularly industrial sources that emit the offending pollutant(s)—are on average much more heavily regulated than similar sources in attainment areas.

For example, in non-attainment areas, industrial plants with the potential to pollute are generally subject to more stringent, more costly technological requirements on their capital equipment, including the installation of additional APA equipment such as filters, scrubbers, precipitators, and the like. In addition to higher capital expenditures, these establishments may face higher operating costs as well—in terms of additional staff and/or staff-time; more and/or

[3] A 1999 report by the Congressional Research Service [21] states that 858 notices of impending sanctions were issued by EPA between 1990 and October 1999. The vast majority of these CAA violations were rectified within the 18-month grace period following formal notification. Sanctions, however, were imposed in 18 instances and a second round of additional sanctions was administered in two of those cases. According to the Federal Highway Administration website (as of May 2003), CAA sanctions are currently in effect in four regions, some with two levels of sanctions in place. In addition, four areas are under deferred sanctions (pending verification of their compliance), and 15 regions have one or more "sanction clocks" approaching the 18-month deadline.

more expensive materials, fuels, and energy; additional capital depreciation, maintenance costs, and/or leasing of equipment; services of outside contractors to perform environmental tasks; and so forth. Regulatory compliance may also necessitate redesigns in production processes, which can be quite costly, especially if output must be suspended in the interim.[4] In general, state and local regulators have discretion in how they choose to bring non-attainment areas into attainment, including which sources to regulate and what to require of them.

In the last several years, there have been a number of studies that have examined the impact of the CAA—and county NAAQS non-attainment status in particular—on manufacturing industries. Henderson [15], for example, finds that, all else being equal, the number of plants in certain industries emitting volatile organic compounds (VOC)—a precursor to tropospheric ozone—was at least 7% lower in ozone non-attainment counties between 1978 and 1987, compared to attainment counties, suggesting that heavier regulation significantly impacts plant location decisions. Kahn [17] finds that counties in TSP non-attainment had 14% lower growth in manufacturing employment between 1982 and 1988, controlling for the level of non-manufacturing employment growth. Greenstone [12] also finds that county non-attainment status (across four different criteria pollutants) reduced the level of manufacturing activity (employment, investment, and output) in those respective counties. According to one estimate, non-attainment counties lost over 590,000 manufacturing jobs between 1972 and 1987—a direct result of being more heavily regulated.

Becker and Henderson [4] examine the effects of ozone non-attainment status on the behavior of manufacturing plants in heavy VOC-emitting industries from 1963 to 1992. A key finding in that study is the 25–45% drop in the number of new plants in these industries opening in non-attainment counties, all else being equal, again suggesting that plant location is sensitive to the additional regulatory costs in those areas.[5] The authors also explore the role of county ozone non-attainment on the survival and investment patterns of plants in those polluting industries.

Collectively, this literature has found a variety of significant effects on industry behavior vis-à-vis county non-attainment status, attributable presumably to stricter environmental regulations and higher compliance costs.[6] Becker and Henderson [5] attempt to actually quantify some of these costs, using plant-level data from the Censuses of Manufactures (CMs). These authors estimate average total cost functions for plants in two industries known to be large emitters of ozone precursors and find that, ceteris paribus, total operating costs are indeed higher for plants located in ozone non-attainment counties. For example, relatively new plants (0–4 years of age) in the industrial organic chemicals industry (SIC 2865–9) in ozone non-attainment areas had total operating costs that were roughly 17% higher than those for similar plants in attainment areas.

[4]Apart from these costs, there are other, more direct regulatory costs that industrial plants in non-attainment areas are also more likely to face. For one, such plants are much more likely to be inspected and hence fined than are similar facilities in attainment areas. In addition, plants in non-attainment areas, particularly those seeking to expand their operations, may be required to purchase pollution offsets from other establishments in the area. Such costs will not be explored in this paper.

[5]List and McHone [20] find similar effects for a sample of new plants in New York State from 1980 to 1990.

[6]A parallel literature has demonstrated some of the *benefits* of these regulations, in terms of reduced air pollution, improved health outcomes, decreased mortality, ecological and agricultural benefits, and so forth. See, for example, Chay and Greenstone [6,7], Greenstone [13], Henderson [15], and EPA [25].

This current paper takes a different, more direct approach to estimating the costs of air quality regulation to manufacturing plants. Rather than infer regulatory costs from general production costs, as Becker and Henderson [5] do using CM data, I directly examine the APA costs incurred by plants, as reported in the PACE survey.[7] Furthermore, the present study will consider *all* manufacturing industries (allowing for control groups) and *all* criteria air pollutants (besides just ozone and ozone precursors). Effects are allowed to differ for plants that are large emitters of multiple air pollutants and/or are located in counties that are in non-attainment vis-à-vis multiple pollutants.

In addition to verifying whether these NAAQS-related regulations are enforced and measuring the magnitude of their effects, this study can also be viewed as a test of the PACE data's quality—a concern that has been raised by a number of observers. Jaffe et al. [16], for example, argue that the PACE data are ''notoriously unreliable'' in part because of difficulties in defining regulatory costs and separating them out from firms' total expenditures. Becker and Henderson [5] elaborate on these arguments, while Gray and Shadbegian [11] actually find some evidence that compliance costs might be under-reported in the PACE survey by as much as a third to two-thirds in some particularly polluting industries. Given the way in which the aggregate PACE data are frequently used in measures of regulatory stringency (e.g., by state and/or by industry), it is certainly worth determining whether survey responses are meaningfully correlated with specific environmental regulations.

3. Data and empirical specification

Conducted annually since 1973, the PACE survey's primary purpose through the years has been to collect timely information from manufacturing establishments on capital expenditures and operating costs associated with pollution abatement efforts. Data from the survey are tabulated and published by the Census Bureau, by industry, state, type of cost, type of pollutant, and combinations thereof [24]. The PACE survey was discontinued in the last decade (1995–1998, 2000–2004), but there is renewed interest in administering it again on a more regular basis, beginning perhaps with the 2005 reference year.

In this study, I use the *establishment-level* data from the PACE surveys of 1979–1982, 1984–1986, and 1988.[8] The variables of interest here are *air pollution abatement capital expenditure* (which includes items such as scrubbers, filters, precipitators, and so forth, as well as relevant capital associated with ''production process enhancements'') and *air pollution abatement operating costs* (which includes relevant salaries & wages, parts & materials, fuel & electricity, capital depreciation, contract work, equipment leasing, etc.). These serve as my dependent variables in the empirical specification described below.

[7] Becker and Henderson [5] also make an effort to look at PACE data. Their analysis, however, is cursory and is limited to a small, cross-sectional subsample of plants in their two industries of interest. And, among other issues, they focus only on ozone non-attainment in 1992 and do not attempt to control for (potentially important) county-level covariates. They find little to no effect of non-attainment status on APA costs. While ''suggestive'', they admit that more definitive work in this area is warranted.

[8] Unfortunately, the establishment-level data from 1973–1978 and 1983 are no longer available. A survey for reference year 1987 was not conducted.

Table 1
Summary of capital expenditures and operating costs (in 1988 dollars)

	Capital expenditures	Operating costs
Number of establishments	89,889	89,889
Total outlays	$403.2 billion	$7,785.0 billion
Air pollution abatement outlays (percent of total outlays)	$13.3 billion (3.3%)	$28.5 billion (0.4%)
Average air pollution abatement outlays per plant	$148,198	$316,885
Number (and percent) of establishments with *non-zero* air pollution abatement outlays	20,620 (22.9%)	41,772 (46.5%)
Average air pollution abatement outlays per plant given non-zero outlays	$646,041	$681,903

To this I merge data that these establishments may have reported in the contemporaneous Annual Survey of Manufactures (ASM). The ASM data provide me with some important, basic information on these plants, including *total* capital expenditure and *total* operating costs (which presumably subsume the above environmental expenditures), as well as employment, value of output, location, industry, age, ownership, and so forth. These primarily enter as explanatory variables in my regressions, as described below. The establishment-level survey data in both the ASM and PACE are confidential, collected and protected under Title 13 of the US Code.[9]

After restricting my attention to cases that were in both the PACE and ASM samples in a given year, and after eliminating survey non-respondents, certain item non-respondents, non-manufacturing establishments, inactive cases, and so forth, I am left with 89,889 plant-years of observations for my empirical analyses.[10] Table 1 contains some basic sample statistics on these establishments' air pollution abatement outlays. Amounts (here and throughout the paper) are in constant 1988 dollars.[11]

We see here that there is about $13.3 billion of *APA capital expenditure* in this sample, accounting for 3.3% of *total* capital expenditures for these plants. The average establishment in this sample has about $148,000 of APA capital expenditure a year. Expenditures are higher in terms of *APA operating costs*, with about $28.5 billion worth in this sample, for an average of

[9]Restricted access to these data can be arranged through the Census Bureau's Center for Economic Studies. See http://www.ces.census.gov/ for details.

