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by

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ABSTRACT

Over the last three decades, ambient concentrations of sulfur dioxide (SO_2) air pollution have declined by approximately 80%. This paper tests whether the 1970 Clean Air Act and its subsequent amendments caused this decline. The centerpiece of this legislation is the annual assignment of all counties to SO_2 nonattainment or attainment categories. Polluters face stricter regulations in nonattainment counties. There are two primary findings. First, regulators pay little attention to the statutory selection rule in their assignment of the SO_2 nonattainment designations. Second, SO_2 nonattainment status is associated with modest reductions in SO_2 air pollution, but a null hypothesis of zero effect generally cannot be rejected. This finding holds whether the estimated effect is obtained with linear adjustment or propensity score matching. Overall, the evidence suggests that the nonattainment designation played a minor role in the dramatic reduction of SO_2 concentrations over the last 30 years.

I.   Introduction

Prior to 1970, states, counties, and municipalities were principally responsible for environmental regulations. In one of the most significant government interventions into the marketplace of the post-World War II era, the federal government made a dramatic foray into the regulation of air pollution with the passage of the Clean Air Act Amendments (CAAAs) and the establishment of the Environmental Protection Agency (EPA) in 1970. Congress further strengthened the provisions of the CAAAs in 1977 and 1990.

The CAAAs are controversial, because reliable evidence on their costs and benefits is not readily available. For instance, there is not even a consensus on whether the CAAAs are responsible for the dramatic improvements in air quality that have occurred in the last 30 years [6, 7, 11, 16, 24]. The fundamental problem is that there is not a valid counterfactual for what would have happened to air quality concentrations in the absence of these regulations.

This paper exploits the structure of the CAAAs to determine whether this legislation is responsible for the remarkable 80% decline in national sulfur dioxide (SO_2) concentrations from .0301 ppm in 1970 to .0048 ppm in 1992.[1] The centerpiece of this legislation is the establishment of the National Ambient Air Quality Standards (NAAQS) – a minimum level of air quality that all counties are required to meet – for SO_2 and six other pollutants.[2] As a part of this legislation, each U.S. county annually receives separate nonattainment or attainment regulation designations for each of the pollutants. The nonattainment designation is reserved for counties whose air contains concentrations of the relevant pollutant that exceed the federal standard. Emitters of the controlled pollutant in nonattainment counties are subject to greater regulatory oversight than emitters in attainment counties.

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[1] These figures are not based on a fixed set of monitors but nevertheless are illustrative of the long-run decline in SO_2 concentrations.
[2] The other pollutants are carbon monoxide, lead, nitrogen dioxide, ozone, small particulate matter, and total suspended particulates.

This paper empirically tests whether SO_2 nonattainment status caused a reduction in SO_2 concentrations relative to attainment status.[3] This is an interesting test, because the primary aim of the CAAAs was to bring all counties into compliance with the federal standards. It is important to note from the outset though that the results are not directly informative about the CAAAs' effect on nationwide air quality, because this legislation also introduced regulations in attainment counties.

The analysis is conducted with comprehensive county-level data files on SO_2 concentrations, nonattainment designations, and economic activity for the 1969-1997 period. Through a Freedom of Information Act request, I obtained summary information on the universe of state and national SO_2 monitors from the EPA. Although the SO_2 attainment/nonattainment status of each county is central to federal environmental law, this is the first study to collect them (from the *Code of Federal Regulations*) and use this information during this key period. The pollution and regulation data are merged to county-level economic data from the *Bureau of Economic Analysis*.

An immediate, yet surprising, finding is that the vast majority of nonattainment counties had pollution concentrations below, in many cases substantially so, the federal SO_2 standard. Despite extensive communications with the EPA, I am unable to conclusively determine why they received this designation. Thus, this paper attempts to evaluate the impact of SO_2 nonattainment status when the selection rule is unknown. The evaluation problem is made even more difficult by the finding that in the "pre-period" nonattainment counties have higher SO_2 concentrations and larger downward trends in ambient SO_2 than the attainment counties.

