The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufactures

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This paper estimates the impacts of the Clean Air Act's division of counties into pollutant-specific nonattainment and attainment categories on measures of industrial activity obtained from 1.75 million plant observations from the Census of Manufactures. Emitters of the controlled pollutants in nonattainment counties were subject to greater regulatory oversight than emitters in attainment counties. The preferred statistical model for plant-level growth includes plant fixed effects, industry by period fixed effects, and county by period fixed effects. The estimates from this model suggest that in the first 15 years

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in which the Clean Air Act was in force (1972–87), nonattainment counties (relative to attainment ones) lost approximately 590,000 jobs, $37 billion in capital stock, and $75 billion (1987 dollars) of output in pollution-intensive industries. These findings are robust across many specifications, and the effects are apparent in many polluting industries.

I. Introduction

Efforts to regulate pollution are among the federal government's most controversial interventions into the marketplace. On the one hand, the Pollution Abatement Costs and Expenditures Survey reports that manufacturing plants spend almost $30 billion a year to comply with environmental regulations (U.S. Bureau of the Census 1993). Manufacturers contend that these expenditures place them at a competitive disadvantage in the global economy and that this leads to the loss of tens of thousands of U.S. jobs. On the other hand, previous empirical research fails to consistently document a negative association between environmental regulations and industrial activity (Bartik 1985; McConnell and Schwab 1990; Gray and Shadbegian 1995; Jaffe et al. 1995; Henderson 1996; Levinson 1996; Becker and Henderson 2000, 2001). In fact, some research suggests that environmental regulations do not harm regulated firms or their workers and may even benefit them (Porter and van der Linde 1995; Berman and Bui 1998, 2001). To set rational policy, it is crucial to understand whether these regulations restrict economic progress.[1] This paper presents new evidence about the relationship between environmental regulations and industrial activity by focusing on the Clean Air Act's impact on polluting manufacturers.

The Clean Air Act, originally passed in 1963 and amended in 1970, 1977, and 1990, is one of the most significant federal interventions into the market in the postwar period. Following the passage of the 1970 amendments, the Environmental Protection Agency (EPA) established separate national ambient air quality standards—a minimum level of air quality that all counties are required to meet—for four criteria pollutants: carbon monoxide (CO), tropospheric ozone (O_3), sulfur dioxide (SO_2), and total suspended particulates (TSPs). As a part of this legislation, every U.S. county receives separate nonattainment or attainment designations for each of the four pollutants annually. The nonattainment designation is reserved for counties whose air contains concentrations of a pollutant that exceed the relevant federal standard. Emitters of the regulated pollutant in nonattainment counties are sub-

[1] See Chay and Greenstone (2000, 2002*a*) for estimates of the benefits associated with the Clean Air Act Amendments.

ject to stricter regulatory oversight than emitters in attainment counties. Nonpolluters are free from regulation in both categories of counties.

This paper brings together a variety of comprehensive data files to empirically determine the effects of these federally mandated county-level regulations on the activity of polluting manufacturers in the 1967–87 period. I compiled annual data on the four pollutant-specific, nonattainment/attainment designations for each of the 3,070 U.S. counties from the *Code of Federal Regulations* and EPA pollution monitors. The structure of these longitudinal regulation data allows for the identification of cross-sectional variation in these regulations, as well as changes in counties' pollutant-specific regulatory status over time. Despite the centrality of these county-level regulations to environmental policy, this is the first time that either a researcher or the EPA has produced a data file with these designations for all four of these criteria pollutants.[2] The regulation file is merged with the 1.75 million plant-level observations from the five Censuses of Manufactures in the 1967–87 period. These censuses contain detailed questions about plants' characteristics (including county of location), input usage, and output. The combined data file is used to relate the growth of employment, investment, and shipments of manufacturers to the federally mandated regulations across the entire country.

The paper's approach overcomes some of the objections to earlier studies of the impact of environmental regulations. First, the preferred specification includes plant fixed effects, industry by period fixed effects, and county by period fixed effects in plant-level models for the growth of employment, investment, and shipments. Consequently, the estimated regulation effects are purged of all permanent plant characteristics that determine growth, all transitory differences in the mean growth of plants across industries, and all transitory determinants of growth that are common to polluters and nonpolluters within a county. These controls are important because this was a period of dramatic changes in the manufacturing sector, including a substantial increase in competition from foreign firms in some industries, a secular movement of plants from the Rust Belt to the South, and two oil price shocks that had differential effects on particular industries and regions.

Second, this paper uses the principal instruments of the Clean Air Act Amendments (CAAAs), the pollutant-specific, county-level attainment/nonattainment designations, as its measures of regulation. These four designations are the "law of the land" and capture the regional

[2] McConnell and Schwab (1990), Henderson (1996), and Becker and Henderson (2000, 2001) use nonattainment status for O_3 but did not collect information on nonattainment status for the other pollutants.

and industry variation that Congress imposed with this legislation.[3] In fact, these designations govern the writing and enforcement of the plant-specific regulations that restrict the behavior of polluters. Moreover, the simultaneous evaluation of all four regulations is important, because many plants emit multiple pollutants and many counties are designated as nonattainment for multiple pollutants. These regulations should address Jaffe et al.'s (1995) criticism that previous studies rely on measures of regulation that are too aggregated (e.g., state-level measures) to detect differences in stringency.

Third, the detailed Census of Manufactures questionnaire allows for an examination of regulation's impact across a number of outcomes and categories of plants. The previous literature generally focuses on the effects of regulation on a single outcome variable (e.g., employment) or on a particular category of plants (e.g., new plants and their location decisions). This narrow focus may provide an incomplete picture of the consequences of environmental regulations. In contrast, this paper examines the impacts of regulation on the growth of employment, capital stock, and shipments. Moreover, its estimates are derived from a sample that includes existing plants as well as newly opened ones.

The results indicate that the CAAAs substantially retarded the growth of polluting manufacturers in nonattainment counties. The estimates suggest that in the first 15 years after the amendments became law (i.e., 1972–87), nonattainment counties (relative to attainment ones) lost approximately 590,000 jobs, $37 billion in capital stock, and $75 billion (1987 dollars) of output in pollution-intensive industries. Importantly, these findings are robust across many specifications, and the effects are evident across a wide range of polluting industries. Although the decline in manufacturing activity was substantial in nonattainment counties, it was modest compared to the size of the entire manufacturing sector.

The paper is organized as follows. Section II describes the statutory requirements of the CAAAs and the variation in regulation that they imposed. Section III describes the data and presents some summary statistics on the regulations' scope. Section IV presents the identification strategy, and Section V discusses the estimation results. Section VI develops two measures of the magnitude of the regulations' impacts and interprets the results. Section VII concludes the paper.

II. The CAAAs and the Variation in Regulation

The ideal analysis of the relationship between industrial activity and environmental regulations involves a controlled experiment in which

[3] A few states and localities (e.g., California) have imposed clean air regulations that are stricter than the federal ones. Any regulations over and above the federally mandated ones are unobserved variables in the subsequent analysis.

environmental regulations are randomly assigned to plants. Then the changes in activity among the regulated and unregulated can be compared with confidence that any differences are causally related to regulation.

In the absence of such an experiment, an appealing alternative is to find a situation in which similar plants face different levels of regulation. The structure of the 1970 and 1977 CAAAs may provide such an opportunity. In particular, the amendments introduce substantial cross-sectional and longitudinal variation in regulatory intensity at the county level. This section describes the CAAAs and why they may offer the opportunity to credibly identify the relationship between environmental regulation and industrial activity.

A. *The CAAAs and Their Enforcement*

Before 1970 the federal government did not play a significant role in the regulation of air pollution; that responsibility was left primarily to state governments. In the absence of federal legislation, few states found it in their interest to impose strict regulations on polluters within their jurisdictions. Disappointed with the persistently high concentrations of CO, O_3,[4] SO_2, and TSPs[5] and concerned about their detrimental health impacts,[6] Congress passed the 1970 Clean Air Act Amendments.[7]

The centerpiece of this legislation is the establishment of separate federal air quality standards for each of the pollutants, which all counties are required to meet. Appendix table A1 lists these air quality standards. The stated goal of the amendments is to bring all counties into compliance with the standards by reducing local air pollution concentrations. The legislation requires the EPA to assign annually each county to either nonattainment or attainment status for each of the four pollutants, on the basis of whether the relevant standard is exceeded.

The CAAAs direct the 50 states to develop and enforce local pollution abatement programs that ensure that each of their counties attains the standards. In their nonattainment counties, states are required to de-

[4] There are separate standards for O_3 and nitrogen dioxide (NO_2), and, in principle, a county could meet one of these standards but not the other. However, O_3 is the result of a complicated chemical process that involves NO_2, and the vast majority of counties that were nonattainment for NO_2 were also nonattainment for O_3. As a result, I designated a county nonattainment for O_3 if the EPA labeled it nonattainment for either O_3 or NO_2. All future references to O_3 refer to this combined measure.

[5] In 1987 the EPA changed its focus from the regulation of all particulates (i.e., TSPs) to the smaller particulate matter (PM10s), which have an aerodynamic diameter equal to or less than 10 micrometers. In 1997 the PM10 regulation was replaced with a PM2.5 one.

[6] See Dockery et al. (1993), Ransom and Pope (1995), and Chay and Greenstone (2002*a*, 2002*b*) on the relationship between air pollution and human health.

[7] See Lave and Omenn (1981) and Liroff (1986) for more detailed histories of the CAAAs.

velop plant-specific regulations for every major source of pollution. These local rules demand that substantial investments, by either new or existing plants, be accompanied by installation of state-of-the-art pollution abatement equipment and by permits that set emissions ceilings. The 1977 amendments added the requirement that any increase in emissions from new investment be offset by a reduction in emissions from another source within the same county.[8] States are also mandated to set emission limits on existing plants in nonattainment counties.

In attainment counties, the restrictions on polluters are less stringent. Large-scale investments require less expensive (and less effective) pollution abatement equipment; moreover, offsets are not necessary. Smaller investments and existing plants are essentially unregulated. Additionally, nonpolluters are free from regulation in both sets of counties.

Both the states and the federal EPA are given substantial enforcement powers to ensure that the CAAAs' intent is met. For instance, the federal EPA must approve all state regulation programs in order to limit the variance in regulatory intensity across states. On the compliance side, states run their own inspection programs and frequently fine noncompliers. The 1977 legislation made the plant-specific regulations both federal and state law, which gives the EPA legal standing to impose penalties on states that do not aggressively enforce the regulations *and* on plants that do not adhere to them. Nadeau (1997) and Cohen (1998) document the effectiveness of these regulatory actions at the plant level. Perhaps the most direct evidence that the regulations are enforced successfully is that air pollution concentrations declined more in nonattainment counties than in attainment ones during the 1970s and 1980s (Henderson 1996; Chay and Greenstone 2000, 2002*a*; Greenstone 2002).

B. *Which Industries Are Targeted by the CAAAs?*

The manufacturing sector is a primary contributor of the four regulated pollutants. Within this sector, the pollutant-specific regulations apply only to emitters of the relevant pollutants. An official list of the emitting industries is unavailable from the EPA, so it was necessary to develop a rule to divide manufacturers into emitters and nonemitters for each of the four pollutants. It is important that this assignment rule be accurate, because the subsequent analysis compares the growth of emitters and nonemitters, and misclassification will bias the estimated regulation effects.

[8] The reduction in pollution due to the offset must be larger than the expected increase in pollution associated with the new investment. The offsets could be purchased from a different facility or generated by tighter controls on existing operations at the same site (Vesilind, Peirce, and Weiner 1988).

After exploring a number of alternatives, I use the EPA's estimates of industry-specific emissions (see App. table A2) to determine pollutant-specific emitter status. Industries that account for 7 percent or more of industrial sector emissions of that pollutant are designated an emitter; all other industries are considered nonemitters.[9] This rule aims to mimic the EPA's focus on the dirtiest industries in the years in which the CAAAs were first in force. Its application causes 12 separate industries to be designated as emitters of at least one of the pollutants. The subsequent analysis demonstrates that the estimated effects of the regulations are largely insensitive to other reasonable definitions of emitter status.