[10]156,417 establishments were selected by the Census Bureau to receive the PACE survey over the 8 years under study here. Of the 66,528 cases that are dropped, most (35,448) have no ASM record, followed in importance by those that failed to respond to the survey (14,878) and those that have inadequate data for one or more of the key data items (9654). Nonetheless, the industrial coverage of the resulting sample is excellent: 435 (97%) of the 449 manufacturing industries recognized by the 1977 Standard Industrial Classification (SIC) system are represented here. The 14 missing industries are all in apparel production (SIC 23), which was purposely excluded from the PACE survey because "these establishments operate primarily in rented quarters where the abatement of pollution (probably most of which is solid waste) is generally arranged by the landlord." [24] Additional detail regarding data sources, variable construction, the research sample, and such can be found in a separate working paper available from the author.

[11]Values are indexed using the U.S. Bureau of Economic Analysis's implicit price deflator for GDP [(23, p. 133)].

about \$317,000 per plant per year. As a fraction of total outlays, however, APA only accounts for 0.4% of *total* operating costs for these plants.

Note that the distributions of APA expenditures (the dependent variables) are quite skewed. Of the 89,889 observations in the sample, only 22.9% actually have *non-zero* APA capital expenditure. This might be expected since capital investment is (by its very nature) lumpy, and not all manufacturing activity is polluting, requiring the installation of special equipment. The average APA capital expenditure per plant, given that it is non-zero, is \$646,000. Similarly, only 46.5% of observations have non-zero APA operating costs, and the average APA operating cost per plant per year, given that it is non-zero, is nearly \$682,000. In 2003 dollars, these amounts are about \$902,000 and \$952,000, respectively.[12]

Since the majority of observations here have zero expenditures, I take two approaches to estimation: (1) a probit model for having non-zero expenditures, and (2) a Tobit specification. The general estimating equation will be the same for both:

$$APA_{it} = \alpha + \phi_{ct} + \beta' X_{it} + \pi' E_n + \psi' Z_{nct} + \varepsilon_{it}, \tag{1}$$

where i indexes an establishment that is in county c and industry n, and t indexes time. Here, the dependent variable (APA capital expenditure or APA operating costs, at plant i at time t) is a function of a constant (α), a county-by-year effect (ϕ_{ct}), a vector of establishment characteristics (X_{it}), a set of indicators (E_n) describing whether the plant is a high emitter of each of the criteria air pollutants (based on its 4-digit SIC industry), and indicators (Z_{nct}) of whether the plant is subject to heightened regulation as a result of the CAA—namely, whether it is a high emitter of any of the criteria pollutants at time t in a county that is in non-attainment of the NAAQS for the respective pollutant(s) at time t. ε_{it} is an error term. Alternate models will be considered below.

The *county-by-year fixed effects* (ϕ_{ct}) are meant to capture the inherent differences *between* counties, as well as time-varying conditions *within* a county, that potentially explain variation in plant-level APA activity. A number of studies have shown, for example, the importance of certain community characteristics in determining local environmental outcomes such as the level of toxic releases, ambient pollution, regulatory enforcement, and the siting of polluting facilities (e.g., [2,14,18]). Potential determinants include household income, house values, educational attainment, poverty rate, home-ownership rate, racial composition, unemployment, voting behavior, political ideology, population density, industrial mix, the level of regulatory resources, and other variables. It is reasonable to assume that local APA expenditure might also be affected by some of these same factors, and perhaps additional (unmeasured and/or unobservable) county-level trends and shocks as well.

The establishment characteristics (X_{it}) I control for here are *plant size*, the *age of the plant*, and whether or not it *belongs to a multi-unit firm*. These three factors have been shown to be important determinants of *who* gets regulated *when* and *how intensely*, at least in terms of air quality regulation [3,4]. They are therefore expected to explain APA expenditure as well. In terms of plant size, a series of categorical variables is used, indicating the quartile of the output distribution

[12] Since larger establishments are sampled more heavily in the PACE and ASM surveys, these figures are not representative of the typical manufacturing establishment.

(measured in 1988 dollars of value added) to which the plant belongs. Establishments owned by multi-unit firms are designated by a simple indicator variable. Plant age is controlled for by a set of categorical variables, with five age groups that are based on the number of years since the establishment's first appearance in a Census of Manufactures. Hypotheses relating to plant characteristics will be discussed later in the paper.

The emissions profile of an establishment (E_n) should have an unambiguous effect on APA expenditure: heavier polluters are subject to greater federal, state, and local regulation and therefore should have higher APA expenditure. The focus here is on the CAA's criteria air pollutants and their precursors: volatile organic compounds (VOC), nitrogen dioxide (NO_2), particulates (PT), carbon monoxide (CO), and sulfur dioxide (SO_2).[13] Five dummy variables are used to indicate whether a plant is a *high emitter of each of these five air pollutants*. I classify establishments as (potential) heavy emitters of the criteria air pollutants according to their 4-digit Standard Industrial Classification (SIC) code.[14] I categorize industries as high emitters based on data in the EPA's Aerometric Information Retrieval System (AIRS).[15] The first two columns of Table 2 show the number and percent of the 89,889 sample observations defined as high emitters of each of the five criteria pollutants under study here as well as these establishments' total employment.

At last, there are the primary explanatory variables of interest in this study—the indicators in vector Z_{nct} of Eq. (1)—whose coefficients (ψ) capture the effects of regulation necessitated by the requirements of the CAA. Five effects are of key interest here: the *effects of O_3 non-attainment on high VOC <u>and</u> high NO_2 emitters, TSP non-attainment on high PT emitters, CO non-attainment on*

[13]VOC and NO_2 are both precursors to the tropospheric ozone (O_3). The sixth criteria pollutant—airborne lead (Pb)—will not be considered in my empirical analyses. During the time period under study, county lead non-attainment status was not listed in the Code of Federal Regulations along with the other criteria pollutants, and I was otherwise unable to locate this information. It is very likely that relatively few counties were actually in lead non-attainment during this time. As of May 2004, only (portions of) three counties were in lead non-attainment.

[14]Previous studies have defined polluters by their 2-digit industry [12,19,20] or according to their 4-digit industry's (relative) environmental expenditures in the PACE survey [10,22]. The former is much too crude, and the latter is obviously inappropriate here since I am trying to *explain* PACE expenditures in this study. The expenditure data are also not pollutant-specific.

[15]Among other things, the AIRS database maintains an inventory of facilities in the United States (classified by industry) that emit a threshold amount of any of the six criteria air pollutants. For each pollutant, I obtained the number of establishments in each 4-digit SIC emitting over the threshold amount set by the EPA. For VOC, NO_2, SO_2, and PT, the threshold is 100 tons per year. For CO, the threshold is 1000 tons per year. For lead, it is 5 tons per year. I then label an industry—and all its plants—a "high emitter" of that air pollutant if it had a minimum number of establishments emitting above that threshold. For CO and PT, industries with 1 or more establishments above the (respective) threshold are considered high emitters. For NO_2 and SO_2, industries with 2 or more establishments above the threshold are considered high emitters. For VOC, industries with 4 or more establishments above the threshold are considered high emitters. These particular cutoffs were chosen so that no more than 50% of the establishments in this sample are designated a high emitter of any pollutant. The assumption here is that the *presence* of the industry in the right tail of the facility emissions distribution says something about the emissions of the *typical* plant in the industry. This classification scheme is validated by the empirical results that follow. An appendix that lists the industries defined as high emitters is available as supplementary material through *JEEM*'s online database at http://www.aere.org/journal/index.html.