To control for the likely confounding due to these observable differences, linear regression and propensity score matching techniques [20] are employed to estimate the effect of SO_2 nonattainment status in three different 6-year periods, 1975-80, 1981-86, and 1987-92. The analysis reveals that

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[3] A number of recent studies have employed similar econometric strategies: Becker and Henderson [3], Greenstone [12], and Henderson [16] examine the relationship between nonattainment status and manufacturing activity; Henderson [16] documents the relationship between ozone nonattainment status and ozone concentrations; Chay and Greenstone [6] explore the impact of TSPs nonattainment status on TSPs concentrations and housing prices; and Chay and Greenstone [7] assess the effects of TSPs nonattainment status on TSPs concentrations and infant mortality rates.

matching is especially useful when the observable differences between the nonattainment and attainment counties are greatest. The results indicate that SO_2 nonattainment status is associated with modest reductions in SO_2 air pollution, but a null hypothesis of zero effect generally cannot be rejected. Overall, the paper finds that the nonattainment designation played a minor role in the dramatic reduction of SO_2 concentrations over the last three decades.

The paper proceeds as follows. Section II describes the structure of the CAAAs and provides some background information on sulfur dioxide pollution. Section III discusses the data sources and presents some summary statistics. Section IV describes the research design and some of the challenges to its validity. Section V presents the econometric strategy and Section VI discusses the results. The paper ends with brief interpretation and conclusion sections.

II. Background on the Evolution of Air Pollution Law and Sulfur Dioxide Pollution

The ideal analysis of the relationship between air pollution and environmental regulations would involve a controlled experiment in which the regulations are randomly assigned. In this case, regulatory status is independent of all other determinants of air quality. Consequently, the subsequent differences in air quality can be causally related to the regulations. In the absence of such an experiment, an appealing alternative is to find a case where the assignment of regulation differs across similar counties. The structure of the CAAAs may provide such an opportunity. This section describes the CAAAs and the opportunity that they may provide to credibly identify the relationship between clean air regulations and sulfur dioxide concentrations. It also briefly reviews sulfur dioxide pollution and its consequences.

A.   The CAAAs and Nonattainment Status

The centerpiece of the CAAAs is the establishment of separate National Ambient Air Quality Standards (NAAQS) for SO_2 and other "criteria" air pollutants, which all counties are required to meet.[4] For SO_2 pollution, a county is in violation of the standards if: 1) its annual mean concentration exceeds .03 parts per million (ppm), or 2) the second highest 24-hour concentration exceeds .14 ppm. The stated

goal of the CAAAs is to bring all counties into compliance with these standards by reducing local air pollution concentrations. To achieve this goal, stricter regulations are imposed on emitters in nonattainment counties than in attainment ones.

The EPA annually assigns separate nonattainment-attainment designations for each of the criteria pollutants. The nonattainment designation is supposed to be reserved for counties whose actual or modeled air pollution concentration exceeds the federal ceiling. Generally, this determination is based on the previous year's actual or modeled air pollution concentration. Chay and Greenstone [6, 7] and Henderson [16] document the effectiveness of nonattainment status in reducing total suspended particulates and ozone air pollution, respectively. The current study empirically tests the effect of nonattainment status on SO_2 concentrations relative to attainment status.

B.   *Background on Sulfur Dioxide Pollution*

Sulfur dioxide is a colorless gas, which is odorless at low concentrations but pungent at very high levels. It results naturally from sources such as volcanoes and decaying organic material. Human activity accounts for approximately 100 million tons SO_2 per year. The primary man-made source of SO_2 is from the combustion of fuels (e.g. coal and oil) that contain sulfur. The largest industrial emitters of SO_2 are the electric utility plants that use cheaper high sulfur coal from the eastern U.S. In the manufacturing sector, the largest emitters are petroleum refineries, smelters, paper mills, chemical plants, and producers of stone, clay, glass, and concrete products.

SO_2 has a number of unwanted effects. It is one of the major contributors to smog. At high levels, it can affect the respiratory system (especially among asthmatics), weaken the lung's defenses, aggravate existing respiratory and cardiovascular diseases, and potentially even lead to premature death [23].[5] At much lower levels, it damages trees and agricultural crops. Along with nitrous oxides, SO_2 is the major contributor to the formation of acid rain.