Under any rule, each industry could emit any of the 16 (i.e., 2^4) possible combinations of the four pollutants. The 7 percent assignment rule divides the manufacturing sector such that eight of the possible combinations are represented. The seven polluting combinations (with the relevant industry names and standard industrial classification [SIC] codes in parentheses) are emitters of O_3 (printing 2711–89; organic chemicals 2861–69; rubber and miscellaneous plastic products 30; fabricated metals 34; and motor vehicles, bodies, and parts 371), SO_2 (inorganic chemicals 2812–19), TSPs (lumber and wood products 24), CO/SO_2 (nonferrous metals 333–34), $CO/O_3/SO_2$ (petroleum refining 2911), O_3/SO_2/TSPs (stone, clay, glass, and concrete 32), and $CO/O_3/SO_2$/TSPs (pulp and paper 2611–31 and iron and steel 3312–13 and 3321–25). The EPA's estimates of emissions indicate that the remaining industries are not major emitters of any of the four pollutants, and I assign these industries to the clean category.[10]

C. *Summarizing the Variation in Regulation Due to the CAAAs*

The structure of the CAAAs provides three sources of variation in which plants were affected by the nonattainment designations. This subsection summarizes this variation and highlights its importance from an eval-

[9] See the Data Appendix for further details on the determination of pollutant-specific emitting status.

[10] It is informative to compare this division of the manufacturing sector into polluters and nonpulluters with those in the previous literature. In each of their papers, Henderson (1996) and Becker and Henderson (2000, 2001) designate different sets of industries as subject to O_3 nonattainment status. The current paper's set of ozone emitters spans the intersection of their three sets, with the exception that the 7 percent rule excludes wood furniture (SIC 2511) and plastic materials and synthetics (SIC 282). Berman and Bui's (1998, 2001) list of regulated industries is not readily comparable with this paper's list for at least two reasons. First, their list is not pollutant-specific. Second, their papers examine local regulations in the South Coast Air Basin that are over and above federal and state regulations, so their set of regulated industries is likely to be broader than those scrutinized by the federal EPA. Nevertheless, there is substantial overlap between their list of industries targeted in the South Coast and the industries that are classified as emitters of at least one pollutant by this paper's assignment rule.

uation perspective. It also briefly discusses some of the sources of this variation and why they may reinforce the credibility of the subsequent analysis.

The first dimension of variation is that at any point in time the pollutant-specific nonattainment designations are reserved for counties whose pollution concentrations exceed the federal standards. This cross-sectional variation allows for the separate identification of industry-specific shocks and the regulation effects. This may be especially important in the 1967–87 period, because there were dramatic shocks (e.g., oil crises, recessions, and increases in foreign competition) that affected industries differentially.

The second dimension of variation is that a county's attainment/nonattainment designations vary over time as its air quality changes. Consequently, individual plants might be subject to regulations in one period but not in a different one. This longitudinal variation allows for the inclusion of plant fixed effects in equations for plant-level growth. Consequently, the paper presents estimated regulation effects that are derived from within-plant comparisons under the attainment and nonattainment regulation regimes.

The third dimension of variation is that within nonattainment counties, only plants that emit the relevant pollutant are subject to the regulations. This intracounty variation allows for estimation of models that include unrestricted county by period effects so that time-varying factors common to all plants *within* a county are not confounded with the effects of regulation. For example, the 1980–82 recession caused polluting and nonpolluting manufacturers in Allegheny County, Pennsylvania (i.e., Pittsburgh), to reduce their operations. Since Allegheny County was designated nonattainment for all four pollutants at this time, this decline would be falsely attributed to the regulations if the intracounty variation in emitting status were unavailable.

Some of the sources of variation in nonattainment status reinforce the credibility of an evaluation based on the CAAAs. Specifically, the county-level nonattainment designations are federally mandated and therefore may be unrelated to differences in tastes, characteristics, or underlying economic conditions across counties. Moreover, the nonattainment designations depend on whether local pollution levels exceed the federal standards. And while pollution levels are not randomly assigned, scientific evidence suggests that during the years under study, many counties were designated nonattainment because of pollution that was related to weather patterns—a factor that is unlikely to be related to local manufacturing sector activity.[11]

[11] Cleveland et al. (1976) and Cleveland and Graedel (1979) document that wind patterns often cause air pollution to travel hundreds of miles and that the concentration of

III. Data Sources and Summary Statistics

This section comprises four subsections. The subsequent analysis is based on the most comprehensive data available on manufacturing activity and clean air regulations, and subsection *A* describes the sources and structure of these data. Subsection *B* documents the scope of the regulatory program both geographically and within the manufacturing sector. Subsection *C* examines whether nonattainment status is orthogonal to observable determinants of plant growth. Subsection *D* explores whether nonattainment status covaries with county shocks that affect emitters and nonemitters.

A. Data Sources and Structure

The manufacturing data come from the micro data underlying the five quinquennial Censuses of Manufactures from 1967 to 1987. In each census a plant observation contains information on employment, capital stock, total value of shipments, age, whether it is part of a multiunit firm, and whether the observation is due to a survey response or derived from an administrative record. The four-digit SIC code and county of location allow the data on which pollutants are emitted and nonattainment designations to be merged. Importantly, the censuses contain a unique plant identifier, making it possible to follow individual plants over time.[12]

I linked consecutive Censuses of Manufactures to create four periods: 1967–72, 1972–77, 1977–82, and 1982–87. A plant observation in an individual period includes information from the censuses at the beginning and end of the period.[13] Plants that appear in the first census of a period but not in the last are considered "deaths"; analogously, plants that appear in the last but not in the first are designated "births." Plants that appear in both censuses of a period are labeled "stayers."[14] There are 1,737,753 plant observations in these four periods.

O_3 in the air entering the New York region in the 1970s often exceeded the federal standards. Figure 2 below graphically depicts the counties that were designated nonattainment for O_3 and reveals that virtually the entire Northeast, even counties without substantial local production of O_3, is O_3 nonattainment for at least one period. It is evident that this region's nonattainment designations partially reflect its location downwind from heavy O_3 emitters in the Ohio Valley.

[12] See the appendix in Davis, Haltiwanger, and Schuh (1996) for a more thorough description of these data.

[13] Approximately 0.5 percent of plants change SIC codes in a period. Plants are equally likely to switch into and out of emitting industries, so it does not appear that they alter their SIC code to evade regulation.

[14] The permanent plant identifier and the criteria specified by Davis et al. (1996) are used to determine whether a period-specific plant observation qualifies as a birth, death, or stayer. The distribution of plants across these categories is 29 percent births, 27 percent deaths, and 44 percent stayers.

Each of the 3,070 counties is assigned four pollutant-specific attainment/nonattainment designations in every period. A county's pollutant-specific designation in a given period is based on its attainment/nonattainment status in the *first* year of that period (e.g., 1982 determines the regulatory status for the 1982–87 period). All counties are attainment for the four pollutants in the 1967–72 period because the CAAAs were not in force until the end of this period. The attainment/nonattainment designations for the 1977–82 and 1982–87 periods are obtained from the list of nonattainment counties published in the *Code of Federal Regulations* (CFR) in the first year of those periods.[15] The CFR does not list the identity of the nonattainment counties in the early 1970s, and the EPA does not maintain a historical record of them. Consequently, I filed a Freedom of Information Act request and obtained data from the EPA's national pollution monitoring network for these years. For the 1972–77 period, I consider a county nonattainment for a pollutant if it had a pollution monitor reading that exceeded the relevant federal standard in 1972. The Data Appendix provides more details on the determination of nonattainment/attainment status.

There are at least two reasons that this definition of the regulation variables is preferable to alternatives based on nonattainment status later in a period. First, it is unlikely that plants can quickly change their production processes in response to regulation. Second, Berman and Bui (1998, 2001) document that the plant-level regulations associated with nonattainment status often set compliance dates a number of years in advance.[16]

B. The Incidence and Geographic Scope of the Nonattainment Designations

Table 1 reports summary information on the incidence of the pollutant-specific nonattainment designations. Column 1 lists the number of counties designated nonattainment for each pollutant, period by period. It is apparent that the regulatory programs for O_3 and TSPs are the most pervasive.

Column 2 details the number of counties that switch from attainment to nonattainment between periods, and column 3 enumerates the

[15] The publication of nonattainment counties in the CFR begins in 1978, so this year determines the designations for the 1977–82 period.

[16] The determination of nonattainment status from a single year might cause measurement error in the regulation variables, leading to attenuation bias in the estimated effects of regulation. In order to explore this possibility, I experimented with designating a county nonattainment if it received this designation in the first or second year of a period or the year before a period begins. (In the case of the 1982–87 period, this is 1981, 1982, or 1983.) I also used as a measure of regulation the total number of years during the period in which the county is designated nonattainment. The paper's findings are unchanged when nonattainment status is assigned in these alternative ways.

TABLE 1
Incidence and Changes in Nonattainment Status

	Nonattainment Period t (1)	Attainment Period $t-1$ and Nonattainment Period t (2)	Nonattainment Period $t-1$ and Attainment Period t (3)
	A. Carbon Monoxide (CO)		
1967–72	0	0	0
1972–77	81	81	0
1977–82	144	90	27
1982–87	137	15	22
	B. Ozone (O_3)		
1967–72	0	0	0
1972–77	32	32	0
1977–82	626	595	1
1982–87	560	104	170
	C. Sulfur Dioxide (SO_2)		
1967–72	0	0	0
1972–77	34	34	0
1977–82	87	75	22
1982–87	60	7	34
	D. Total Suspended Particulates (TSPs)		
1967–72	0	0	0
1972–77	296	296	0
1977–82	235	108	169
1982–87	176	24	83

Note.—There are 3,070 counties in the Census of Manufactures data files. See the Data Appendix for a description of how the pollutant-specific nonattainment designations are assigned.

changes from nonattainment to attainment. It is evident that there is substantial movement into and out of nonattainment status between periods. For example, of the 945 counties that are designated nonattainment for at least one of the pollutants, only 21 retain the same designations for all four pollutants throughout the three periods in which the CAAAs are in force. These changes in regulatory status reflect a number of factors, including the EPA's increasing awareness of which counties exceeded the federal standards (e.g., the large increase in the number of nonattainment counties between 1972–77 and 1977–82, particularly in the case of ozone), air quality improvement in nonattainment counties, and deterioration in attainment ones. This intercounty variation in nonattainment status is important for identification purposes because it allows for the inclusion of county or plant fixed effects in the econometric models.

Figures 1–4 graphically summarize the incidence of the four nonattainment designations. The shading indicates the number of periods a county is designated nonattainment for the relevant pollutant: white for zero, light gray for one, gray for two, and black for three. By moving

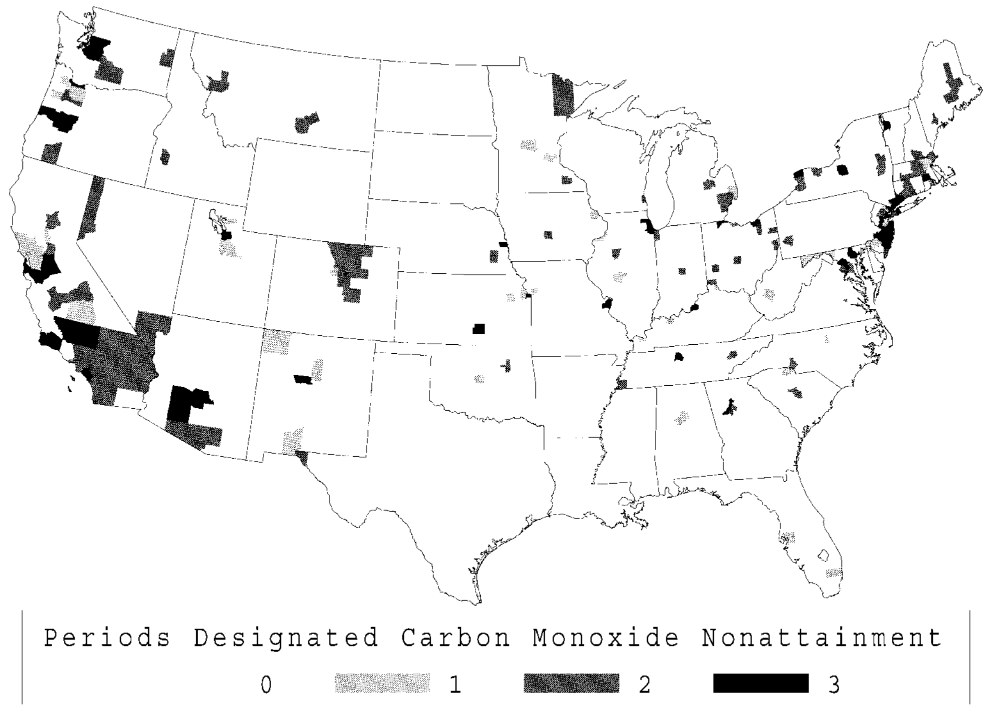

FIG. 1.—Incidence of nonattainment for carbon monoxide by county (1972–77, 1977–82, and 1982–87). Source: EPA Air Quality Subsystem Database, *Code of Federal Regulations* (various issues).