Table 2
Number (and percent) of establishments that are "high emitters" of the criteria air pollutants and subject to CAA-related regulation

	High emitters		Subject to CAA regulation	
	Establishments	Employment	Establishments	Employment
Volatile organic compounds (VOC)	43,686 (48.5%)	28,520,578 (53.9%)	27,269 (30.3%)	19,487,357 (36.8%)
Nitrogen dioxide (NO_2)	38,904 (43.3%)	27,385,967 (51.8%)	22,712 (25.3%)	18,610,779 (35.2%)
Particulates (PT)	39,660 (44.1%)	23,908,623 (45.2%)	18,933 (21.1%)	13,256,713 (25.1%)
Carbon monoxide (CO)	17,342 (19.3%)	12,743,348 (24.1%)	5,135 (5.7%)	4,241,687 (8.0%)
Sulfur dioxide (SO_2)	37,291 (41.5%)	24,978,760 (47.2%)	3,641 (4.1%)	3,494,637 (6.6%)
At least one of the above	62,114 (69.1%)	38,787,315 (73.3%)	39,766 (44.2%)	27,594,446 (52.2%)

high CO emitters, and SO_2 non-attainment on high SO_2 emitters.[16,17] Given the structure of Eq. (1), these regulatory costs are identified by comparing high and low emitters within *non-attainment* county-years, with the effect of merely being a high emitter coming from the comparison of high and low emitters within *attainment* county-years and the county-by-year fixed effects identified by comparing low emitters across all county-years.

The final two columns of Table 2 show the number and percent of establishments in this sample—and their total employment—under more stringent (pollution-specific) regulation as a result of the CAA. Overall, 44.2% of the establishments in this sample faced heightened regulation for at least one of these five pollutants, representing 52.2% of the sample on an employment-weighted basis. Section 4 will explore whether APA capital expenditures and APA operating costs are indeed higher for these more heavily regulated plants, as is expected.

[16]County non-attainment status vis-à-vis nitrogen dioxide (NO_2) will not be considered here for two reasons. First, during the time period being studied, no more than a dozen counties were ever in NO_2 non-attainment. Second, since ground-level ozone (O_3) forms through the interaction of both NO_2 and VOC emissions, ozone non-attainment status is actually relevant to high emitters of both pollutants (and is treated as such). Incidentally, those dozen NO_2 non-attainment counties were also always in ozone non-attainment at the same time.

[17]Every year, beginning in 1978, every county is designated as being either in attainment or non-attainment of the NAAQS for each of the six pollutants. This information is released each July in the Code of Federal Regulations (Title 40, Part 81, Subpart C). For this study, an establishment is deemed to have been in a county with more stringent regulation vis-à-vis a particular pollutant, if the county was classified in non-attainment of the NAAQS for that pollutant in the prior calendar year (i.e., the July 1978 designation affects APA expenditures in 1979, and so forth). Counties in violation of the "secondary" NAAQS standard (for SO_2 and TSP), or where only portions of the county were out of compliance, are also considered to have been in non-attainment for the purposes of this study. Note that there is no need for the separate inclusion of these county non-attainment statuses in Eq. (1) since they are absorbed by the county-by-year parameter ϕ_{ct}.

Table 3
Estimated effects of CAA regulation[a]

	APA capital expenditure		APA operating costs	
	Probit	Tobit	Probit	Tobit
Emission characteristics (of 4-digit SIC)				
High VOC emitter	+4.97**	+323.3**	+10.76**	+300.0**
	(0.44)	(78.6)	(0.30)	(66.4)
High NO_2 emitter	+2.31**	−29.2	+5.77**	−153.8*
	(0.49)	(92.1)	(0.30)	(79.2)
High PT emitter	+8.01**	+596.0**	+15.67**	+706.4**
	(0.45)	(71.2)	(0.33)	(62.2)
High CO emitter	+13.18**	+1272.7**	+18.81**	+1513.5**
	(0.48)	(63.4)	(0.31)	(59.0)
High SO_2 emitter	+3.29**	+367.1**	+6.99**	+520.6**
	(0.33)	(60.2)	(0.22)	(54.0)
Establishment subject to CAA regulation				
High VOC emitter × O_3 non-attainment county	−1.47**	+56.0	−4.87**	+129.3*
	(0.49)	(89.7)	(0.32)	(77.3)
High NO_2 emitter × O_3 non-attainment county	−0.76	+49.7	−2.39**	+115.4
	(0.50)	(93.3)	(0.31)	(80.6)
High PT emitter × TSP non-attainment county	+2.27**	+147.1*	+2.83**	+280.6**
	(0.42)	(80.6)	(0.25)	(71.8)
High CO emitter × CO non-attainment county	+0.41	+361.7**	−3.18**	+296.0**
	(0.49)	(87.4)	(0.40)	(84.2)
High SO_2 emitter × SO_2 non-attainment county	+2.86**	+470.1**	+3.32**	+569.8**
	(0.53)	(108.9)	(0.35)	(102.5)

[a]Samples consist of 89,889 observations. All specifications include county-by-year effects and establishment characteristics (size, age, and a multi-unit firm dummy). The estimates from the probit models (for having non-zero expenditures) reflect the change in probability for discrete changes in the dummy variables. The estimates from the Tobit models (on real expenditures) are in thousands of 1988 dollars. Standard errors are in parentheses. Statistical significance at the 10% and 5% level are indicated by * and **, respectively.

4. Results

Table 3 contains (partial) regression results on APA capital expenditures and APA operating costs, for the model specified in Eq. (1). The first and third columns contain estimates from probit models for having non-zero expenditures, where values reflect the *change in probability* for discrete changes in the dummy variables and infinitesimal changes in the continuous variables (at the variable means). The second and fourth columns contain estimates from Tobit models on real expenditures. The units here are in thousands of 1988 dollars. In the interest of space, only the π and ψ parameters will be presented and discussed here. The regulatory impacts of the establishment characteristics will be explored later in this paper.

Results here show that the emission characteristics of establishments are, not surprisingly, significant determinants of APA expenditure. With little exception, heavy emitters of the criteria pollutants had both higher likelihoods and higher levels of APA outlays in terms of both capital expenditures and operating costs. This reflects greater local, state, and federal regulation of these types of emission sources, relative to plants in less-polluting industries and regardless of county attainment status. Among the minimum requirements on large emitters during this time period were various New Source Performance Standards (see 40 CFR Part 60), the Prevention of Significant Deterioration (CAA, §169), standards on hazardous pollutants (CAA, §112), and in later years Toxics Release Inventory reporting. To some extent, the higher spending seen here may also represent *voluntary* adoption of air pollution control technologies by polluting industries. In any event, I believe these findings validate my particular classification of "high emitters." Nevertheless, I will also explore alternative definitions below.

In terms of actual results, Table 3 shows that the added probability of non-zero APA capital expenditures for high emitters ranged from 2.3 to 13.2 percentage points, for high NO_2 and CO emitters, respectively, while dollars of additional capital expenditure averaged $323,300 for high VOC emitters, $367,100 for high SO_2 emitters, $596,000 for high PT emitters, and nearly $1.3 million for high CO emitters. In terms of APA operating costs, likelihoods ranged from 5.8 to 18.8 percentage points higher, for high emitters of NO_2 and CO, respectively, and additional costs ranged from $300,000 for high VOC emitters, $520,600 for high SO_2 emitters, $706,400 for high PT emitters, to over $1.5 million for high CO emitters.[18] Alternatively, NO_2 emitters are not found to have had higher APA expenditures, ceteris paribus, which may be indicative of the fact that very few counties were actually in NO_2 non-attainment during this period—the regulation of NO_2 sources in general may have been a relatively low priority nationwide.

The final set of coefficients in Table 3 is the one of primary interest in this study: controlling for county-by-year effects, establishment characteristics, and emissions, did manufacturing plants with high emissions located in counties that were in non-attainment of the NAAQS for the respective pollutant(s) indeed have higher APA expenditure? Compliance with the CAA would have presumably subjected these establishments to more stringent standards, at least on average.

In terms of capital expenditure (columns 1 and 2), high VOC emitters in O_3 non-attainment areas were actually *less* likely to have had non-zero APA outlays, all else being equal, but the Tobit results show that the effect in dollar terms is (statistically) zero. Ozone non-attainment status is also found to have had no effect on the other important contributors to tropospheric ozone—high NO_2 emitters—but for high emitters of the other pollutants, greater regulation is evident. High PT emitters in TSP non-attainment counties had an additional likelihood of 2.3 percentage points of having non-zero APA capital expenditure and had, all else being equal, $147,100 more capital expenditure. High CO emitters in CO non-attainment areas were not more likely to have had APA capital expenditures but, on average, had $361,700 more such expenditure. And high SO_2 emitters in SO_2 non-attainment counties had an additional likelihood of 2.9 percentage points and had APA capital expenditure that was $470,100 higher than for similar plants in SO_2 attainment areas.