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[4] See Lave and Omenn [17] and Liroff [18] for more detailed histories of the CAAAs.

III. Data and Overview of Trends in Sulfur Dioxide Concentrations and Regulation

To implement the analysis, I compiled the most detailed and comprehensive data available on SO_2 concentrations and nonattainment status. This section describes the data and its sources and presents summary statistics on national trends in SO_2 monitoring, concentrations, and regulation.

A.   SO₂ and Regulation Data

The SO_2 concentration data were obtained by filing a Freedom of Information Act request with the EPA. This yielded the *Quick Look Report* data file, which is derived from the EPA's *Air Quality Subsystem* database. For each SO_2 monitor operating at any point in the 1969-1997 period, the file contains annual information on the number of recorded hourly readings, the average across all these readings, and the two highest readings for 1, 3, and 24 hour periods. It also reports the monitor's county.

Annual county-level SO_2 concentrations are calculated as the weighted average of the annual arithmetic means of each monitor in the county, with the number of observations per monitor used as weights. In practice, I calculate this from the set of monitors that operated for at least 75% of the year (i.e., 6,570 hours). These monitors meet the EPA's minimum summary criterion and this sample restriction is applied in throughout the analysis.[6]

The annual county-level SO_2 nonattainment designations were determined from the annual *Code of Federal Regulations (CFR)*. For each of the criteria 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." Additionally, the *CFR* occasionally indicates that only part of a county did not meet the primary standards. I assigned a county to the SO_2 nonattainment category if all or part of it failed to meet the SO_2 "primary standards";

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[5] See Chay, Dobkin, and Greenstone [5], Chay and Greenstone [7, 8], Dockery et al. [10], and Ransom and Pope III [19] on the relationship between air pollution and human health.

[6] To preclude the possibility that counties or states place monitors to produce false pollution concentrations, the *Code of Federal Regulations* contains precise criteria that govern the siting of a monitor. Among the most important criteria is that the monitors capture representative pollution concentrations in the most densely populated areas of a county. Moreover, the EPA must approve the location of all monitors and requires documentation that the monitors are actually placed in the approved

otherwise, I designated it attainment. These annual, county-level, designations were hand entered for the 3,063 U.S. counties for the years 1978-1992. Although these designations were applied before 1978, the identity of the nonattainment counties is unavailable from earlier *CFRs* and the EPA. This poses some difficulties for the analysis, because it means that there is no "pre-period" where the regulations are not in force. This issue is discussed further below.

B.   *National Trends in SO$_2$ Monitoring, Concentrations, and Regulation*

Table I presents annual summary information from the SO$_2$ monitor and nonattainment data. Column (1) reports the number of monitors that meet the EPA's minimum summary criteria. Columns (2) and (3) present the number of counties in which these monitors are located and their population. The passage of the 1970 CAAAs led to an extensive program to site monitors around the U.S. and obtain better readings of the prevailing SO$_2$ concentrations. Since the late 1970s, the number of operating monitors has varied between approximately 500 and 650. These monitors are spread out over approximately 300 counties, implying that on average there are slightly less than 2 monitors operating in each county.[7] From 1980 onward, the population in counties monitored for SO$_2$ ranges between 110 and 125 million, demonstrating that the monitoring program was focused on the most heavily populated of the more than 3,000 U.S. counties.

Although the total number of monitored counties is roughly constant after the late 1970s, there is a lot of churning in the set of monitored counties. For example, 576 different counties are monitored over the 1969-97 period. Since the monitoring program is aimed at the dirtiest counties, the EPA and the states generally remove monitors from counties that become "clean" and add monitors in "dirty" counties. In order to avoid any biases associated with compositional changes, the subsequent tests of the effect of nonattainment status on SO$_2$ concentrations are conducted on fixed sets of counties. In the presence of

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locations. This information is derived results from the *Code of Federal Regulations* 1995, title 40, part 58 and a conversation with Manny Aquilania and Bob Palorino of the EPA's District 9 Regional Office.