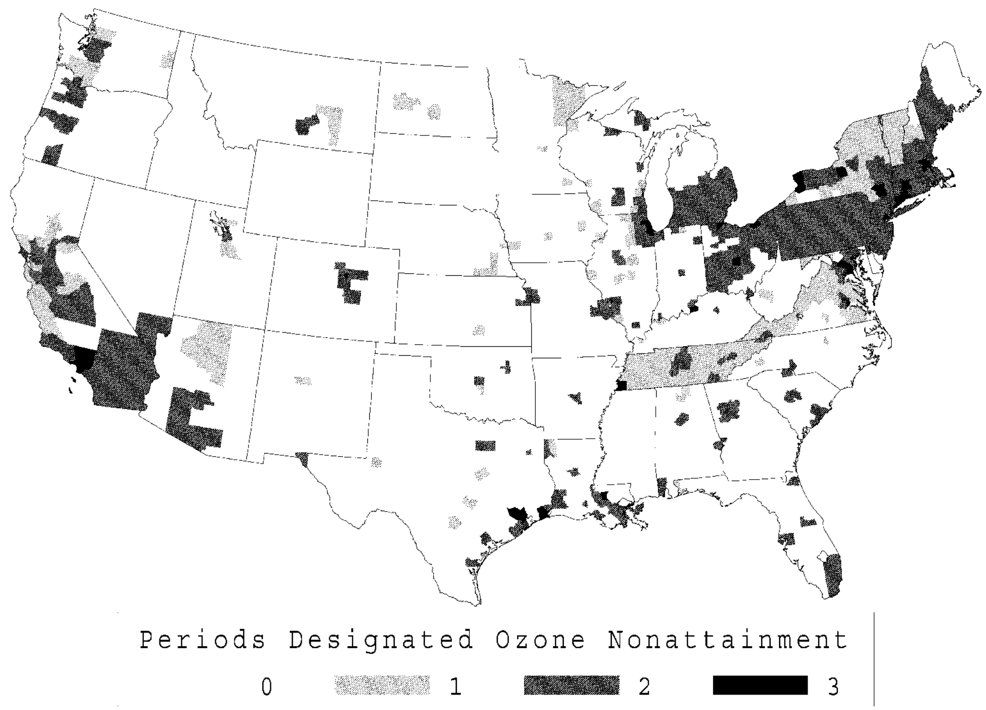

Fig. 2.—Incidence of nonattainment for ozone by county (1972–77, 1977–82, and 1982–87). Source: EPA Air Quality Subsystem Database, *Code of Federal Regulations* (various issues).

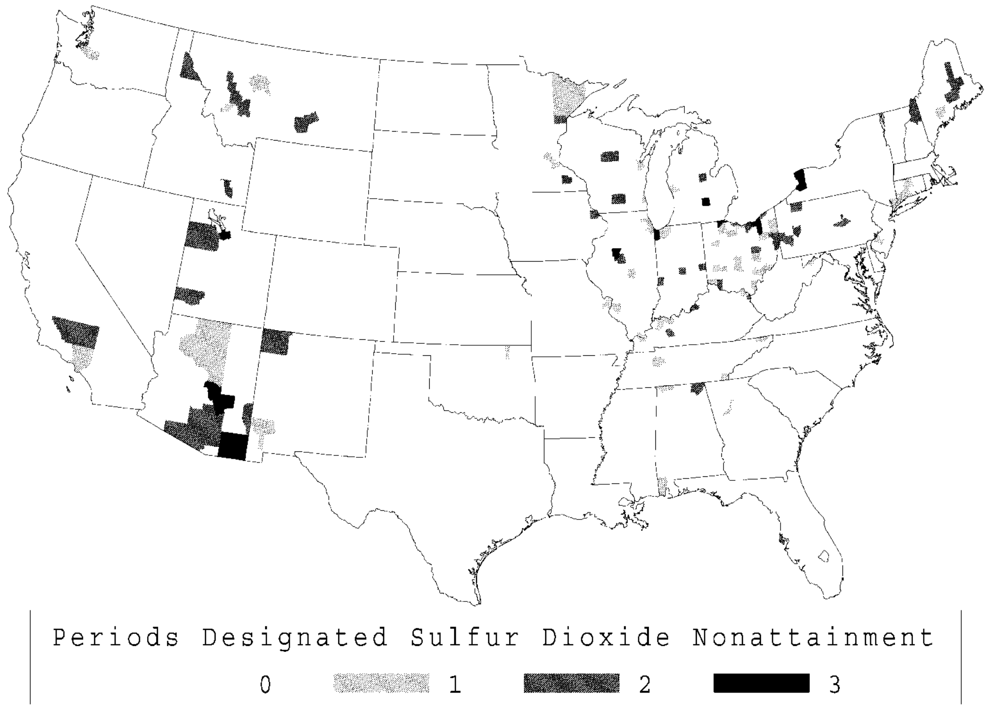

FIG. 3.—Incidence of nonattainment for sulfur dioxide by county (1972–77, 1977–82, and 1982–87). Source: EPA Air Quality Subsystem Database, *Code of Federal Regulations* (various issues).

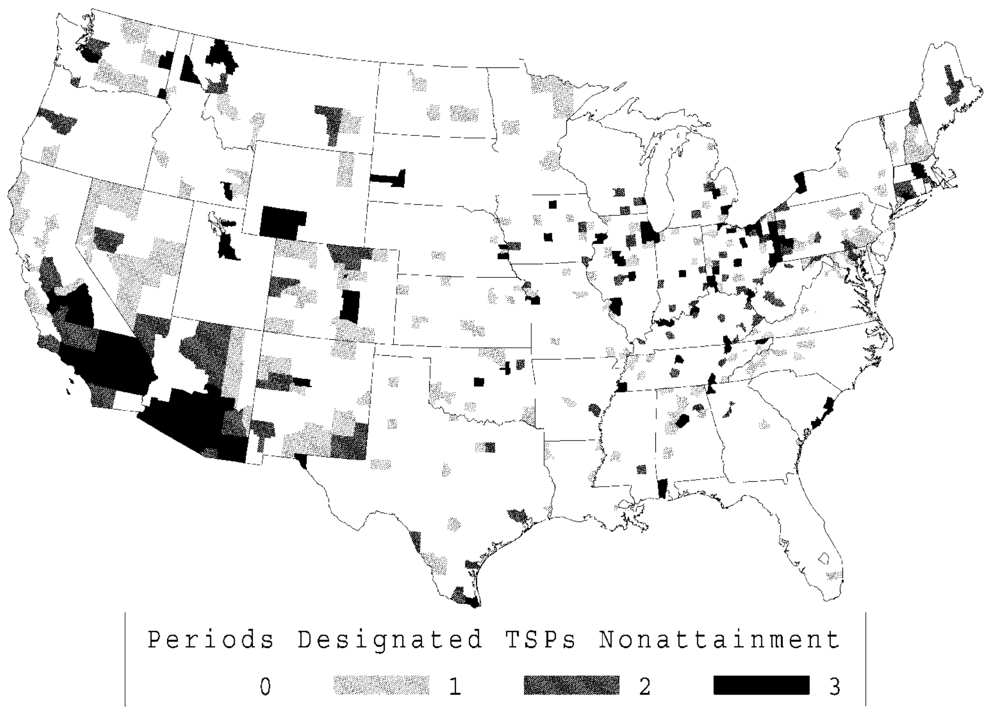

FIG. 4.—Incidence of nonattainment for total suspended particulates by county (1972–77, 1977–82, and 1982–87). Source: EPA Air Quality Subsystem Database, *Code of Federal Regulations* (various issues).

TABLE 2
Manufacturing Employment, by Pollutant Emitted and Pollutant-Specific Attainment Status

	1967–72 (1)	1972–77 (2)	1977–82 (3)	1982–87 (4)
CO-emitting plants	1,111,534	1,040,563	951,515	744,061
CO attainment	1,111,534	839,456	648,526	517,767
CO nonattainment	…	201,108	302,989	226,294
O_3-emitting plants	5,453,418	5,581,151	5,542,548	5,412,151
O_3 attainment	5,453,418	5,108,078	1,294,500	1,492,627
O_3 nonattainment	…	473,073	4,248,048	3,919,524
SO_2-emitting plants	1,783,243	1,717,904	1,598,742	1,358,083
SO_2 attainment	1,783,243	1,468,781	1,233,592	1,170,479
SO_2 nonattainment	…	249,123	365,150	187,604
TSPs-emitting plants	2,101,561	2,071,924	1,899,173	1,697,843
TSPs attainment	2,101,561	1,303,442	1,114,749	1,160,430
TSPs nonattainment	…	768,482	784,424	537,413
Total manufacturing sector	17,438,187	17,350,726	17,521,355	17,100,413

Note.—See the note to table 1. Employment is the mean of total employment in the first and last years of each five-year period covered by the 1967–87 Censuses of Manufacturers.

back and forth between the maps, one can see that many counties were regulated for more than one pollutant (e.g., parts of southern California, Arizona, and the Rust Belt). The national scope of the regulatory programs is also evident: all 48 continental states have at least one nonattainment county.[17]

Table 2 presents the levels of employment for emitters of each of the pollutants and the entire manufacturing sector in the four periods.[18] The level is calculated as the mean of the levels in the first and last years of a period. The table also separately lists employment in nonattainment and attainment counties within the four categories of emitters by period.

The portion of the manufacturing sector that is an emitter varies across the pollutants. For instance, O_3 emitters account for the largest share (roughly 31.7 percent) of total manufacturing employment. The shares for the other polluting industries are 11.2 percent for TSPs, 9.3 percent for SO_2, and 5.5 percent for CO. Although they are not shown in table 2, the ranges for capital stock and shipments are 19.9 percent (TSPs emitters) to 46.2 percent (O_3 emitters) and 10.7 percent (TSPs emitters) to 37.9 percent (O_3 emitters), respectively. Regardless of the measure, it is apparent that the emitting industries account for a substantial proportion of the manufacturing sector.

[17] Alaska and Hawaii are excluded from the analysis.

[18] Many plants emit multiple pollutants, so the pollutant-specific rows (e.g., CO-emitting plants) of table 2 are not mutually exclusive. Consequently, summing across the rows within a single period overstates employment in plants that emit any pollutant in that period.

Table 2 also documents that within the four sets of emitting plants, a meaningful share of employment is located in both attainment and nonattainment counties. Consequently, it may be possible to obtain precise estimates of the effects of the pollutant-specific nonattainment designations. Finally, the level of employment in emitting industries located in nonattainment counties is a summary measure of the size of the group that was potentially affected by these designations.

C. Is Nonattainment Status Orthogonal to Observable Determinants of Plant Growth?

In the ideal case, nonattainment status would be orthogonal to all determinants of plant growth. The regulation effects could then be calculated by a simple comparison of mean growth rates in the two sets of counties.

While it is impossible to make statements about unobserved covariates, it is instructive to compare observable ones in nonattainment and attainment counties. If the observable covariates are balanced across the two sets of counties, then the unobservables may be more likely to be balanced (Altonji, Elder, and Taber 2000). Further, consistent inference does not rely on functional form assumptions about the relationship between the observables and plant growth when the observable determinants are balanced. To the extent that the observables are unbalanced, these comparisons will identify likely sources of bias and inform the choice of statistical model.