[18] While it may seem that high CO emitters were particularly affected here, cross-pollutant comparisons such as this are somewhat capricious. Given the variation in toxicity across pollutants, the thresholds set by the EPA for inclusion in the AIRS database, and the criteria used here to define high emitters, the equivalence of high emitters of the different air pollutants is at best indefinite. We should not, therefore, necessarily expect the magnitude of these effects to be the same.

In terms of additional APA operating costs (columns 3 and 4), high VOC emitters in O_3 non-attainment areas were, again, less likely to have had non-zero expenditures; however, they had \$129,300 in higher costs, on average, as compared to plants that did not face CAA-related regulation of VOC emissions. Similarly, high NO_2 emitters were also less likely to have had non-zero expenditures in O_3 non-attainment areas, but the effect on their average expenditure is positive and nearly significant. High PT emitters in TSP non-attainment counties had both higher likelihoods (by 2.8 percentage points) and higher levels (+\$280,600) of APA operating costs, compared to other plants, as did high SO_2 emitters in SO_2 non-attainment areas, who had probabilities that were 3.3 percentage points greater and costs that were \$569,800 higher. High CO emitters in CO non-attainment areas were less likely to have APA operating costs (by 3.2 percentage points) but, on average, had \$296,000 more such expenditure.

In summary, three of these five categories of establishments, under heightened CAA regulation, had higher APA capital expenditure, and four of the five had higher APA operating costs. These additional costs each was in the range of hundreds of thousands of (1988) dollars, and an establishment obviously may have incurred *both* types of outlays, possibly for *multiple* air pollutants.[19] Fig. 1 depicts these regulatory effects, using (only) the statistically significant point estimates from the Tobits in Table 3. The figure shows the additional outlays by high emitters (relative to low emitters) in attainment versus non-attainment counties. For the most part, being located in a non-attainment county had only a secondary effect on the APA expenditures of high emitters—the one exception being high SO_2 emitters, where (conditional) expenditures were well over twice as high in SO_2 non-attainment counties relative to attainment counties.[20]

The results from the probit regressions in Table 3 are more mixed. Four of the ten estimates indicate a greater likelihood of having had non-zero expenditures, while four estimates indicate a lower propensity. The notion that the effects of an explanatory variable on the *probability* of expenditure versus the *level* of expenditure can be independent (and even opposite) of one another is certainly not new [8]. And perhaps it should not be surprising in this context, since the goal here of regulators is not pollution abatement expenditure per se, but rather reducing collective emissions in (presumably) a cost-effective manner. A choice can obviously be made between regulating more sources or fewer sources (and perhaps larger ones) more intensively. The latter may reflect an efficient use of limited regulatory resources.

4.1. Alternative definitions of high emitters

In this section, I examine the sensitivity of the above findings to alternative definitions of high emitter status (E_n). Table 4 presents the results from three alternatives. In the interest of space, only the regulatory coefficients (ψ) of the Tobit specification in Eq. (1) are shown here, with

[19]Measured against these plants' *total* annual expenditures (on environmental and non-environmental matters) however, these magnitudes are relatively small. In particular, the results imply that CAA regulation of VOC, NO_2, PT, CO, and SO_2 emissions accounted for just 0.80%, 0.58%, 2.07%, 3.45%, and 4.67% of these establishments' total capital expenditures, respectively, and only 0.09%, 0.07%, 0.19%, 0.13%, and 0.28% of their total operating costs in a given year. Table 1 had suggested magnitudes of this nature.

[20]This is an interesting contrast to recent findings by Greenstone "that the SO_2 nonattainment designation [only] played a minor role in the dramatic reduction of SO_2 concentrations over the last three decades" [(13, p. 609)].

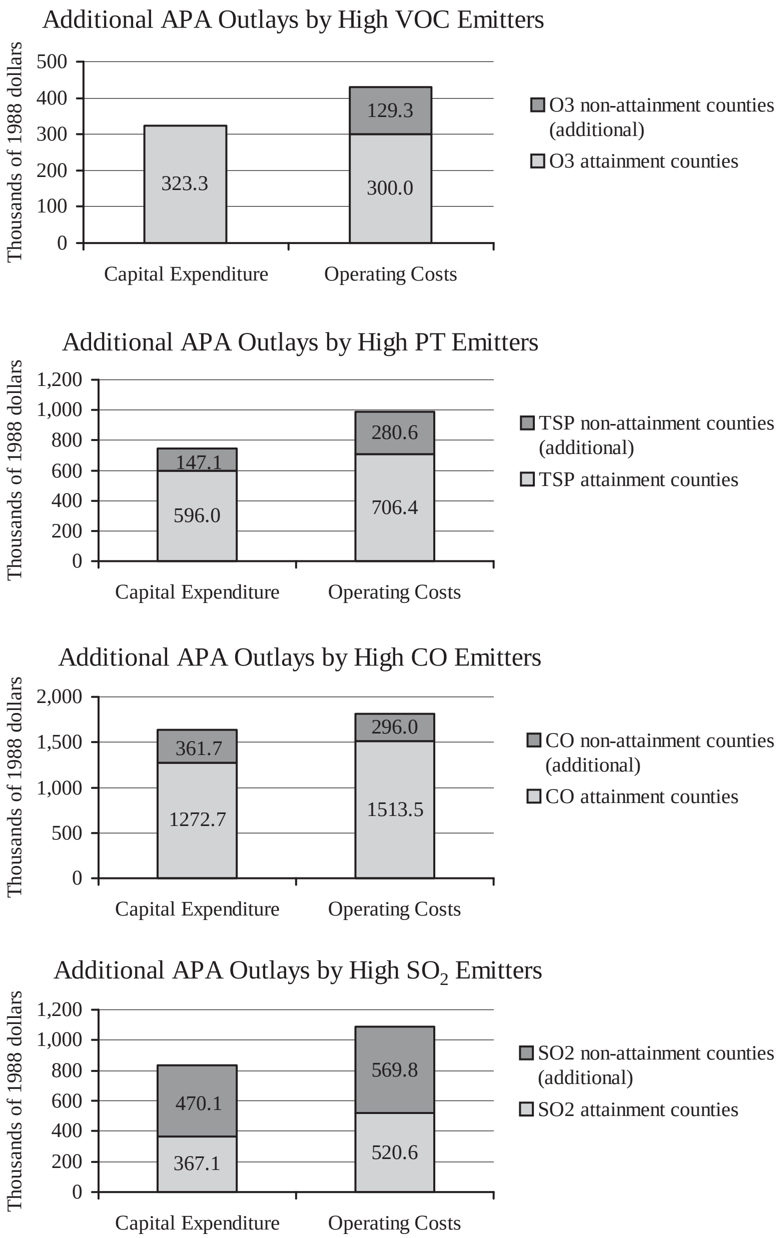

Fig. 1. Costs of CAA regulation.

estimates for capital expenditures and operating costs appearing in the top and bottom panels, respectively.

The first alternative considered here, in column 1, is a very simple variant of the classification used above in Table 3. In particular, it combines high VOC emissions and high NO_2 emissions into a single indicator (i.e., of being a high emitter of O_3 precursors), as is done in Greenstone [12].

Table 4
Alternative definitions of high emitters[a]

	(1)	(2)	(3)
	Baseline ($VOC+NO_2$)	Greenstone (*JPE 2002*)	Stricter Definition
	APA capital expenditure		
Establishment subject to CAA regulation			
High VOC/NO_2 emitter $\times$ O_3 non-attainment county	+52.5	+421.9**	+154.7*
	(90.2)	(87.7)	(85.4)
High PT emitter $\times$ TSP non-attainment county	+148.5*	−209.7*	+154.6
	(79.4)	(116.3)	(106.9)
High CO emitter $\times$ CO non-attainment county	+369.7**	+613.7**	+515.1**
	(86.2)	(121.5)	(124.7)
High SO_2 emitter $\times$ SO_2 non-attainment county	+468.6**	+625.8**	+849.8**
	(109.0)	(139.3)	(132.8)
	APA operating costs		
Establishment subject to CAA regulation			
High VOC/NO_2 emitter $\times$ O_3 non-attainment county	+91.9	+875.7**	+430.8**
	(77.6)	(76.4)	(75.2)
High PT emitter $\times$ TSP non-attainment county	+311.1**	−452.2**	+270.7**
	(70.7)	(104.0)	(100.0)
High CO emitter $\times$ CO non-attainment county	+319.3**	+750.6**	+850.4**
	(83.1)	(118.1)	(125.0)
High SO_2 emitter $\times$ SO_2 non-attainment county	+574.3**	+678.7**	+943.6**
	(102.6)	(134.6)	(132.6)

[a]Samples consist of 89,889 observations. All specifications include county-by-year effects, establishment characteristics (size, age, and a multi-unit firm dummy), and high emitter indicators. The specification in column (1) combines the indicators of high VOC and high NO_2 emissions into a single indicator variable (i.e., of being a high emitter of O_3 precursors). The specification in column (2) employs the classification of high emitters developed by Greenstone [12]. The specification in column (3) utilizes this paper's basic classification methodology but restricts the proportion of high emitters in this sample to be the same as that under the Greenstone methodology. See the text for details. The estimates are from Tobit models (on real expenditures) and are in thousands of 1988 dollars. Standard errors are in parentheses. Statistical significance at the 10% and 5% level are indicated by * and **, respectively.