[7] In the vast majority of counties, only 1 monitor records SO$_2$ concentrations. However, in large, industrial counties, such as Los Angeles, CA, Cook (Chicago), IL, and Wayne (Detroit), MI, it is not uncommon for more than 10 monitors to operate simultaneously.

the churning, however, this restriction means that there is a tension between the number of years and counties in any sample.

Columns (4) and (5) report the unweighted and weighted (where county population is the weight) mean annual concentration across all operating monitors. Column (6) lists the annual means of the 2nd highest 24-hour county-level readings. Each county's 2nd highest reading is the maximum of the 2nd highest daily readings across all monitors (not just those that meet the minimum summary criteria) within a county by year and the entry is the unweighted mean of these readings.

All three measures reveal a dramatic decline in SO_2 concentrations in the last 30 years. For example, the unweighted (population weighted) annual average declined from .0380 ppm (.0359 ppm) in 1969 to .0105 (.0098) in 1980 and then to .0048 (.0050) in 1997. The extreme concentration readings follow a similar pattern. It is evident that the national average SO_2 concentration was well below the federal standards by the mid-1970s. Figure 1 graphically displays the SO_2 trends and the population in monitored counties. In light of the similarity in the unweighted and weighted concentrations, the subsequent analysis exclusively uses the unweighted measures.

Columns (7)-(9) report the number of counties with monitor readings exceeding the annual, daily, or either federal standard. All of these measures exhibit a strong downward trend. In fact since 1981, fewer than 10 of the monitored counties exceeded the SO_2 NAAQS in any year. And since 1986, it is fewer than 5.

Columns (10) and (11) list the number of counties designated nonattainment in the *CFRs*. The former column reports this information among the set of monitored counties, while the latter column reports it for all counties.[8] The number of nonattainment counties always greatly exceeds the number of

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[8] A comparison of the two columns reveals that many counties that do not meet the criterion for sufficient monitoring are designated SO_2 nonattainment. Presumably, the EPA's models indicate that these counties have SO_2 concentrations that exceed the NAAQS.

counties exceeding the SO_2 NAAQS in the previous year. In fact a number of the nonattainment counties had not exceeded the standard for many years.[9]

It is evident that SO_2, nonattainment status is not mechanically assigned according to whether a county violates the NAAQS. This finding greatly complicates an evaluation of the effect of nonattainment status on SO_2 concentrations. Since the NAAQS specify the selection rule that in principle determines nonattainment status, it is natural to evaluate this program with a regression discontinuity approach as in Chay and Greenstone [6, 7]. Such an evaluation technique relies on the assumption that counties just above and below the NAAQS threshold are virtually identical and that comparisons near the threshold will produce unbiased estimates of the effect of nonattainment status on air pollution concentrations.

This section's findings reveal that the selection rule for the SO_2 nonattainment designation is unknown, so it is not appropriate to use a regression discontinuity design here. Consequently, the validity of the subsequent analysis turns on the successfulness of adjusting for the heterogeneity across nonattainment and attainment counties. This is the subject of the remainder of the paper.

IV. The Research Design and Challenges to Its Validity

A.   Research Design

This paper conducts separate analyses of the impact of SO_2 nonattainment status on SO_2 air pollution in 3 non-overlapping periods, 1975-1980, 1981-1986, and 1987-1992. In order to be included in the sample for a period, a county must have at least one monitor that meets the minimum summary criteria in every year of that period.[10] The extension of the sample beyond 6 years causes the sample sizes

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[9] As an example, the paper examines 19 counties that are designated SO_2 nonattainment in 1990. 12 of these 19 counties did not exceed the NAAQS in any of the previous 10 years.

[10] The advantage of fixing the sample is that it avoids any biases associated with changes in the composition of monitored counties. The disadvantage is that the EPA's decision to stop monitoring a county may be associated with nonattainment status. In particular, the nonattainment regulations may reduce SO_2 concentrations and the EPA may systematically cease monitoring the counties with these improvements in air quality. In this case, this paper's use of a fixed sample approach will cause the effect of the nonattainment designation to be biased upward.

to deteriorate rapidly. Further, due to the small number of monitored counties in the early 1970s, it is not practical to begin the analysis until 1975, 5 years after the passage of the 1970s CAAAs.