Table 3 displays the means of determinants of plant growth within three categories of counties. These categories comprise counties that are attainment for CO in the 1972–77 period (col. 1*a*), attainment for CO in 1972–77 but CO nonattainment in a later period (col. 1*b*), and CO nonattainment in 1972–77 (col. 2). Panel A of the table presents means of county-level covariates, and panel B documents means of the characteristics of CO-emitting plants. The comparison of 1972–77 CO nonattainment and attainment counties is only one of the comparisons that underlie the subsequent analysis, but it captures many of the themes that are present in comparisons of nonattainment and attainment counties in different periods and for different pollutants.

Inspection of columns 1*a* and 2 provides a comparison of all CO attainment counties with CO nonattainment counties in the 1972–77 period. It is evident that both the county-level and plant-level characteristics differ with nonattainment status. In particular, nonattainment counties have higher population densities, rates of urbanization, average education levels, per capita income, and per capita government revenues. Moreover, a smaller fraction of their jobs are in the manufacturing sector, and they have lower poverty rates. Importantly, the average num-

TABLE 3
Means of County and Plant Characteristics by 1972–77 CO Nonattainment Status

	CO Attainment, 1972–77 (1*a*)	CO Attainment, 1972–77, and CO Nonattainment, 1977–82 or 1982–87 (1*b*)	CO Nonattainment, 1972–77 (2)
	A. County Characteristics in 1970		
Number of counties	2,989	100	81
Population	47,157	395,376	620,654
Population density	1,826	6,354	4,868
% urban	.65	.90	.94
% ≥12 years of education	.50	.55	.57
% ≥16 years of education	.10	.11	.13
% employment in manufacturing	.262	.266	.242
Unemployment rate	.044	.045	.046
Poverty rate	.119	.082	.081
Income per capita (1982–84 dollars)	7,456	8,712	9,414
Per capita government revenues	248	296	403
	B. CO-Emitting Plant Characteristics in 1972		
Number of CO-emitting plants	1.0	6.8	14.2
Average employment	269	362	175
% operating at least 10 years	55.2	59.3	51.3
% part of multiunit firm	34.6	40.7	40.1

Note.—See the note to table 1. All entries are averages across counties in the relevant category. The data on county characteristics are derived from the 1970 Census. The 1972 Census of Manufactures is used to determine the means of CO-emitting plant characteristics. The entries in col. 1*a* are calculated from the 2,989 counties that are designated CO attainment in the1972–77 period, and the sample in col. 2 comprises the 81 counties that are CO nonattainment in the same period. Col. 1*b* is the subset of the col. 1*a* counties that are CO attainment in 1972–77 and CO nonattainment in at least one of the 1977–82 and 1982–87 periods.

ber of CO-emitting plants is substantially higher in nonattainment counties (14.2) than in attainment counties (1.0). Further, CO-emitting plants in nonattainment counties are younger, more likely to be part of a multiestablishment firm, and smaller (as measured by employment).

An alternative to forming the "counterfactual" from all CO attainment counties is to restrict this group to counties that are CO attainment in 1972 but CO nonattainment in later periods. A statistical model that includes county fixed effects effectively refines the counterfactual group in this way. Columns 1*b* and 2 permit an exploration of the similarity of these two sets of counties. It is evident that this subset of 1972–77 CO attainment counties is more similar to the nonattainment counties than the unrestricted set of attainment counties was. For example, the means of the population density, level of education, income per capita, and poverty rate in column 1*b* are all closer to the means of these variables in nonattainment counties. However, the average number of CO-emitting plants and the mean characteristics of these plants differ across these columns.

It is apparent that nonattainment status is not orthogonal to observable county- or plant-level determinants of plant growth in either set of attainment counties. Moreover, it is plausible that the same is true for unobservable characteristics. It will be necessary to estimate statistical models that attempt to control for these differences to obtain consistent estimates of the regulation effects.

D. Do Countywide Shocks Covary with Nonattainment Status?

This subsection explores the validity of the assumption that nonattainment status is orthogonal to county-specific determinants of growth that are common to polluters and nonpolluters. This identifying assumption is pervasive in the previous literature (e.g., Bartik 1985; Barbera and McConnell 1986; McConnell and Schwab 1990; Henderson 1996; Levinson 1996; Berman and Bui 1998, 2001; Becker and Henderson 2000, 2001). For brevity I focus on the case in which the dependent variable is the percentage growth in plant employment, but the findings are similar for capital stock and shipments.[19]

Table 4 presents two estimates of the effect of the regulation of each pollutant on employment growth. The first estimate is derived from a sample that is limited to plants that emit the relevant pollutant and is contained in column 1. The column 2 estimate is obtained from all 1,620,942 plant observations with nonmissing employment growth. In both cases the reported parameter is taken from an indicator that is equal to one if the county is nonattainment for the specified pollutant and the plant is an emitter of that pollutant.

The regressions control for a number of plant-level variables that the next section describes in greater detail. Additionally, the two specifications include county fixed effects and industry by period indicators. For the column 1 specification's estimated regulation effect to be unbiased, it is necessary to assume that the regulation of that pollutant is the *only* county-level determinant of employment growth that differs between nonattainment and attainment counties. In contrast, the column 2 specification controls for unobserved, permanent county-level determinants of growth common to emitters and nonemitters.

A comparison of the estimates in columns 1 and 2 provides an in-

[19] The percentage growth is calculated as the change in plant employment between t and $t-5$, divided by the mean of the t and $t-5$ levels. Section IV provides more details about this measure of percentage change.

TABLE 4

Estimated Regression Models for the Percentage Change in Employment with One Regulation Effect per Regression

	Carbon Monoxide		Ozone		Sulfur Dioxide		Total Suspended Particulates	
	CO Emitters (N=14,456) (1)	All Plants (N=1,620,942) (2)	O_3 Emitters (N=543,121) (1)	All Plants (N=1,620,942) (2)	SO_2 Emitters (N=99,854) (1)	All Plants (N=1,620,942) (2)	TSPs Emitters (N=257,135) (1)	All Plants (N=1,620,942) (2)
CO regulation effect	−.041	−.074						
	(.040)	(.031)						
O_3 regulation effect			.068	.025				
			(.011)	(.009)				
SO_2 regulation effect					−.049	−.040		
					(.030)	(.027)		
TSPs regulation effect							−.021	−.016
							(.017)	(.014)
R^2	.127	.100	.112	.100	.095	.100	.121	.100

Note.—The entries are taken from regressions in which the dependent variable is the change in plant employment between t and $t-5$, divided by the mean of the t and $t-5$ levels. The equations are weighted by the denominator of the dependent variable. All specifications include county fixed effects and industry by period indicators. Heteroskedastic-consistent standard errors are reported in parentheses.

formal test of this assumption. The estimates will differ if nonemitters' growth rate covaries with nonattainment status. The regulation effects for SO_2 and TSPs are similar in the two columns. However, the regulation effects for CO and O_3 in column 1 appear to be biased upward. Most dramatically, the column 1 O_3 estimate suggests that nonattainment status at the beginning of a period is associated with a 6.8 percent increase in employment in O_3-emitting industries five years later. Since pollution can be modeled as an input and regulation as a tax on pollution, standard neoclassical models predict an ambiguous effect on demand for other inputs (e.g., labor). Nevertheless, such a large, positive effect is surprising. In column 2, the estimated regulation effect for O_3 shrinks to 2.5 percent, demonstrating the importance of allowing for county-specific factors common to emitters and nonemitters.

It is evident that in the case of CO and O_3, nonattainment status is *not* orthogonal to county-level shocks to growth. The next section describes the preferred statistical models and explains how they try to purge the likely sources of bias.

IV. Identification Strategy

In order to explore more rigorously the effects of the nonattainment designations on the growth of manufacturers' activity, the plant-level data are fit to the following equation:

$$
\begin{aligned}
\%\Delta E_{pt} &= \frac{E_{pt} - E_{pt-5}}{(E_{pt} + E_{pt-5})/2} \\
&= \beta_1 \mathbf{X}_{pt-5} + \beta_{2t}\mathbf{ind}_i + \beta_{3t}\mathbf{nonattain}_{ct-5} \\
&\quad + \beta_4 1(\text{emit CO} = 1 \ \& \ \text{nonattain CO} = 1)_{cit-5} \\
&\quad + \beta_5 1(\text{emit O}_3 = 1 \ \& \ \text{nonattain O}_3 = 1)_{cit-5} \\
&\quad + \beta_6 1(\text{emit SO}_2 = 1 \ \& \ \text{nonattain SO}_2 = 1)_{cit-5} \\
&\quad + \beta_7 1(\text{emit TSPs} = 1 \ \& \ \text{nonattain TSPs} = 1)_{cit-5} + \Delta\epsilon_{pt},
\end{aligned}
$$

where $\Delta\epsilon_{pt} = \alpha_p + \gamma_{ct} + \Delta u_{pt}$. Here p indexes a plant, c references county, i indexes industry, and t and $t-5$ index the last and first years of a period, respectively. The term $\%\Delta E_{pt}$ is the dependent variable (i.e., employment, capital stock, and the value of shipments) and is measured as the percentage change between t and $t-5$.[20] The term $\Delta\epsilon_{pt}$ is the stochastic error term. Equation (1) is weighted by the denominator of the dependent variable to account for differences in cell size.

The term $\mathbf{X}_{pt-5}$ is a vector of variables, calculated at $t-5$ so that they are "pretreatment." There are indicators for four categories of plant size based on shipments (i.e., smaller than the median, between the median and the seventy-fifth percentile, between the seventy-fifth percentile and the mean, and greater than the mean); whether the plant has operated for at least 10 years; ownership by a firm with multiple establishments; and whether the observation is a response to the Census Bureau questionnaire or is derived from federal administrative records. Previous research shows that these variables are important determinants of plant-level growth (Dunne, Roberts, and Samuelson 1989*a*, 1989*b*; Davis and Haltiwanger 1992). The vector $\mathbf{X}_{pt-5}$ also contains the average industry-specific wage in the plant's county as a measure of labor costs and the number of employees at other plants in the same industry within the same county to adjust for agglomeration effects (Krugman 1991).

The term $\mathbf{ind}_i$ is a vector of industry indicator variables whose effects are allowed to vary by period. In most of the subsequent analysis, there are 13 industry indicators: one for each of the 12 industries that are classified as an emitter of at least one of the four regulated pollutants and one for the remaining "clean" industries. These variables nonparametrically absorb all time-varying industry-level unobservables at the level at which the regulations are applied. Further, the $\mathbf{nonattain}_{ct-5}$ vector contains a separate dummy variable for each of the four pollutant-specific nonattainment designations. These dummies control for unobserved factors that equally affect polluting and nonpolluting plants in nonattainment counties. Their effect is also allowed to vary by period.

The parameters β_4–β_7 capture the variation in the dependent variables specific to polluting plants (relative to nonpolluters) in nonattainment counties (relative to attainment ones). These parameters provide estimates of the mean effect of the pollutant-specific regulations on the plants that are directly targeted by them. Henceforth, they are referred to as the "regulation effects." An attractive feature of this specification is that, in contrast to the previous literature, each of the estimated

[20] This measure of percentage change is an alternative to the difference of the natural logarithms of the year t and $t-5$ levels. It is a second-order approximation to the ln difference measure, ranges from -2.0 to $+2.0$, and portrays expansion and contraction symmetrically (Davis et al. 1996). Importantly, it allows the sample to contain observations on "births" and "deaths," i.e., plants that do not operate in either the first or last year of a period. A comparison of the results from a sample of "stayers" reveals that the estimated regulation effects are nearly identical when the dependent variable is calculated as the ln difference.

regulation effects is obtained while holding the others constant.[21] This is relevant because many plants were subject to more than one of the nonattainment designations.[22]

Prior research indicates that there are important permanent and transitory regional determinants of manufacturing activity.[23] There are a number of ways to model these factors with the available data. One possibility is to include county fixed effects so that counties that were never designated nonattainment for a particular pollutant do not help identify the parameters of interest. In this case, the pollutant-specific regulation effects are estimated from 189 (CO), 730 (O_3), 134 (SO_2), and 436 (TSPs) counties.