Perhaps not surprisingly, this has relatively little impact on results: there is still no evidence that O_3 non-attainment status had a strong effect on the APA outlays of high emitters of O_3 precursors, and the other six effects continue to be positive, statistically significant, and of very similar magnitudes to those in Table 3. These results serve as a good baseline for assessing the effects of the final two alternate classification schemes.

In column 2, the categorization of high emitters employed is that of Greenstone [12], which is based on industrial emissions estimates from EPA's Sector Notebook Project. For CO and SO_2, the results above are clearly supported, with positive and statistically significant coefficients. The magnitudes are larger here, most likely reflecting the fact that the Greenstone methodology classifies fewer—and presumably more pollution intensive—industries and establishments as high emitters of these pollutants. The same might explain the positive and statistically significant effects of O_3 non-attainment status on the APA expenditures of high emitters of the ozone precursors where previously none were found. The results for high PT emitters, however, obviously contradict the above findings. Here we see statistically significant *negative* coefficients for regulated PT emitters, and the coefficients on the high PT emitter dummy (not presented here) are also negative and significant. This perhaps suggests shortcomings with the designation of high PT emitters in this particular classification system.[21]

Finally, the alternative in column 3 again utilizes my basic methodology (described above in Section 3) but employs stricter definitions of high emitters by choosing cutoffs that yield the same proportion of high emitters in this sample as does the Greenstone methodology, which ranges from 7% in the case of CO to 32% for O_3 precursors. As such, the estimated coefficients here are expected to be greater than those found in column 1, which is in fact true—upwards of four times larger—in all but one of the eight cases. And the effects of O_3 non-attainment are statistically significant here, which is not the case under the more liberal definition of high emitters. As a final point, because the classification schemes used in columns 2 and 3 both designate the same numbers of high emitters, the two sets of results can be used to judge the effectiveness of the two methodologies in separating high and low emitters. That is, the "cleaner" of the two classifications should yield larger estimates. In that case, it appears that this paper's methodology performs better in identifying high PT and high SO_2 emitters, while Greenstone's does better in categorizing emitters of the O_3 precursors.

Overall, aside from the few noted exceptions, the results from using these alternative definitions of high emitter status are essentially what one would expect.

4.2. Alternate empirical specifications

Here I explore some alternate specifications. First, to help understand the sensitivity of results to the Tobit model's assumptions, I re-estimate the model in Eq. (1) using ordinary least squares (OLS).[22] These results appear in column 2 of Table 5, with the baseline Tobit estimates from Table 3 recapitulated in column 1 for comparison purposes. As in Table 4, I present only the coefficients of interest, for APA capital expenditures and APA operating costs, respectively. The OLS estimates support the same basic conclusions as before, with positive coefficients on all the regulatory variables (ψ) and nine of the ten actually achieving statistical significance (versus seven of the ten in the baseline Tobit). The coefficients for regulated PT, CO, and SO_2 emitters are all smaller (which is the suspected direction of any OLS bias in this context), while those for regulated VOC and NO_2 emitters are actually larger and more significant. It does not appear therefore that the Tobit specification is driving results.

Next, note that the model in Eq. (1) is already robust to location-specific heterogeneity. In particular, the 13,956 county-year effects (ϕ_{ct}) control for all permanent and transitory factors in a county affecting high and low emitters alike. The potential importance of this has been

[21] And indeed, the hypothesized effects of county TSP non-attainment on PT emitters are (mostly) not found by Greenstone [12].

[22] Of course OLS is not without its own issues, particularly when there is a large degree of left-censoring as we have here.

Table 5
Results from alternate specifications[a]

	(1)	(2)	(3)	(4)	(5)
	Baseline (Tobit)	Baseline (OLS)	Industry-by-year effects	Plant effects	Per unit costs
	APA capital expenditure				
Establishment subject to CAA regulation					
High VOC emitter × O_3 non-attainment county	+56.0	+76.6**	+54.5	−49.1	−91.3
	(89.7)	(27.7)	(68.4)	(211.4)	(95.3)
High NO_2 emitter × O_3 non-attainment county	+49.7	+88.0**	+51.8	+98.0	−54.7
	(93.3)	(29.1)	(71.2)	(210.9)	(98.9)
High PT emitter × TSP non-attainment county	+147.1*	+3.7	+53.3	+63.4	+173.5**
	(80.6)	(26.3)	(61.8)	(212.8)	(85.7)
High CO emitter × CO non-attainment county	+361.7**	+180.6**	+219.8**	+581.8**	+134.1
	(87.4)	(33.9)	(73.9)	(296.7)	(94.3)
High SO_2 emitter × SO_2 non-attainment county	+470.1**	+232.2**	+363.6**	+295.8	+262.3**
	(108.9)	(39.1)	(86.4)	(248.2)	(116.4)
	APA operating costs				
Establishment subject to CAA regulation					
High VOC emitter × O_3 non-attainment county	+129.3*	+200.0**	+151.7**	−50.7	−40.6
	(77.3)	(45.7)	(71.2)	(82.0)	(62.9)
High NO_2 emitter × O_3 non-attainment county	+115.4	+195.8**	+141.0*	+51.6	−97.6
	(80.6)	(48.0)	(74.4)	(81.6)	(67.4)
High PT emitter × TSP non-attainment county	+280.6**	+136.9**	+233.7**	−26.9	+86.1
	(71.8)	(43.4)	(65.8)	(84.4)	(58.6)
High CO emitter × CO non-attainment county	+296.0**	+201.9**	+155.1*	+380.3**	+23.1
	(84.2)	(56.0)	(80.2)	(124.7)	(68.8)
High SO_2 emitter × SO_2 non-attainment county	+569.8**	+418.9**	+512.1**	+76.9	+313.6**
	(102.5)	(64.6)	(95.3)	(102.2)	(83.0)

[a]Samples consist of 89,889 observations. All specifications include establishment characteristics (size, age, and a multi-unit firm dummy) and the high emitter indicators. The specifications in columns (1), (2), (3), and (5) also include county-by-year effects, while the one in (4) contains plant fixed effects with time-varying county non-attainment statuses and year effects. In columns (1), (3), and (4), the estimates are from Tobit models (on real expenditures) and are in thousands of 1988 dollars, as are the OLS estimates in column (2). In column (5), the estimates are from Tobit models (on per unit expenditures) and are in dollars per $10,000 of value added. Standard errors are in parentheses. Statistical significance at the 10% and 5% level are indicated by * and **, respectively.

demonstrated by Greenstone [12], who found evidence that county non-attainment status is not orthogonal to other observable county characteristics (to say nothing of unobservable factors) and that countywide shocks may covary with non-attainment. A remaining concern, however, may be unobserved industry-level shocks. One way of treating this potential source of bias is by allowing the effects on E_n to vary by year, as in

$$\mathrm{APA}_{it} = \alpha + \phi_{ct} + \beta' X_{it} + \pi_t' E_n + \psi' Z_{nct} + \varepsilon_{it}. \tag{2}$$

Column 3 of Table 5 shows the Tobit estimates using this particular specification.[23]

As before, all of the effects of county non-attainment status on the expenditures of high emitters have the expected positive sign. Some of the point estimates, however, are appreciably lower than in column 1, by as much as \$140,000 in the case of CO emitters. Other than some potential quantitative differences, the only real qualitative difference between the results in columns 1 and 3 is the now insignificant effect of TSP non-attainment on the APA capital expenditure of high PT emitters and the now statistically significant impact of O_3 non-attainment on the APA operating costs of high NO_2 emitters. The latter had already been close to statistical significance in the baseline Tobit. Overall, the conclusion here is basically the same: there is evidence that the CAA impacted the APA capital expenditure and operating costs of certain (but not all) high emitting plants.