The paper tests the effect of the nonattainment designation that is assigned in the 4th year of each period. Since the nonattainment designation is supposed to be based on the previous year's pollution concentration the third year is henceforth referred to the "regulation selection year" or year "t-1". Thus, each period contains 3 years before the assignment of this designation and 3 years subsequent to it. The 3 "pre-period" years are used to adjust for differences across the nonattainment and attainment counties. The CAAAs frequently require the implementation of abatement activities over a period of a few years and the 3 "post-period" years allow the effect to vary over time.

B.   *Pre-Period Differences in Attainment and Nonattainment Counties*

Since the nonattainment designation is not assigned randomly, this subsection examines the association between nonattainment status and the likely determinants of changes in SO_2 concentrations in the post-period. Because the CAAAs require the assignment of nonattainment status to be based on SO_2 concentrations, it is to be expected that there are differences across the categories of counties. The identification of these differences is important, because it reveals the sources of heterogeneity that must be adjusted for in order to avoid confounding the effect of nonattainment status with them.

Table II explores some of these sources of heterogeneity. Each 6-year period is examined in a separate panel. Columns (1) and (2) detail the number of counties and their populations in each period. Columns (3a)-(3e) report the mean SO_2 concentration in the regulation selection year (i.e., 1977, 1983, and 1989), the change between t-1 and t-3, and the number of counties exceeding the SO_2 NAAQS in each of the pre-period years, respectively.

Figures 2 and 3 graphically describe the pre-period heterogeneity. Figure 2 plots the annual SO_2 concentrations by nonattainment status. The points to the right of the vertical line are the post-period years. Figure 3 presents separate kernel density plots of the distribution of SO_2 concentrations in the regulation selection year for nonattainment and attainment counties. Both figures include separate panels for each period.

1975-80. This period is structured to take advantage of the first publication of the nonattainment designations in 1978. It may be an especially interesting period, because it allows for a test of nonattainment status in the first year that the 1977 CAAAs were in force. There are 44 attainment and 18 nonattainment counties, with populations of 23.6 and 15.7 million, respectively. A simple before and after comparison suggests that nonattainment status reduced SO_2 concentrations.

There are at least two important differences in the pre-period concentrations of SO_2. First, mean SO_2 concentrations are roughly two times higher in nonattainment counties. From the kernel density plots in Figure 3A, it is evident that this mean difference is not due to a few outliers. In particular, there are few attainment counties with concentrations in the range covered by the majority of the nonattainment distribution. Second, there is a downward trend in the nonattainment counties in the pre-period, while concentrations are essentially flat in the attainment ones.

Columns (3c)-(3e) of Table II reveal that only 7 of the 18 counties designated nonattainment met the statutory requirements necessary for this designation. Among the attainment counties, only 1 of them exceeds the federal standards. Overall, it is evident that the practical selection rule for nonattainment status differed from the statutory one.

In summary, Figure 2A suggests that 1978 nonattainment status reduced SO_2 concentrations, but a closer examination of the data leads to a less certain conclusion. In particular, it is possible that the observable differences among attainment and nonattainment counties or the unobserved variables that determine the selection rule for nonattainment status explain the relative post-period decline in nonattainment counties. It is evident that in order to obtain a consistent estimate of nonattainment status, the subsequent analysis will need to successfully adjust for these factors.

1981-86. The 1980s are often regarded as a period when environmental regulations were not enforced vigorously. This period provides an opportunity to empirically test this hypothesis. There are 139 counties with 76.3 million people in the 1984 attainment category and 23 counties with a combined population of 9.7 million in the nonattainment one. In the years in which 1984 nonattainment status applied, the nonattainment counties have a slightly larger decline in SO_2.