As the specification of $\Delta\epsilon_{pt}$ indicates, another possibility is to include a full set of fixed effects for the more than 735,000 plants in the sample and county by period indicators. The plant fixed effects greatly reduce the degrees of freedom, but they control for differences in permanent plant growth rates that might be correlated with nonattainment status. Such a correlation might occur if nonattainment counties provide the conditions necessary for emitting plants or industries to flourish (e.g., easy access to the interstate highway system, a workforce that suits their technology, or proximity to a natural resource). In this specification, the regulation effects are identified from within-plant comparisons of growth rates under the nonattainment and attainment regimes. The county by period indicators nonparametrically adjust for time-varying shocks to growth common to emitters and nonemitters within the same county.

In the subsequent tables, heteroskedastic-consistent standard errors of the regression parameters are reported (White 1980). Since the data are taken from censuses, the standard errors' interpretation is not straightforward. On the one hand, the sample includes all the members of a finite population, so the standard errors need not be calculated. On the other hand, the observed finite population can be considered

[21] I also experimented with including the 12 "cross-pollutant" interactions (e.g., 1(emit O_3 = 1 & nonattain CO = 1) in the specification. Across the dependent variables and specifications, the hypothesis that they are jointly equal to zero is generally not rejected by a χ^2 test at standard confidence levels. Moreover, in these plant-level regressions, their inclusion does not substantially alter the estimates of the four regulation effects. Notably, the cross-pollutant interactions are more important in grouped regressions and with stricter definitions of emitter status, as in Greenstone (1998).

[22] McConnell and Schwab (1990), Henderson (1996), and Becker and Henderson (2000, 2001) use the equivalent of the O_3 nonattainment designation but restrict the effect of the other pollutant-specific designations to equal zero. The remainder of the literature uses regulatory measures that do not account for the pollutant-specific nature of the CAAAs.

[23] Bartik (1985) and Holmes (1998) show that a number of local factors including unionization density, tax rates, the provision of public services, and right-to-work laws affect firms' investment decisions. Moreover, Blanchard and Katz (1992) demonstrate that shocks to regions' growth rates can persist for as long as a decade.

a member of an unobserved superpopulation; thus the standard errors associated with regression parameters have their usual interpretation.

In summary, the estimated regulation effects are purged of many likely sources of bias. For example, the specification that includes plant fixed effects, county by period indicators, and industry by period dummies is robust to all unobserved permanent determinants of plant growth, all unobserved transitory factors common to polluting and nonpolluting plants within a county, and all unobserved industry-specific shocks to growth. However, the estimated regulation effects are not robust to transitory determinants of growth specific to emitting industries (or plants) located in counties that are nonattainment for the emitted pollutant(s). In other words, county by industry and county by plant shocks to growth are potential sources of bias.

V. The Amendments' Impact on Manufacturing Sector Activity

This section is divided into three subsections. Subsection *A* presents the estimated effects of the regulations on the growth rates of employment, shipments, and capital from fitting the preferred specifications discussed in Section IV. Subsection *B* tests for heterogeneity in the regulation effects across industries. Subsection *C* probes the robustness of the results.

A. The Effects of the CAAAs on Manufacturing Activity

In a standard neoclassical model in which pollution, labor, and capital are inputs in the production process, the predicted effect of regulation, which increases the price of pollution, on labor and capital demand is ambiguous. The theoretical prediction on output is unambiguously negative. This subsection tests these predictions.

Total Employment

Table 5 presents the employment results from the estimation of equation (1), using data from all plant observations over the four periods. The columns correspond to specifications that include additional sets of controls as one reads from left to right; the exact controls are noted at the bottom of the table. The mean five-year growth rate of total employment is −1.4 percent.

The specification in column 1 includes industry by period fixed effects and allows the effect of nonattainment status to vary by period. Here, the estimated regulation effects are derived from comparisons between all attainment and nonattainment counties.

The results in column 1 suggest that nonattainment status modestly

TABLE 5
Estimated Regression Models for the Percentage Change in Employment

	(1)	(2)	(3)	(4)
CO regulation effect (β_4)	−.084	−.075	−.086	−.163
	(.032)	(.031)	(.030)	(.045)
O_3 regulation effect (β_5)	.001	.022	−.011	−.049
	(.011)	(.010)	(.010)	(.015)
SO_2 regulation effect (β_6)	−.004	−.016	.003	.001
	(.029)	(.028)	(.029)	(.036)
TSPs regulation effect (β_7)	−.024	−.010	−.020	−.024
	(.014)	(.013)	(.013)	(.024)
R^2	.109	.119	.144	.504
Industry by period fixed effects	yes	yes	yes	yes
Nonattainment by period fixed effects	yes	yes	no	no
County fixed effects	no	yes	no	no
County by period fixed effects	no	no	yes	yes
Plant fixed effects	no	no	no	yes

Note.—See the note to table 4. In all specifications, the sample includes the 1,620,942 plant observations with nonmissing and nonnegative employment levels. The mean five-year growth rate of employment in the sample is −1.4 percent.

retards the growth of employment. The estimates indicate that a CO nonattainment designation at the beginning of a period is associated with an 8.4 percent reduction in employment levels in CO-emitting plants five years later. This estimate would be judged statistically significant at conventional levels. The regulation effect for TSPs is −2.4 percent and would be considered significant at the 10 percent level but not by stricter criteria. In contrast, O_3 and SO_2 nonattainment statuses are basically uncorrelated with the respective growth of emitters of those pollutants. Interestingly, the estimated regulation effects for O_3 and SO_2 differ from the estimates that did not account for the effects of the other nonattainment designations as in table 4.

Columns 2 and 3 report the results from adding county fixed effects and county by period effects to the specification, respectively. In both cases, F-tests easily reject the null that the additional parameters are jointly equal to zero. As discussed above, the regulation effects from the specification in column 2 are due to comparisons of counties that experience a change in attainment status over the course of the sample. The estimates in column 3 are based on comparisons between emitters and nonemitters within nonattainment counties. In light of the differences in these first three specifications, it is striking that the estimated regulation effects are essentially the same across the columns.

The specification that requires the least restrictive assumptions for unbiasedness of the regulation effects is the one in column 4, which includes a full set of plant fixed effects. All permanent differences in plant growth rates are controlled for here. As evidenced by the marked increase in the R^2 statistic (.504 compared to .144), the "fit" of the regression is substantially greater. However, an F-test fails to reject the null that the plant fixed effects are jointly equal to zero. This "overparameterization" explains the increased standard errors of the four regulation effects.

The intent in estimating this model is to probe the robustness of the estimated regulation effects from columns 1–3. In this specification, two of the regulation effects imply a larger negative effect on employment and two are essentially unchanged relative to the other specifications. In particular, CO nonattainment status at the beginning of a period is associated with a 16.3 percent decline in employment in CO-emitting plants by the end of the period. The magnitude of the regulation effect for O_3 is larger, and the estimate is now -0.049; moreover, it would be judged statistically significant at standard levels. The increased magnitude of these two regulation effects is consistent with the notion that CO and O_3 nonattainment counties offer competitive advantages to emitters of these pollutants. In contrast, the regulation effects for SO_2 and TSPs are essentially unchanged from the other specifications.[24]

Capital Stock

The last subsection documented a robust negative correlation between nonattainment status and employment growth. Here, I explore whether nonattainment status is associated with the capital stock growth rate. Investment may be particularly sensitive to regulation because it reflects plants' conjectures about future profitability. Although it is difficult for plants to adjust their capital stock in the short run, the length of time between observations (five years) means that any impact of regulation should be apparent. In particular, it is likely that five years is enough time for establishments to bring new investments "on line," to substantially reduce their capital stock through depreciation,[25] to open new plants, or to cease operations. Interestingly, the previous literature finds

[24] It is thought that environmental regulations weaken polluters' competitive position by causing them to hire additional nonproduction workers (e.g., engineers or environmental compliance officers) that aid in ensuring adherence to the regulations but do not directly contribute to the production of the firm's output. I examined this hypothesis and found that the regulations' effects were approximately equal across production and nonproduction workers. In other words, these data do not support this hypothesis.

[25] Dixit and Pindyck (1994) show that the sunk cost nature of many investments combined with uncertainty about the future may make it more profitable for a firm to respond to a large negative shock by allowing its capital stock to depreciate, rather than by ceasing operations.

that environmental regulations are not a significant deterrent to new investment in plants and equipment.[26]

There are at least three limitations to the Census of Manufactures data on capital stock. First, the censuses' measure of capital stock comprises productive capital *and* potentially "nonproductive" pollution abatement equipment that is mandated by the regulations. This combined measure may cause the estimated regulation effects to be biased upward, relative to the preferred measure of productive investment.[27] Second, the book value method is used to measure capital stock, which likely overstates the importance of recent investment relative to a perpetual inventory measure.[28] Third, the capital stock measure does not allow for a test of whether the regulations cause plants to change the rate of new investment or affect the value of existing capital. A measure of capital stock that separates new investment from the depreciation/retirement of existing capital would allow for a more nuanced analysis.

Panel A of table 6 presents estimates of the impact of the nonattainment designations on capital stock accumulation. The mean five-year growth rate of capital stock when the book value method is used is 36.5 percent. The columns correspond to specifications that include additional sets of controls as in table 5.

Across the specifications, the capital stock estimates suggest that nonattainment status retards investment, but the evidence is less decisive than in the employment regressions. Similarly to the employment results, the estimated regulation effects are roughly constant across the first three specifications. The commonality of these estimates is especially apparent in the context of the standard errors. The estimates indicate that the effect of the nonattainment designations on capital stock ranged from small and positive (TSPs) to somewhat large and negative (CO and SO_2). However, the regulation effect for CO in column 3 is the only one that would be judged statistically different from zero.

The addition of plant fixed effects in column 4 greatly increases the

[26] A review article concludes that "environmental regulations do not deter investment to any statistically or economically significant degree" (Levinson 1996).

[27] The "lumping" of these two types of investment together introduces a positive, mechanical relationship between regulation and observed investment. A preferred measure of capital stock would exclude the investments in pollution abatement equipment that were mandated by the amendments. The 1986 Pollution Abatement Costs and Expenditures Survey provides some indirect evidence on the magnitude of this bias. It shows that the heaviest-polluting industries devote approximately 4–10 percent of total investment to abatement equipment. This share is likely to be larger in nonattainment counties and indicates that the upward bias may not be insignificant (see Becker 2001).

[28] A book value system permanently records the value of an investment at its purchase price. This value is never updated to reflect inflation or changes in the good's market value. Therefore, the relative contribution of recent investment, which is entered in current dollars, is overstated. A perpetual inventory measure of capital stock accounts for these changes but is not feasible with the Census of Manufactures questionnaire.

TABLE 6
Estimated Regression Models for the Percentage Change in Capital Stock and Shipments

	(1)	(2)	(3)	(4)
	A. Capital Stock (N=1,607,332)			
CO regulation effect (β_4)	−.047	−.047	−.097	−.092
	(.043)	(.042)	(.043)	(.062)
O_3 regulation effect (β_5)	−.009	.016	−.001	−.041
	(.022)	(.021)	(.021)	(.029)
SO_2 regulation effect (β_6)	−.024	−.048	−.057	−.063
	(.047)	(.049)	(.055)	(.048)
TSPs regulation effect (β_7)	.026	.042	.010	−.043
	(.027)	(.025)	(.024)	(.039)
R^2	.074	.109	.155	.462
	B. Shipments (N=1,737,753)			
CO regulation effect (β_4)	−.058	−.036	−.072	−.146
	(.029)	(.029)	(.029)	(.046)
O_3 regulation effect (β_5)	.022	.048	.019	−.032
	(.018)	(.018)	(.016)	(.024)
SO_2 regulation effect (β_6)	−.007	−.026	−.027	−.010
	(.033)	(.030)	(.030)	(.039)
TSPs regulation effect (β_7)	−.014	−.002	−.010	−.032
	(.019)	(.018)	(.018)	(.034)
R^2	.127	.142	.185	.516
Industry by period fixed effects	yes	yes	yes	yes
Nonattainment by period fixed effects	yes	yes	no	no
County fixed effects	no	yes	no	no
County by period fixed effects	no	no	yes	yes
Plant fixed effects	no	no	no	yes

Note.—See the note to table 5. The mean five-year growth rates of capital stock and shipments are 36.5 percent and 10.0 percent, respectively.