Next, I explore the possibility that there may be unobserved plant heterogeneity, related to APA expenditure and perhaps correlated with county non-attainment and hence regulation. The inclusion of plant fixed effects (α_i), as in the model below, handles all permanent plant characteristics that determine APA spending:

$$\mathrm{APA}_{it} = \alpha_i + \delta_t + \theta' N_{ct} + \beta' X_{it} + \pi' E_n + \psi' Z_{nct} + \varepsilon_{it}. \tag{3}$$

Here the regulatory effects (ψ) are identified by the within-establishment comparisons of APA of plants that changed regulatory status (Z_{nct}), either because their high emitter status (E_n) changed while in a non-attainment county or because their county's non-attainment status (N_{ct}) changed while remaining a high emitter.[24] This specification is quite demanding with its 28,831 plant fixed effects, 9355 of which represent establishments that appear in the sample only once. Of the remaining plants, relatively few help identify the regulatory effects—from 248 in the case of CO regulation to just over 1400 in the cases of VOC and NO_2.

Column 4 of Table 5 shows the Tobit results from this specification. The costliness of this approach can be seen in the standard errors, which are mostly larger than those previously, especially in the capital expenditure regression. In terms of APA capital, the point estimates suggest potentially sizable effects on the expenditures of regulated CO and SO_2 emitters, as they did in the previous specifications, with the effect of CO regulation rising to statistical significance.

[23] Another way of treating this is by adding industry-by-year fixed effects (λ_{nt}) to the model in Eq. (1). Those results are largely similar to the ones reported here.

[24] Note the inclusion of N_{ct} in Eq. (3), representing the vector of county non-attainment statuses (for O_3, TSP, CO, and SO_2). Previously, this had been absorbed by the county-by-year parameter ϕ_{ct}. Current econometric packages cannot sustain the simultaneous inclusion of thousands of county-year effects in addition to thousands of plant fixed effects in a non-linear specification such as the Tobit. The county-year effects are therefore replaced by the time-varying county characteristic of most importance here, while time-invariant county characteristics are naturally absorbed by the plant fixed effects. The year effect (δ_t) captures national trends in APA activity.

In terms of APA operating costs, however, the magnitudes and statistical significance of the previous results all but disappear—the effect of CO non-attainment being the one exception. This suggests that the APA operating costs of a high (VOC, NO_2, TSP, or SO_2) emitting plant did not adjust as its county's status moved from non-attainment to attainment vis-à-vis the respective pollutant.[25] This is entirely plausible if the level of APA activity required of plants to bring their county into attainment must be maintained to keep it from slipping back into non-attainment.

However, there are some serious concerns with this particular specification, which may cast doubt upon these results. First, certain longitudinal data issues may prevent sound within-plant comparisons. In particular, it is quite likely that some of the within-plant industrial reclassifications, which may have triggered changes in E_n and Z_{nct}, were not "real" changes in production (and emissions) but rather rectifications of previous misclassifications. Such reclassifications are not uncommon, and there is strong evidence that this may in fact be an issue here.[26] Another possible concern is that establishments under-report their year-to-year change in pollution abatement expenditure, reducing estimated effects.[27] Finally, there is the unique nature of the (relatively few) establishments that help identify regulatory effects in the current model: they are found to be much larger, older, and more likely to belong to a multi-unit firm than the typical high emitter in this sample.[28] If they were atypical in this respect, they may have also been atypical in their responsiveness to regulatory change. For these reasons, the previous specifications, which relied on within-plant as well as between-plant comparisons (within a county), might be deemed preferable.

Finally, because studies in this area sometimes focus on *unit* pollution abatement costs (e.g., [9]), I re-estimate the model in Eq. (1) using APA expenditure intensity as the dependent variable, namely dollars of APA expenditure per \$10,000 of value added produced. The outcome of using this unit cost measure appears in column 5 of Table 5. The results from the capital expenditure regression are nearly similar to those in the baseline: establishments that faced greater regulation of their high PT, CO, and SO_2 emissions all had higher expenditure, though the CO effect does not quite achieve traditional levels of statistical significance. In terms of operating costs however,

[25]In this sample, 90% of the status change faced by plants is from non-attainment to attainment.

[26]Among the most robust results in the other models of Tables 3–5 are the higher levels and likelihoods of APA expenditure among high emitters. Oddly, however, *none* of the estimates of π are positive and significant here in the plant fixed effect model, where these coefficients are identified by plants that moved from being a high to low emitter or vice versa. This lack of effects on the high emitter dummies is consistent with the notion that changes in these plants' 4-digit SIC code, which triggered these changes in their emissions classification (E_n), were not *real* changes in production and hence emissions, but were in fact corrections made by the Census Bureau upon learning that the establishment had been misclassified. This may in part explain the lack of significant ψ coefficients as well.

[27]That is, even if the changes in regulation were real and plants adjusted their APA spending accordingly, there is a question of whether there was a likewise change in *reported* expenditures. The establishments that help identify the regulatory effects here in this specification were, for the most part, perennial PACE respondents appearing in most survey years. To alleviate their survey response burden, they may have called upon their completed questionnaires from prior years. As a result, there may be (false) persistence in responses, or plants may have reported smaller changes than actually occurred. No one has expressed this concern about the PACE survey in particular, but this issue has been raised in the context of a number of household panel surveys and more recently with the ASM.

[28]This is to be expected. To have experienced a change in non-attainment status, a high emitting plant must naturally appear in the sample in more than one year, and more appearances increase the chances of having experienced a change. Since the probability of being sampled for the PACE survey is positively related to the size of the establishment, it stands to reason that plants identifying the regulatory effects in this specification are larger.

the four to five significant regulatory effects seen in columns 1 and 3 are not apparent here. The only exception is the effect of county SO_2 non-attainment on high SO_2 emitters, with such plants having spent \$314 more per \$10,000 of value added than similar emitters in attainment areas, all else being equal. The lack of effects here relative to the previous specifications suggests that regulated plants may indeed have had higher APA operating costs but they were also proportionally larger. In Section 4.3, I explore more fully the role of plant size as well as the other establishment characteristics.

4.3. Regulatory implications of establishment characteristics

The notion here is that certain classes of establishments may incur proportionally higher costs under regulation than otherwise similar plants. Dean et al. [9] provide a useful framework for discussing why unit abatement costs might vary: statutory asymmetries, enforcement asymmetries, and compliance asymmetries.

Statutory asymmetries exist when regulations explicitly impose less stringent requirements on businesses of a certain stripe. For example, many regulations exempt small firms from their most rigorous requirements. This is true for the CAA, which exempts small, new polluters in attainment areas from the BACT requirements their larger counterparts face. The CAA also differentiates by the age of the facility, with new facilities facing more stringent requirements than existing facilities.[29] The spatial variation in regulation, between attainment and non-attainment areas, is also an obvious statutory asymmetry. And the SIPs themselves can and often do have their own asymmetries. For example, individual states have additional exemptions for new emitters in non-attainment areas that are under a certain size and/or requirements that apply only to multi-site firms [3].

Enforcement asymmetries result when regulators choose to target certain establishments (for inspections, fines, enforcement, etc.) over others. For example, some have suggested that larger facilities experience greater regulatory scrutiny than smaller ones. In a world of limited regulatory resources and a fixed cost incurred with each establishment investigated [22], this can be an efficient strategy. Furthermore, plants belonging to more prominent (multi-unit) firms, besides being larger than average, may be inherently more sensitive to environmental concerns, since these firms may have that much more to lose—in terms of corporate assets, reputation, and so forth—if found to be environmentally negligent. Their greater visibility may also make these establishments attractive targets for regulators wanting to send signals to other firms in the area and to the public—much more so than relatively small, independent, locally based, entrepreneur-run firms, which may be politically unpopular targets in their own right. Others, however, have argued the opposite—that larger corporations are more politically influential and/or are better able to thwart enforcement through legal challenges.

Finally, *compliance asymmetries* arise when regulations are equally applied to facilities; however the fixed costs associated with compliance (e.g., certain administrative costs and/or the installation of specific capital-intensive technologies such as scrubbers) translate into higher costs *per unit of output* for the smaller establishments. There is little doubt that compliance

[29] These existing establishments, however, are to lose their "grandfathered" status with any expansion or major modification.

asymmetries are real. The question is how much regulatory and enforcement asymmetries negate this effect. Dean et al. [9] find that industries with high pollution abatement costs had fewer small business formations, suggesting compliance asymmetries outweighed the others, at least when the sum total of environmental regulations are considered. However, for regulation of VOC emissions at least, Becker and Henderson [4] find that statutory and enforcement asymmetries dominated. As measured by their avoidance of ozone non-attainment areas, smaller, single-unit establishments were regulated later and with less intensity than the larger facilities of multi-unit firms.[30] This advantage, however, appears to have diminished with time.