Again, there are important pre-period characteristics of the counties that vary with nonattainment status. For example, the regulation selection year mean SO_2 concentrations are higher in nonattainment counties. Also, the pre-period decline is greater in the nonattainment counties (roughly .0037 ppm versus .0008 ppm). Notably, only 1 of the nonattainment counties exceeded the SO_2 NAAQS in the regulation selection year. This finding is salient because it indicates that the statutory selection rule did not determine the assignment of SO_2 nonattainment in this period too. This reinforces the point that a regression discontinuity evaluation strategy is not appropriate.

1987-92. This period allows for a test of the effect of nonattainment status in the first years in which the 1990 CAAAs were in force. There are 184 counties with a population of 87.4 million in the 1990 attainment category and 19 counties with approximately 7.7 million people in the nonattainment group. Together these counties accounted for approximately 40% of the U.S. population in this period. Figure 2C reveals an association between nonattainment status and a post-period reduction in SO_2 concentrations.

However, there are substantial pre-period differences in the two sets of counties. In the nonattainment counties during the pre-period, SO_2 concentrations are higher and there is a larger downward trend. Further, the rule that determines nonattainment status remains a mystery. It appears likely that just as in the other periods, a simple pre and post comparison will not reveal the causal effect of nonattainment status on SO_2 concentrations.

C.   *Intra-County Variation in Nonattainment Status*

An important issue for this analysis is that there is little intra-county variation in counties' attainment-nonattainment designation over time. This is because few counties' nonattainment status changed after 1978. The last three columns of Table II demonstrate this point in the three periods examined here. Columns (4a) (4b), and (4c) report the number of counties designated nonattainment in any of the pre-period years (i.e., t-1, t-2, and t-3), all the pre-period years, and in all years from 1978 through year t-1, respectively. Column (4b) reveals that almost all counties that are nonattainment in the 4th year of the 1981-6 and 1987-92 periods are also nonattainment throughout the pre-period. Further, 20

(13) of 23 (19) 1984 (1990) SO_2 nonattainment counties were also nonattainment in <u>every</u> year from 1978 through the regulation selection year. Interestingly, a small, but nontrivial, fraction of the attainment counties were previously designated nonattainment.

The absence of time variation in nonattainment status has a number of important implications. First, the "pre-period" years are not before the counties are regulated, but simply before the arbitrarily chosen 1978, 1984, and 1990 nonattainment designations that this paper evaluates. For ease of exposition, I use "pre" and "post" throughout the remainder of the paper but note that their meaning here differs from the standard definitions.

Second, although it would be interesting to determine whether there is heterogeneity in the effect of nonattainment status, it will be difficult to investigate some likely sources. For example, the effect might vary with the number of years that a county has been designated nonattainment (i.e., the effect on SO_2 concentrations may be greater in the 1st year that a county is nonattainment than in the 9th year). Alternatively, the EPA's enforcement intensity may vary with the political climate. Unfortunately, it is impossible to separately identify these two potential sources of heterogeneity because almost all counties that were ever nonattainment were first designated nonattainment in 1978. The subsequent analysis allows the effect of nonattainment status to differ in each of the three periods but whether any differences are due to the length of time that a county was designated nonattainment or the President's preferences about the environment cannot be assessed.

Third, and most importantly, the analysis is structured to evaluate the effect of the nonattainment designation assigned in the 4th year of each period, but this interpretation of the estimated effects may not be valid. Although linear regression and propensity score matching are used to adjust for the pre-period differences (e.g., in SO_2 concentrations) between the nonattainment and attainment counties, the absence of within county variation in nonattainment status means that it is impossible to directly control for pre-period differences in the incidence of the nonattainment designation. Consequently, it may be more appropriate to interpret the estimated treatment effect as a measure of the effect of a county being

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designated nonattainment over a longer period, rather than the effect of the 4th year's nonattainment designation.

V. Econometric Strategies

This paper utilizes a variety of statistical models to control for the differences between attainment and nonattainment counties that were documented in the previous section. Here, I describe these econometric strategies.