R^2 statistic. But the null that these extra parameters are jointly equal to zero is not rejected at conventional significance levels. As in the employment regressions, this specification indicates that the nonattainment designations have a larger negative impact on growth. In particular, the estimated regulation effects from this specification are −0.092 for CO, −0.041 for O_3, −0.063 for SO_2, and −0.043 for TSPs. The loss of the more than 700,000 degrees of freedom causes three of the four standard errors to increase so that the null hypothesis of zero is not rejected for any one of them.

Shipments

Panel B of table 6 reports estimation results for the growth in constant-dollar shipments. The mean five-year growth rate of shipments is 10.0

percent.[29] In columns 1–3, the regulation effect for CO is negative and statistically distinguishable from zero in two of the three specifications. These estimates indicate that CO nonattainment status is associated with a 3.6–7.2 percent decrease in shipments by CO emitters. The regulation effect for O_3 is small and positive, and those for SO_2 and TSPs are small and negative.

As with the employment and capital stock regressions, controlling for plant fixed effects in column 4 causes the estimated negative effects of nonattainment status to have a greater magnitude. In this specification, the estimated regulation effects are −0.146 for CO, −0.032 for O_3, −0.010 for SO_2, and −0.032 for TSPs. Again the interpretation of the standard errors is not obvious, but the regulation effect for CO is the only one that is statistically significant at conventional levels. Overall, these results imply that nonattainment status, particularly CO nonattainment status, is associated with a reduction in shipments by polluting manufacturers.

A Comparison of the Estimates across the Dependent Variables

A comparison of the estimates across the three dependent variables within and across specifications provides a crude view into the "black box" of how firms respond to environmental regulations. For example, consider the regulation effects for CO. In the specifications in columns 1–3, they range from −0.075 to −0.086 for employment, −0.047 to −0.097 for capital stock, and −0.036 to −0.072 for shipments. The estimates from the specification in column 4 are −0.163, −0.092, and −0.146, respectively. Within these two divisions of the specifications, the estimates are approximately equivalent across the dependent variables, particularly in the context of the associated standard errors. The same pattern is evident in the effects of the other nonattainment designations, although they are not as large either economically or statistically. Overall, the estimates suggest that the nonattainment designations cause the growth of employment, capital stock, and shipments to decline by roughly equivalent proportions.[30]

B. Is There Heterogeneity in the Regulation Effects across Industries?

This subsection explores whether the regulation effects vary by industry. This is informative for at least two reasons. First, it serves as an internal

[29] Four-digit industry deflators from the Bartelsman and Gray (1994) NBER Productivity Database are used to express the total value of shipments in 1987 dollars.

[30] It would be informative to have plant-level data on pollution emissions. These data would allow for the calculation of the marginal rate of technical substitution between pollution and labor or capital. These measures of the ease of substitution are important policy parameters and are left for future research.

validity check on the results above. If the negative effects are concentrated in a small subset of industries, it may be reasonable to assume that the overall regulation effects are due to an unobserved factor that is unrelated to regulation. As an example, union activism might differ over time and the union activity in a particular industry might be more heavily concentrated in nonattainment counties (e.g., in the Rust Belt). Further, such an unobserved factor could interact with the dramatic reductions in demand experienced by some industries during the periods under consideration; for instance, employment of production workers in primary metal industries (SIC code 33) declined from 1,059,000 in 1967 to only 538,000 in 1987. Second, it provides an opportunity to measure the effects of these regulations across industries. This could be useful in evaluating the claims that particular industries are especially harmed by the CAAAs.

Table 7 presents the industry-specific regulation effects from the estimation of equation (1) for employment. The results for capital stock and shipments are qualitatively similar but are not presented here because of space considerations. The estimated specification includes plant fixed effects, county by period effects, and industry by period effects, as in column 4 of table 5. The regulation effects are allowed to vary across the industries that emit the relevant pollutant, so there are a total of 23 estimated regulation effects. Columns 1–4 report the industry-specific regulation effects and heteroskedastic-consistent standard errors (in parentheses). Each row pertains to an industry so that by reading down a column, one can compare the pollutant-specific regulation effects in each of the relevant industries. The final row lists the χ^2 statistic and associated p-value (in parentheses) from tests that the pollutant-specific regulation effects are equal across industries.

A number of points emerge from the table. First, it is apparent that the estimation of industry-specific regulation effects demands a lot from the data. For example, the standard errors are substantially larger than they were in table 5. Notably, the positive estimates tend to be especially poorly determined.

Second, the four χ^2 tests fail to reject the null hypothesis that the pollutant-specific regulation effects are equal across industries. This is certainly related to the imprecision of the estimates, but an "eyeball" test does reveal striking similarities in the parameters within a column (see especially the CO and TSPs effects).

Third, almost all the emitting industries are negatively affected by the nonattainment designations. Only five of the 23 estimated industry-specific regulation effects are greater than zero. Of these five, four occur in industries that emit other pollutants for which the associated regulation effect is negative; thus the overall effect of the CAAAs on these industries may still be negative. I conclude that the estimated regulation

TABLE 7
DO THE EMPLOYMENT REGULATION EFFECTS VARY BY INDUSTRY?

Industry Name (SIC Code)	CO Regulation Effects (1)	O_3 Regulation Effects (2)	SO_2 Regulation Effects (3)	TSPs Regulation Effects (4)
Lumber and wood (24)				−.006 (.034)
Pulp and paper (2611–31)	−.080 (.077)	−.110 (.056)	−.105 (.074)	.006 (.064)
Iron and steel (3312–13, 3321–25)	−.177 (.061)	−.104 (.068)	.038 (.059)	−.012 (.050)
Printing (2711–89)		−.072 (.027)		
Organic chemicals (2961–69)		.071 (.151)		
Rubber and plastic (30)		−.093 (.046)		
Fabricated metals (34)		−.013 (.026)		
Motor vehicles (371)		−.026 (.057)		
Inorganic chemicals (2812–19)			−.089 (.113)	
Petroleum refining (2911)	−.133 (.092)	.172 (.101)	−.180 (.109)	
Stone, clay, and glass (32)		−.072 (.039)	.039 (.062)	−.063 (.039)
Nonferrous metals (333–34)	−.169 (.163)		−.063 (.147)	
χ^2 statistic of equality	1.03 (.79)	11.67 (.17)	5.82 (.32)	1.57 (.67)

NOTE.—See the note to table 5. All the entries are taken from a single regression in which the dependent variable is the change in plant employment between t and $t-5$ divided by the mean of the t and $t-5$ levels. The specification includes plant fixed effects, county by period effects, and industry by period effects, as in col. 4 of table 5. The regulation effects are allowed to vary across the industries that emit the relevant pollutant. Cols. 1–4 report the industry-specific regulation effects and heteroskedastic-consistent standard errors (in parentheses). The last row lists the χ^2 statistic and associated p-value (in parentheses) from tests that the pollutant regulation effects are equal across industries that emit the relevant pollutant.

effects in table 5 do not reflect the experiences of a small subset of emitting industries.

Fourth, the total effect of the regulations is particularly harsh on industries that emit multiple pollutants in counties that are nonattainment for those pollutants. For example, a literal interpretation of the coefficients suggests that pulp and paper plants located in counties that are nonattainment for all four pollutants at the beginning of a period experience an employment decline of almost 29 percent over five years. Similar calculations suggest that employment declines by 14.1 percent in a period at petroleum-refining plants in counties that are nonattainment for CO, O_3, and SO_2.

C. *Robustness Checks*

This paper has used variation in regulation across counties, industries, and time in an effort to estimate the causal effect of regulation on industrial activity. However, as is always the case with a nonexperimental design, there is a form of unobserved heterogeneity that can explain the findings without a causal interpretation. In addition to the efforts presented above, I probed the robustness of the estimates in a number of other ways but found little evidence that undermines the basic conclusions.

Table 8 reports the results of some of these robustness checks in columns 1–3. The entries are the estimated regulation effects and heteroskedastic standard errors (in parentheses). The results for the three dependent variables are in separate panels. Each column represents a different specification or sample. All specifications include county by period fixed effects and industry by period indicators. The results are qualitatively similar when the specification with plant fixed effects is fit, but the standard errors increase substantially because two of the robustness checks significantly cut the sample size. The entries in column 0 are taken from column 3 of tables 5 (employment) and 6 (capital stock and shipments) and should be compared to the entries in the other columns.

One potential source of bias arises from the manner in which nonattainment status is determined and dynamics in the growth of manufacturing activity. Recall that a county's nonattainment designations are determined by its pollution concentrations, which are increasing in manufacturing activity. Thus nonattainment status in the first year of a period is likely an increasing function of previous growth. This may induce a mechanical correlation between the regulation variables and the unobserved components of the dependent variable in equation (1) if manufacturing growth follows a dynamic process. When the process is mean-reverting, this correlation is likely to bias the estimated regulation effects downward.[31]

To determine whether the results above are due to dynamics, column 1 presents results from the estimation of an equation that includes as controls the lagged value of the dependent variable (i.e., the percentage change between $t-5$ and $t-10$) and interactions of the lag with the four pollutant-emitted indicators. The parameters from the lagged de-

[31] To understand the direction of bias, consider the case in which there is "above-average" growth among emitters of a pollutant in a county in the period between $t-5$ and $t-10$. This growth might cause the county to be designated nonattainment in $t-5$. If the dependent variable follows a mean-reverting process, these polluters are likely to have smaller growth in the period between t and $t-5$. This slower growth would have occurred even in the absence of regulation, yet the regression would attribute this decline to regulation.

TABLE 8
PROBING THE ROBUSTNESS OF THE REGULATION EFFECTS

	Base Specification (0)	Dynamic Model (1)	Limit Sample to "Stayers" (2)	4.5% Emission Rule (3)
	A. Total Employment			
CO regulation effect (β_4)	−.086	−.094	−.059	−.097
	(.030)	(.028)	(.023)	(.028)
O_3 regulation effect (β_5)	−.011	−.007	−.019	−.016
	(.010)	(.010)	(.008)	(.010)
SO_2 regulation effect (β_6)	.003	.005	.010	.006
	(.029)	(.027)	(.021)	(.028)
TSPs regulation effect (β_7)	−.020	−.013	−.022	−.013
	(.013)	(.014)	(.011)	(.013)
	B. Capital Stock			
CO regulation effect (β_4)	−.097	−.134	−.110	−.115
	(.043)	(.041)	(.033)	(.040)
O_3 regulation effect (β_5)	−.001	−.007	−.021	−.009
	(.021)	(.021)	(.016)	(.020)
SO_2 regulation effect (β_6)	−.057	−.085	−.032	−.006
	(.055)	(.045)	(.036)	(.052)
TSPs regulation effect (β_7)	.010	.002	−.038	.010
	(.024)	(.024)	(.021)	(.033)
	C. Shipments			
CO regulation effect (β_4)	−.072	−.092	−.048	−.075
	(.029)	(.027)	(.024)	(.027)
O_3 regulation effect (β_5)	.019	−.019	.000	.016
	(.016)	(.016)	(.015)	(.016)
SO_2 regulation effect (β_6)	−.027	−.054	−.023	−.020
	(.030)	(.025)	(.025)	(.030)
TSPs regulation effect (β_7)	−.010	−.054	−.037	.008
	(.018)	(.016)	(.015)	(.020)

NOTE.—See the notes to tables 5 and 6. The entries are the estimated regulation effects and heteroskedastic standard errors (in parentheses) from separate regressions for the three dependent variables. The dependent variable is identified in the panel heading. Each column represents a different specification or sample. All specifications include county by period effects and industry by period effects. The entries in col. 0 are taken from col. 3 of tables 5 (employment) and 6 (capital stock and shipments) and should be compared to the other columns. In col. 1, the lagged dependent variable is included as a regressor, and its effect is allowed to vary by the pollutant emitted. The sample size is 884,812 for employment, 921,403 for capital stock, and 944,596 for shipments. In col. 2, the sample is limited to stayer plants, and the respective sample sizes are 762,513, 764,115, and 768,096. In col. 3, industries that account for at least 4.5 percent of industrial sector emissions of a pollutant are classified as an emitter of that pollutant (see App. table A2).