To explore the regulatory implications of establishment characteristics empirically, I estimate a variant of Eq. (1) that interacts the establishment characteristics with the high emitter indicators and the regulatory indicators:

$$\text{APA intensity}_{it} = \alpha + \phi_{ct} + \beta' X_{it} + \pi'(E_n \otimes X_{it}) + \psi'(Z_{nct} \otimes X_{it}) + \varepsilon_{it}. \tag{4}$$

My interest is the *unit* abatement cost by establishment type; I therefore employ expenditure intensity as my dependent variable, namely dollars of APA expenditure per \$10,000 of value added. The (partial) results from two Tobit regressions using this specification appear in the top and bottom panels of Table 6 for APA capital expenditure and operating costs, respectively. I discuss only the impacts of establishment size and multi-unit status.[31]

We see in both regressions that establishment characteristics had a variety of effects. First, it is interesting to note that plant characteristics mattered even for low emitters of the criteria pollutants (column (a)).[32] Indeed we see here that progressively larger facilities had progressively higher unit abatement costs, ceteris paribus. And plants belonging to multi-unit firms also had higher expenditure than single-unit businesses, all else being equal, with an additional \$185 and \$477 of APA capital expenditure and operating costs, respectively, per \$10,000 of value added.

The main interest here, however, is in the expenditure of higher emitters, particularly those in non-attainment areas (i.e., columns (c), (e), (g), (i), and (k)). In terms of the interaction between regulation and plant size, effects are seen to differ across criteria pollutants. Among high VOC emitters, for example, the burden of ozone non-attainment (as seen in column (c)) appears to have fallen hardest (and rather equivalently) on the smallest three quartiles of plants, suggesting perhaps some form of enforcement asymmetries that favored the largest plants. The results from Becker and Henderson [4], however, suggest that the largest plants were targeted most intensely in the 1970s (i.e., prior to the period under study here). Their greatest APA expenditures, therefore, may already have been behind them.

The effect of SO_2 non-attainment on high SO_2 emitters (column (k)) is somewhat similar in that the very smallest plants appear to have borne a disproportional amount of the burden in the effort to bring counties into attainment. Another interpretation, however, is that the larger SO_2 emitters

[30] Interviews with regulators and industry representatives in the state of Rhode Island corroborate this finding [3].

[31] These data are not fully adequate to examine age-related issues. The greatest regulatory difference is expected to be between new and existing plants, particularly on capital expenditures. Costs incurred by new plants under construction, however, are not collected by the PACE survey. And among existing plants, the effects of age are somewhat ambiguous, as older categories will potentially consist of both weakly regulated "grandfathered" plants and plants that have surrendered their grandfathered status and are therefore stringently regulated.

[32] It is of course possible that these plants have requirements on other types of air pollution, like their toxic emissions or their indoor air quality, though the PACE survey aims to exclude the latter.

Table 6
Impact of establishment characteristics[a]

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
	All plants	High VOC emitters		High NO_2 emitters		High PT emitters		High CO emitters		High SO_2 emitters	
		All	Regulated	All	Regulated	All	Regulated	All	Regulated	All	Regulated
	APA capital expenditure										
Constant	–	+918.0**	−589.7	−394.7	+124.6	−897.8**	+922.0**	+962.4**	−1117.2**	+783.8**	+4.8
		(392.0)	(432.6)	(499.7)	(475.3)	(360.8)	(363.3)	(399.1)	(569.6)	(360.6)	(595.2)
2nd size quartile	+295.2**	−175.0	+46.1	+340.8	−358.8*	−533.4**	+574.9**	−446.9**	+193.8	−41.5	−522.1**
	(66.3)	(169.3)	(184.8)	(211.1)	(201.1)	(149.4)	(150.5)	(174.9)	(233.9)	(146.6)	(234.8)
3rd size quartile	+708.6**	+28.9	−165.3	+205.3	−37.1	−372.2**	+510.8**	−517.3**	+284.9	−363.6**	−540.1**
	(67.9)	(172.7)	(188.7)	(214.6)	(201.9)	(151.1)	(150.4)	(171.3)	(228.3)	(150.9)	(232.0)
4th size quartile	+1305.1**	+289.1	−403.6**	+398.3*	+54.7	−598.3**	+686.5**	−545.7**	+189.8	−667.9**	−630.6**
	(70.6)	(179.4)	(196.9)	(211.4)	(204.4)	(152.8)	(147.5)	(165.2)	(220.8)	(147.4)	(224.3)
Multi-unit firm	+185.0**	−182.0	+252.0	−1.8	−73.8	+541.4**	−657.4**	+376.4*	+106.2	+258.7	+781.9**
	(73.3)	(206.8)	(221.8)	(258.6)	(243.9)	(182.1)	(185.4)	(228.1)	(288.2)	(167.9)	(294.8)
	APA operating costs										
Constant	–	+1286.1**	−1137.8**	−1113.2**	+984.8**	+221.3	+205.6	+633.3**	−326.7	+631.9**	−299.1
		(291.5)	(328.7)	(378.1)	(363.3)	(274.0)	(282.4)	(312.2)	(454.1)	(284.1)	(483.1)
2nd size quartile	+336.8**	+293.0**	−125.5	+124.8	−97.0	−548.6**	+436.2**	−1010.7**	+530.8**	−359.3**	−1137.2**
	(53.0)	(126.0)	(140.3)	(159.1)	(153.0)	(114.4)	(117.5)	(134.9)	(187.2)	(114.4)	(192.5)
3rd size quartile	+696.8**	+306.1**	−60.1	+101.2	+178.0	−582.2**	+416.9**	−1214.4**	+359.5*	−600.3**	−1216.5**
	(54.3)	(128.6)	(143.6)	(162.8)	(153.8)	(116.5)	(118.3)	(133.2)	(184.4)	(118.9)	(19.0)
4th size quartile	+1232.3**	+605.8**	−404.6**	−26.0	+393.1**	−899.5**	+464.6**	−1384.2**	+358.9**	−623.0**	−1370.9**
	(56.6)	(136.1)	(151.9)	(162.1)	(157.5)	(119.2)	(116.7)	(129.1)	(178.9)	(116.9)	(18.4)
Multi-unit firm	+476.6**	−685.4**	+420.4**	+382.9*	−307.1	+468.0**	−310.8**	+572.9**	+5.0	+140.1	+893.0**
	(59.5)	(155.9)	(170.1)	(199.0)	(188.7)	(140.7)	(145.7)	(175.8)	(229.7)	(134.0)	(243.0)

[a]The sample for these two regressions consists of 89,770 observations (requiring value added to be positive). The *All Plants* column contains the β coefficients of Eq. (4), showing the general effect of establishment characteristics. The estimates of π appear under the *All* heading of the respective pollutant, while the regulatory effects (ψ) appear under the *Regulated* header. The omitted category here—reflected in the constants—is a single-unit plant in the smallest of the four size quartiles and the youngest of the five age groups. The age variables are not shown here. Specifications also include county-by-year effects. The estimates from these two Tobit regressions (on per unit expenditures) are in dollars per $10,000 of value added. Standard errors are in parentheses. Statistical significance at the 10% and 5% level are indicated by * and **, respectively.

already undertook substantial abatement, regardless of location, such that there was not much more that they could be asked to do in non-attainment areas. Interestingly, aggregating together all reasons for pollution abatement among these regulated SO_2 emitters (i.e., summing columns (a), (j), and (k)) reveals a U-shaped unit cost curve with respect to establishment size.[33] This suggests a confluence of compliance asymmetries that favored larger establishments and enforcement/statutory asymmetries that favored smaller plants—the net effect being an advantage to mid-sized facilities.

Alternatively, the results on the other three criteria pollutants (NO_2, PT, and CO) suggest a positive relationship between plant size and unit abatement costs attributable to CAA-related regulation (columns (e), (g), and (i), respectively). For example, new multi-unit PT-emitting plants in the smallest size class had \$265 more capital expenditure (per \$10,000 of value added) in TSP non-attainment counties than similar plants in attainment counties, while those in the larger size classes had an *additional* \$511–687 in expenditure (column (g)), though the rise was not monotonic.