pendent variables are not reported in the table but provide evidence of dynamic patterns of growth in manufacturing activity. However, the commonality of the estimates in columns 0 and 1 implies that the regulation effects are not due to these dynamics.[32]

It is frequently assumed that environmental regulations primarily affect the location decisions of new plants (e.g., Bartik 1985; McConnell and Schwab 1990) because "grandfather" clauses and political lobbying

[32] The estimates are virtually identical when the col. 0 sample is limited to plants with nonmissing lagged dependent variables.

protect incumbent plants. In column 2 of table 8, the sample is limited to "stayers," that is, plants that are operating in both the first and last years of a period. The estimated regulation effects in this column are remarkably similar to those from the base specification, indicating that the regulations also restrict the growth of stayers. The negative coefficients from the capital stock regression are noteworthy because the regulations frequently require stayers to install "end of the line" pollution abatement equipment that increases measured investment (but not productive investment).[33]

I also examine the sensitivity of the estimated regulation effects to the definitions of emitting status. For example, column 3 of table 8 presents the results from regressions in which the group of emitters is expanded such that industries that account for more than 4.5 percent of the industrial sector's emissions of a pollutant are classified as an emitter of that pollutant (see App. table A2). The estimated regulation effects are generally unchanged by this expansion of the list of emitters. Further, I tested whether the effects differed when an industry is required to account for at least 9 percent of industrial sector emissions to qualify as a polluter. The estimated regulation effects are also qualitatively similar in this case.[34]

Another possible source of bias is that plants located in a county that is currently nonattainment but is "expected" to become attainment in the near future might delay investments until the regulation designation is changed. In the presence of this type of temporal shifting, the estimated regulation effects would be negative; but over longer periods, regulation would have no effect on manufacturing activity. In order to explore this possibility, I restricted the sample so that plant observations from counties that are nonattainment for a particular pollutant in a given period but attainment for the same pollutant in the next period are dropped. This sample restriction is implemented four separate times, once for each of the pollutant-specific nonattainment designations. The estimated regulation effects from these restricted samples are statistically indistinguishable from estimates based on the full sample. Consequently, it is unlikely that this form of temporal shifting of investment is the source of the estimated regulation effects.

A further potential source of bias comes from unobserved regional shocks to industries. I estimated a model that included industry by period by region fixed effects, where industry is defined as one of the 13 industries described above and regions are the nine Census Bureau regions of the United States. The estimated regulation effects from this

[33] Greenstone (1998) provides evidence on the regulations' effect on plant location and exit decisions.

[34] These results and the other results discussed in the remainder of this subsection are available from the author.

specification are also similar to those presented in tables 5 and 6. Additionally, I fit a model that allows the industry shocks to vary at the state level rather than the census region level. In a further specification, I disaggregated industry and estimated an equation that includes SIC three-digit industry by period by census region fixed effects. Neither of these alternatives changes the estimated regulation effects by a meaningful amount. Overall, there is little evidence that the regulation effects are due to regional industry shocks.

Finally, owing to the coincidence of the implementation of these regulations and the decline in manufacturing activity in "Rust Belt" states, it is sometimes thought that the regulations caused this decline (e.g., Kahn 1999). To examine this possibility, I separately estimated the regulation effects on samples from the Rust Belt and non–Rust Belt states.[35] Across the three measures of manufacturing activity, the estimates indicate that the regulations retard the growth of polluting manufacturers in both sets of states.

VI. The Magnitude of the Regulation Effects and Their Interpretation

The analysis above indicates that the CAAAs reduced the *relative* growth of pollution-intensive manufacturing activity in nonattainment counties. This section provides answers to three important questions about the estimated regulation effects. How large are they? Can they be used to assess claims that the CAAAs cause manufacturers to shift production (and jobs) abroad? Further, do they provide estimates of the costs of the nonattainment designations that can be compared with estimates of their benefits?

A. *The Magnitude of the Regulation Effects*

Table 9 develops two measures of the magnitude of the regulation effects. Notice that there are three panels, one for each of the measures of manufacturing activity. Column 1 presents the estimated regulation-induced change in the measures of activity. This is calculated by multiplying the sum of the activity in targeted plants (recall table 2) by the relevant estimated regulation effects from the specification that includes plant fixed effects (i.e., col. 4 of tables 5 and 6). The estimated regulation-induced changes are presented separately by pollutant, and their sum is listed in the "all manufacturers" row. Column 2 lists the 95 percent confidence interval of these estimates. Column 3 reports the change in

[35] The Rust Belt is defined to include Illinois, Indiana, Michigan, New York, Ohio, and Pennsylvania.

TABLE 9
Two Measures of the Magnitude of the Regulation Effects

	Estimated Regulation-Induced Change, 1972–77 to 1982–87: Mean (1)	95% Confidence Interval (2)	Change 1972–77 to 1982–87 (3)	Mean of 1972–77 and 1982–87 Levels (4)	Ratio of Col. 1 to Col. 3 (5)	Ratio of Col. 1 to Col. 4 (6)
		A. Total Employment				
CO emitters	−119,100	[−54,600, −183,500]	−296,502	892,312	.402	−.133
O_3 emitters	−423,400	[−169,400, −677,400]	−169,000	5,496,651	2.505	−.077
SO_2 emitters	800	[57,400, −55,800]	−359,821	1,537,994	−.002	.001
TSPs emitters	−50,200	[48,200, −148,500]	−374,081	1,884,883	.134	−.027
All manufacturers	−591,900	[−118,400, −1,065,200]	−250,183	17,215,016	2.366	−.034
		B. Capital Stock (Millions of Dollars)				
CO emitters	−7,500	[2,400, −17,500]	65,977	110,639	−.114	−.068
O_3 emitters	−18,600	[7,200, −44,300]	175,235	258,645	−.106	−.072
SO_2 emitters	−4,800	[2,400, −11,900]	85,092	144,078	−.056	−.033
TSPs emitters	−5,700	[4,500, −15,900]	56,635	108,261	−.101	−.053
All manufacturers	−36,600	[16,400, −89,600]	409,687	565,888	−.089	−.065
		C. Shipments (Millions of 1987 Dollars)				
CO emitters	−25,700	[−9,800, −41,500]	−25,601	235,616	1.003	−.109
O_3 emitters	−40,500	[19,000, −100,000]	2,281	773,443	−17.751	−.052
SO_2 emitters	−1,500	[10,000, −13,000]	−29,806	310,140	.050	−.005
TSPs emitters	−7,600	[8,200, −23,500]	−24,581	211,875	.310	−.036
All manufacturers	−75,300	[27,400, −178,000]	227,673	2,051,492	−.331	−.037

Note.—The entries in col. 1 are calculated by multiplying the parameter estimates from col. 4 of tables 5 (employment) and 6 (capital stock and shipments) and the level of the outcomes in emitters in nonattainment counties; table 2 presents the employment levels. For instance, the effect of CO regulation on employment in CO-emitting industries is calculated by multiplying the estimated effect of CO nonattainment (−.163) by the sum of the levels of employment in CO-emitting plants located in CO nonattainment counties for 1972–77 (201,108), 1977–82 (302,989), and 1982–87 (226,294), which yields an estimated change of −119,100 jobs. Col. 2 presents the 95 percent confidence interval of this estimate based on the heteroskedastic-consistent standard errors. The entries in col. 3 are the difference between the 1972–77 and 1982–87 levels of the outcome variables, and the entries in col. 4 are the means of these two values. The shipments measures were converted to 1987 dollars using the Bartelsman and Gray (1994) NBER Productivity Database four-digit deflators.

the measure of activity between the period in which the CAAAs were first in force and the last period (i.e., 1972–77 and 1982–87), separately for emitters of each of the pollutants and the entire manufacturing sector. Finally, column 4 lists the mean of the levels from these two periods for the same categories of plants.

The entries in columns 1, 3, and 4 are used to calculate the two measures of the magnitude of the regulation effects. Column 5 reports the ratio of the entries in columns 1 and 3, and column 6 lists the ratio of columns 1 and 4. Thus these columns normalize the regulation-induced changes by the total change in and mean of the measures of activity, respectively.

Panel A reports these calculations for employment. For example, they indicate that employment in CO-emitting industries located in CO nonattainment counties declined by 119,100 jobs (relative to CO emitters in CO attainment counties) in the first 15 years in which the CAAAs were in force.[36] The 95 percent confidence interval of this estimate is [−54,600, −183,500]. Analogous calculations indicate that the cumulative regulation-induced change (95 percent confidence interval) in employment in nonattainment counties is −423,400 [−169,400, −677,400] for O_3, 800 [57,400, −55,800] for SO_2, and −50,200 [48,200, −148,500] for TSPs. The large decline in O_3 employment reflects the high levels of employment in O_3-emitting industries. The sum of the regulation-induced changes is −591,900 [−118,400, −1,065,200].

Column 5 reports that the total regulation-induced change in employment is almost 2.4 times as large as the decline in manufacturing sector employment (roughly 250,000 jobs). This ratio is large, but manufacturing sector employment was essentially flat in these periods. The second measure reveals that the regulation-induced change in employment in nonattainment counties was a more modest 3.4 percent of total manufacturing sector employment.

Panels B and C present the analogous calculations for capital stock and shipments, respectively. The cumulative regulation-induced changes in capital stock and shipments across all four regulations are $36.6 billion [$16.4 billion, −$89.6 billion] and $75.3 billion (1987 dollars) [$27.4 billion, −$178.0 billion], respectively. These changes are 8.9 percent and 33.1 percent of the total change in these measures of manufacturing activity. When they are normalized by the mean levels of capital stock and shipments, they are 6.5 percent and 3.7 percent, respectively.

Overall, these two measures indicate that during the first 15 years in which the CAAAs were in force, the cumulative regulation-induced changes in manufacturing activity in nonattainment counties were not insignificant relative to either changes in or the level of total manufacturing sector activity. It is important to bear in mind, however, that the legislation also specified regulations for attainment counties. Consequently, it is likely that the total effect of the CAAAs is even larger than indicated in table 9.

B. *Interpretation*

It would be informative if the estimated regulation effects could be used to determine how much production (and employment) was shifted abroad as a result of the nonattainment designations.[37] This would pro-

[36] This is calculated by multiplying the estimated effect of CO nonattainment status (−0.163) by the sum of the levels of employment in CO-emitting plants located in nonattainment counties for 1972–77 (201,108), 1977–82 (302,989), and 1982–87 (226,294).

[37] A related question is whether environmental regulations alter the international location decisions of polluters. An extrapolation of this paper's findings to this question suggests that international differences in the stringency of environmental regulation will tend to shift polluters' production to countries with relatively lax environmental standards.

vide one measure of the national costs of these regulations. Unfortunately, such a calculation is not possible because it cannot be determined whether the lost activity in nonattainment counties moved to foreign countries or attainment counties. Since it is likely that the regulation effects partially reflect some shifting of manufacturing activity within the United States, they probably *overstate* the national loss of activity due to the nonattainment designations. Moreover, the possibility of intracountry shifting means that the regulation effects are also likely to overstate losses in nonattainment counties. The reason is that the identification strategy relies on comparisons between nonattainment and attainment counties, which leads to "double counting" when production is moved from a nonattainment county to an attainment one.[38]

There are at least two reasons to doubt that the regulation effects entirely reflect a movement of plants from nonattainment to attainment counties. First, counties frequently move into and out of nonattainment status. Thus firms may consider it unlikely that they can remain in the United States and escape future regulation. Second, production in many of the regulated industries (e.g., iron and steel and pulp and paper) requires substantial "sunk" costs that make it costly to shift locations.

The estimated regulation effects have an additional limitation as a measure of the costs of regulation. They are calculated in terms of employment, investment, and shipments, but these measures are not readily comparable to standard measures of the benefits of regulation. The conversion of these measures into a monetary unit would have great practical importance. For instance, it would then be possible to compare the costs of the regulations with hedonic housing market estimates of the monetary gains to homeowners from regulation-induced pollution reductions.

A full monetizing of the regulation-induced losses is left to future research, but it is worth noting that this task is tractable. In a freely functioning market economy, jobs and capital are not lost or made obsolete. In response to a shock such as the imposition of environmental regulations, these factors of production generally become employed in another capacity. Thus the losses due to regulation are the adjustment costs associated with the shifting of resources to new sectors. It is evident that monetized estimates of the costs of the CAAAs require reliable estimates of the magnitude of these frictions.

Recent research indicates that these frictions may be quite substantial and can persist for as long as a decade (Blanchard and Katz 1992). Jacobson, LaLonde, and Sullivan (1993) document that displaced work-

[38] In the extreme, the estimated regulation effects entirely reflect a movement of manufacturing activity from nonattainment to attainment counties. In this scenario there is no loss of production (and jobs) to foreign countries, and the regulation effects overstate the lost production in nonattainment counties by a factor of two.

ers endure substantial wage losses. Further, Goolsbee and Gross (2000) and Ramey and Shapiro (2001) show that it is costly for firms to adjust their capital stock in response to demand shocks. Consequently, workers and firms that were affected by the CAAAs may have suffered substantial losses.

VII. Conclusions

This paper provides new evidence that environmental regulations restrict industrial activity. I find that in the first 15 years after the CAAAs became law (1972–87), nonattainment counties (relative to attainment ones) lost approximately 590,000 jobs, $37 billion in capital stock, and $75 billion (1987 dollars) of output in polluting industries. Although these estimates are not derived from a randomized experiment and therefore cannot meet a strict definition of causality, they provide robust evidence that these regulations deter the growth of polluters. In the first place, the findings are derived from the most comprehensive data available on clean air regulations and manufacturing activity. Second, the preferred statistical model for plant-level growth controls for all permanent plant characteristics, unrestricted industry shocks, and unrestricted county shocks. Third, the effects are robust across a variety of specifications. Finally, the regulation effects are evident across three different measures of manufacturing activity and a wide range of polluting industries.

The federal standards for ozone and particulates were tightened recently, causing a substantial increase in the number of nonattainment counties.[39] The balance of evidence from this paper suggests that the new nonattainment counties will experience reductions in employment, investment, and shipments in polluting industries. To gain a clearer understanding of whether it is worthwhile to incur the costs associated with these reductions, it is crucial to understand the regulations' effectiveness at cleaning the air and the benefits of cleaner air. Recent research finds that these policies are effective at reducing concentrations of air pollution and that cleaner air, particularly reductions in TSPs, provides substantial monetary benefits to homeowners and reduced infant mortality rates (Smith and Huang 1995; Henderson 1996; Chay and Greenstone 2000, 2002*a*, 2002*b*). Regardless of whether these policies pass or fail a cost-benefit test, this paper's findings undermine the contention that environmental regulations are costless or even beneficial for the regulated.

[39] Although legal wrangling over this policy change is not concluded, the Supreme Court's *Whitman v. American Trucking Associations* decision appears to uphold the EPA's decision to tighten these standards.

TABLE A1
Selected National Ambient Air Quality Standards

	Maximum Allowable Concentration (Primary Standard)
Carbon monoxide:	
Maximum 8-hour concentration	9 parts per million
Maximum 1-hour concentration	35 parts per million
Nitrogen dioxide:	
Annual arithmetic mean	.053 parts per million
Ozone:	
Maximum 1-hour concentration	.12 parts per million (after 1979) .08 parts per million (through 1979)
Sulfur dioxide:	
Annual arithmetic mean	.03 parts per million
Maximum 24-hour concentration	.14 parts per million
Total suspended particulates:	
Annual geometric mean	75 micrograms per cubic meter
Maximum 24-hour concentration	260 micrograms per cubic meter

Note.—A county is in violation of one of the hourly based standards (i.e., one-hour, eight-hour, or 24-hour) if it exceeds the standard more than once in a year. In 1987 the EPA switched its focus from the regulation of all particulates (i.e., TSPs) to small particulates (i.e., PM10s). In 1997 the ozone standard was revised, and the particulates standard was further modified to regulate even smaller particulates (i.e., PM2.5s).

Data Appendix

A. Determining the County-Level, Pollutant-Specific Regulation Designations

The centerpiece of the Clean Air Act Amendments is the annual county-level assignment of nonattainment and attainment status for CO, O_3, SO_2, and TSPs. The legislation specifies that the pollutant-specific designations be based on whether a county's ambient pollution concentration exceeds the relevant federal air quality standard. Table A1 lists the standards. This section describes how these designations are determined for each of the four periods (i.e., 1967–72, 1972–77, 1977–82, and 1982–87) examined in this paper.

Although the 1970 amendment passed before the 1967–72 period ended, the associated enforcement activities did not commence until late 1972 (Liroff 1986). Consequently, every county is designated attainment for all four pollutants in the 1967–72 period.

The determination of the nonattainment designations in the 1977–82 and 1982–87 periods is relatively straightforward. In 1978 the EPA began to publish annually a list of nonattainment counties in the *Code of Federal Regulations*.[40] For each of the regulated pollutants, the CFR lists every county as "does not meet primary standards," "does not meet secondary standards," "cannot be classified," "better than national standards," or "cannot be classified or better than national standards." Further, the CFR occasionally indicates that a part of a county did not meet the primary standards. For the 1977–82 (1982–87) period, a county is assigned to the pollutant-specific nonattainment category if all or part of it failed to meet the pollutant-specific "primary standards" in 1978 (1982); otherwise, it is assigned to the pollutant-specific attainment category. These annual county-level, pollutant-specific designations were hand entered for the 3,070 U.S. counties.

[40] Vernon Henderson and Randy Becker generously allowed me to photocopy the relevant sections of the CFR.

The determination of the identities of the nonattainment counties in the 1972–77 period is more complicated. The EPA did not publish them in the early years of regulation, and I was told that records from that period "no longer exist." Consequently, I filed a Freedom of Information Act request and obtained the EPA's "Quick Look Report" data file, which contains annual summary information on the readings from each EPA pollution monitor.[41] This file is used to replicate the EPA's statutory selection rule; counties with monitor readings exceeding the pollutant-specific national standard in 1972 are assigned to the pollutant-specific nonattainment category for the 1972–77 period. All other county by pollutant combinations are designated attainment.[42]

B. *Determining Which Plants Were Subject to the Regulations*

An important part of the analysis is the determination of which manufacturing plants (or industries) were not targeted by the regulations in the examined period. A historical list of regulated plants or industries is unavailable from the EPA. Consequently, I devised a system to divide the manufacturing sector into emitters and nonemitters that attempts to mimic the EPA's focus on the dirtiest plants and industries in the initial years of regulation.

The EPA's estimates of industrial emissions are used to determine the pollutants emitted by each industry. These estimates are reproduced in table A2. The table lists the estimated annual emissions of each of the regulated pollutants by industry, as well as each industry's share of total industrial sector emissions. Industries that are excluded from the table either produce negligible levels of the regulated pollutants or had escaped the EPA's attention as late as the early 1990s. Communications with EPA officials indicate that it is unlikely that the excluded industries were subject to significant regulatory oversight in the 1970s and 1980s.

In the assignment of polluter status to industries, one possibility is to assume that the industries listed in table A2 are regulated for all the pollutants. Since some industries are major polluters of a particular pollutant but not of another, it is evident that this is not a sensible approach. Consequently, I label all industries that account for at least 7 percent of the industrial sector emissions of a pollutant to be an emitter of that pollutant; excluded industries and those whose emissions fall below the 7 percent threshold are considered nonemitters of that pollutant. An industry is designated an O_3 emitter if it exceeds the 7 percent threshold for either nitrogen dioxide or volatile organic compounds, both of which are precursors of ozone. The results are insensitive to other "reasonable" definitions of emitter status. These results are discussed in Section V.

[41] This date file comes from the EPA's Air Quality Subsystem database and contains annual statistics on the readings from all state and national pollution monitors for the four criteria pollutants.

[42] I tested whether the results were sensitive to the choice of a pollution monitor–based definition of which county/pollutant combinations were heavily regulated for this period (i.e., 1972–77). The paper's conclusions are insensitive to dropping the 1972–77 period from the sample.

TABLE A2

ANNUAL INDUSTRIAL SECTOR POLLUTANT RELEASES BY INDUSTRY

INDUSTRY (SIC Code)	CARBON MONOXIDE Emissions (1)	CARBON MONOXIDE Share (2)	NITROGEN DIOXIDE Emissions (1)	NITROGEN DIOXIDE Share (2)	VOLATILE ORGANIC COMPOUNDS Emissions (1)	VOLATILE ORGANIC COMPOUNDS Share (2)	SULFUR DIOXIDE Emissions (1)	SULFUR DIOXIDE Share (2)	TOTAL SUSPENDED PARTICULATES Emissions (1)	TOTAL SUSPENDED PARTICULATES Share (2)	EMITTER STATUS (3)
Metal mining (10)	5,391	.2%	28,583	1.6%	1,283	.1%	84,222	3.5%	140,052	15.4%	*
Nonmetal mining (14)	4,525	.1%	28,804	1.6%	1,736	.1%	24,129	1.0%	167,948	18.5%	*
Lumber and wood products (24)	123,756	3.5%	42,658	2.4%	41,423	3.0%	9,149	.4%	63,761	7.0%	TSPs
Wood furniture and fixtures (parts of 25)†	2,069	.1%	2,981	.2%	59,426	4.4%	1,606	.1%	3,178	.3%	Clean
Pulp and paper (2611–31)	624,291	17.5%	394,448	21.7%	96,875	7.1%	341,002	14.0%	113,571	12.5%	$CO/O_3/SO_2$/TSPs
Printing (2711–89)	8,463	.2%	4,915	.3%	101,537	7.5%	1,728	.1%	1,031	.1%	O_3
Inorganic chemicals (2812–19)	166,147	4.7%	108,575	6.0%	52,091	3.8%	182,189	7.5%	39,082	4.3%	SO_2
Organic chemicals (2861–69)	146,947	4.1%	236,826	13.0%	201,888	14.8%	132,459	5.4%	44,860	4.9%	O_3
Petroleum refining (2911)	419,311	11.8%	380,641	21.0%	309,058	22.7%	648,153	26.6%	36,877	4.1%	$CO/O_3/SO_2$
Rubber and miscellaneous plastic products (30)	2,090	.1%	11,914	.7%	140,741	10.3%	29,364	1.2%	5,355	.6%	O_3
Stone, clay, glass, and concrete (32)	58,043	1.6%	338,482	18.6%	30,262	2.2%	339,216	13.9%	171,853	18.9%	O_3/SO_2/TSPs
Iron and steel (3312–33, 3321–25)	1,518,642	42.6%	138,985	7.7%	82,292	6.0%	238,268	9.8%	83,017	9.1%	$CO/O_3/SO_2$/TSPs
Nonferrous metals (333–34)	448,758	12.6%	55,658	3.1%	27,375	2.0%	373,007	15.3%	22,490	2.5%	CO/SO_2
Fabricated metals (34)	3,851	.1%	16,424	.9%	102,186	7.5%	4,019	.2%	3,136	.3%	O_3
Electronics (36)	367	.0%	1,129	.1%	4,854	.4%	453	.0%	293	.0%	Clean
Motor vehicles, bodies, and parts (371)	35,303	1.0%	23,725	1.3%	101,275	7.4%	25,462	1.0%	12,853	1.4%	O_3
Dry cleaning (721)	101	.0%	179	.0%	7,310	.5%	152	.0%	28	.0%	*
Industrial sector total	3,568,055		1,814,927		1,361,612		2,434,578		909,385		

SOURCE.—EPA Sector Notebook Project (1995).

NOTE.—For each pollutant, emissions in col. 1 lists the number of short tons emitted per year. Share in col. 2 reports the fraction of industrial sector emissions. The paper's analysis designates an industry an emitter of a pollutant if it accounts for at least 7 percent of industrial sector emissions. Each industry's emitter status is summarized in col. 3. Nitrogen dioxide and volatile organic compounds are the primary ingredients of ozone (O_3). If an industry emitted more than 7 percent of either of these pollutants, it is designated an O_3 emitter. The remainder of the manufacturing sector is designated nonemitters of all criteria pollutants and labeled clean.

* Metal mining, nonmetal mining, and dry cleaning are outside of the manufacturing sector.

† Wood furniture and fixtures comprises the following SIC codes: 2511, 2512, 2517, 2519, 2521, 2531, and 2541.

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