Overall, some of these results certainly suggest the existence of statutory and enforcement asymmetries in NAAQS-related regulation that favor smaller establishments. Other results, however, suggest asymmetries that may favor the large, and still other results suggest that mid-sized plants may be advantaged. At the very least, we can conclude that the regulatory effect of plant size is not uniform across pollutants, at least not during the time period under study here.

Nor is the effect of belonging to a multi-unit firm. High PT emitters, for example, appear to have garnered more regulatory attention in TSP non-attainment areas if they were single-unit establishments (column (g)). Particulate pollution, however, may be a somewhat exceptional case.[34] High SO_2 emitters that belonged to multi-unit firms, on the other hand, had APA capital expenditures and operating costs that were, respectively, \$782 and \$893 higher in SO_2 non-attainment areas than otherwise similar single-unit establishments, per \$10,000 of value added (column (k)). And multi-unit VOC emitters had operating costs that were \$420 higher (per \$10,000 value added) than comparable single-unit firms in ozone non-attainment areas (column (c)). These particular results suggest that multi-unit firms were indeed targeted more stringently by regulators and/or were more responsive to CAA regulation. The VOC result is also consistent with the Becker and Henderson [4] finding that new, multi-unit VOC emitters avoided ozone non-attainment areas to a greater extent than did single-units, presumably because of these higher costs.

[33] For example, relative to the high SO_2 emitters in SO_2 non-attainment areas in the smallest size quartile, the APA capital expenditure per \$10,000 of value added was \$269 lower for regulated plants in the second quartile (+295–42–522), \$195 lower for regulated plants in the third quartile (+709–364–540), and a mere \$6 higher for regulated plants in the largest size quartile (+1305–668–631).

[34] Unlike gaseous emissions, particulates are more likely to settle in the communities immediately surrounding the plant. Furthermore, the industries cited most in the AIRS database for their particulate emissions (i.e., sawmilling, powdered cement manufacturing, the crushing and grinding of minerals, etc.) are notoriously dusty places to work, raising issues of worker health and safety. For liability reasons, multi-unit firms in these industries, which presumably have more at stake in terms of reputation and assets, may be more likely to invest in particulate abatement, regardless of location and county attainment status. The disproportionate effect of TSP non-attainment on single-unit PT emitters seen here may have been an effort to close this abatement gap.

5. Conclusion

This paper has examined some of the costs to manufacturing plants of the CAA and its amendments. Results from the baseline specification suggest that facilities subjected to stringent CAA-related regulation—namely, high emitters of one of five criteria air pollutants in a county designated as being in non-attainment of the NAAQS for that pollutant—generally had higher APA expenditures than otherwise similar high emitters located in NAAQS attainment counties. It is these additional costs that implicitly underlie the findings of a number of recent studies [4,12,15,17], which all document significant impacts of county non-attainment status on local manufacturing activity, including plant location, employment, investment, and survival. While significant regulatory costs are apparent in all these studies, they were never directly observed.

Results specifically show that the regulation of a particular air pollutant generally resulted in hundreds of thousands of dollars worth of additional APA capital expenditures (operating costs) for the average affected plant in this sample, and an establishment obviously may have had additional outlays of *both* types of costs, possibly for *multiple* pollutants. Perhaps not surprisingly, the effect of regulation on the average level of APA expenditure was less ambiguous than on the probability of having had such expenditures. And interestingly, with the exception of SO_2 emitters, being a high emitter in a non-attainment county only had a secondary effect on one's APA expenditures (relative to low emitters). It seems high emitters do a significant amount of APA regardless of local attainment status. As would be expected, the use of stricter definitions of high emitters results in larger estimated effects.

With some important exceptions, the alternate empirical specifications support many of the same conclusions. The addition of industry-year effects, as in model (2), yields largely similar results with somewhat lower point estimates. And while model (3)—with its plant fixed effects—produces little that is statistically significant, there is good reason to question the soundness of those particular results. Meanwhile the final specification in Table 5, which focuses on *unit* abatement costs, largely supports previous conclusions vis-à-vis APA capital expenditure, but not so for operating costs.

The lack of effects here, and particularly on the capital expenditures of regulated VOC and NO_2 emitters in many of these specifications, could indicate limitations with the PACE data. In particular, there may be something inherent in the technologies and techniques used to abate these particular pollutants that make their costs especially difficult to quantify. For example, to use PACE terminology, capital expenditures of the *end-of-line* variety—such as scrubbers—may be relatively easy to identify and measure, but those associated with *changes-in-production-processes* have long been recognized as difficult to account for, and capturing the various types of operating costs may be equally (or more) problematic [5]. Moreover, establishments generally do not keep special track of their outlays on environmental protection; they must therefore *estimate* such expenditures, sometimes a year or more after they have actually occurred. Since more-regulated plants were more likely to have had these difficult-to-estimate costs, they may also have been more likely to under-report (or at least misreport) their total pollution abatement expenditures. And then there are the costs that the PACE survey makes no attempt to capture, such as fines, permits, pollution offsets, the potentially sizable capital investments of nascent establishments, and output that may have been lost from plant shutdowns (to install APA equipment) or from production efficiency sacrificed in the name of environmental protection.

While the results of this current study are not directly comparable to those in Becker and Henderson [5], which (among other things) looked at plants' *total* operating costs, a crude ''back-of-the-envelope'' comparison is nonetheless illustrative. In that study, new multi-unit plants in the industrial organic chemicals industry—a high emitter of both VOC and NO_2—are found to have had average total costs that were roughly 17% higher in ozone non-attainment counties than in attainment counties. Using the coefficients from Table 6, a new multi-unit plant that was a high emitter of both VOC and NO_2 and located in an ozone non-attainment county had APA operating costs that were about 2.7% higher, *as measured as a proportion of value added*, than that of a similar plant in an ozone attainment area.[35] As a proportion of total operating costs, this percentage is lower,[36] though one then needs to account for the fact that industrial organic chemical plants have about twice the emission intensity of the average high VOC and NO_2 emitter here and that the cost of capital services is not captured, as it was in Becker and Henderson [5]. Even so, the estimated cost differential is probably no more than a few percent—far shy of what Becker and Henderson [5] had estimated for this group. This suggests a degree of under-reporting in the PACE survey akin to that which Gray and Shadbegian [11] find.

The verdict on the PACE survey, therefore, is somewhat mixed. Clearly in many instances, reported APA expenditures are correlated with these specific measures of air quality regulation. And with few exceptions, outlays are positively related to having been a high emitter of these pollutants, as is expected. There are other instances, however, where PACE responses appear unrelated to regulatory stringency, as with APA capital expenditures for regulated VOC and NO_2 emitters.[37] In light of the previous literature, this more likely indicates deficiencies in the PACE data than suggests that these CAA-related regulations were not enforced or that it was relatively inexpensive to comply with them. It is important to note that, because of these potential limitations in the PACE data, all of the estimates of the costs of CAA regulations found in this study are likely *lower bounds* on the true costs to manufacturing plants.

This paper has also begun to explore the potential impact of establishment characteristics on NAAQS-related regulatory costs. Effects are found to vary across the pollutants—sometimes suggesting that regulations and enforcement favored smaller plants, sometimes the reverse. Differences are also seen in the impact of corporate status. Preventing easy generalizations here may be the fact that the target of regulators (and regulations) may be shifting over time, and at different times for the different pollutants, while here we observe only the intermediate years of CAA regulation. While these results are evocative, more work is recommended to understand the exact nature and dynamics of the asymmetries at play here.

Future research might also look at these APA expenditures in greater detail. For example, the survey data allow one to identify capital investment devoted to the abatement of specific air pollutants, to examine the incidence of end-of-line versus change-in-production-process capital expenditures, and to relate APA capital investment with that for other pollution media (water and

[35]Using only statistically significant coefficients: $-1{,}137.8+984.8+420.4=267.4$. An additional \$267.40 per \$10,000 of value added implies 2.7%. Note that plant size plays no significant role in this particular example.

[36]Among industrial organic chemical plants in my sample, value added is roughly 42% of output, and operating costs are roughly 77% of output. $267.4/[10{,}000*(1/.42)*.77]\approx 1.5\%$.

[37]Having said that, there is evidence in Table 4 that more extreme emitters of these O_3 precursors *did* have higher capital expenditures in non-attainment areas.

solid waste), as well as with investment decisions in general. Different types of APA operating expenses (labor, materials & energy, services & equipment leasing, and depreciation) can also be distinguished in certain years of the PACE survey. And data on tons of various air pollutants abated (collected prior to 1986) make it possible to also consider some of the potential *benefits* of this regulation, along with the costs that have been the focus of this paper.

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