First Differences. The first differences strategy is based on the assumption that any differences in SO_2 concentrations between the two sets of counties are due to permanent factors (e.g., a county's topography) that have time invariant effects on SO_2 pollution. Let D_{i4} be an indicator variable that equals 1 when county i is designated nonattainment in the 4th year of one of the 6 year periods and 0 if it is attainment. Now, consider:

(1) $Y_{it} - Y_{i3} = \theta_t + \alpha_t D_{i4} + \eta_{it}$,

where t denotes the year and $4 <= t <= 6$, indicating that the dependent variable is the change in SO_2 concentrations between the 4th, 5th, or 6th year and the 3rd year. θ_t is a nonparametric time effect that is common to attainment and nonattainment counties and η_{it} is the idiosyncratic unobserved component of the change in SO_2 concentrations.

α_t is the parameter of interest and measures the difference in the change in SO_2 concentrations between nonattainment and attainment counties. Formally, $\alpha_t = E[Y_{it} - Y_{i3}|D_{i4}=1] - E[Y_{it} - Y_{i3}|D_{i4}=0]$. Equation (1) is estimated separately for each of the post-period years and the t subscript on α highlights that the effect of nonattainment status is allowed to vary across years within a period.[11] For example, it may be of a larger magnitude in the 6th year of a period (e.g., 1980) than in the 4th (e.g., 1978). Notably, the differencing removes the time-invariant characteristics that are the only source of bias under this model's assumptions.

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[11] For example in the 1975-80 period, I separately estimate (1) when the dependent variables are $Y_{i1978} - Y_{i1977}$, $Y_{i1979} - Y_{i1977}$, and $Y_{i1980} - Y_{i1977}$.

The mapping that assigns a value to the nonattainment indicator merits further discussion. This mapping emphasizes that the aim of this exercise is to evaluate the effect of the 4th year nonattainment designation. The difficulty is that the pre-period SO_2 nonattainment designations are highly correlated with D_{i4}. This correlation will cause the estimated α_t to capture the effect of the 4th year nonattainment designation <u>and</u> the effect of the pre-period SO_2 nonattainment designations. The point is that it is likely to be incorrect to interpret α_t as the effect of the 4th year nonattainment designation only.

A more troubling possibility is that the identifying assumptions of this model are unlikely to be valid. This is because the nonattainment designation is highly correlated with past pollution levels, which in turn are likely correlated with current pollution levels through η_{it}. This would be the case if, for example, there is mean reversion in SO_2 concentrations. Moreover, the differential pre-period trends in SO_2 concentrations documented in Section IV are likely to cause a correlation between D_{i4} and η_{it}. Such unwanted correlations will bias the estimated effect of nonattainment status, α_t.

Adjusted First Differences. In light of these issues, the paper also linearly adjusts for the heterogeneity across attainment and nonattainment counties. The model is:

(2) $Y_{it} - Y_{i3} = \theta_t + X_{ib}'\beta + P_{ib}'\varphi + \alpha_t D_{i4} + \eta_{it}$,

where the b subscript indicates the pre-period. The substantive difference with equation (1) is that here the estimated effect of nonattainment status on the change in SO_2 concentrations is conditional on linear adjustment for the vectors X_{ib} and P_{ib}.

In practice, X_{ib} includes nonattainment status for carbon monoxide, ozone, and total suspended particulates in the same year that D_{i4} is measured (i.e., 1978, 1984, and 1990). As Table II demonstrated, there is little within county variation in SO_2 nonattainment status, so it is not practical to include measures of this variable from earlier years. The vector also includes county-level measures of per capita income, the average wage, total employment, and total population.[12] Moreover in some specifications, X_{ib} includes a full set of state fixed effects so that the estimated treatment effect is based on intra-state comparisons of SO_2 attainment and nonattainment counties.

P_{ib} is a vector that includes a number of measures of lagged SO_2 pollution concentrations in order to break the unwanted correlation between D_{i4} and η_{it}. For instance, it includes the mean SO_2 concentration from the t-2 and t-3 pre-period years (e.g., 1976 and 1975 in the 1975-80 period). The vector also includes the annual maximum 1 hour, 3 hour, and 24 hour readings from t-1, the regulation selection year. Since the correct functional form for the lagged SO_2 pollution variables is unknown, some specifications will include squares and cubes of these variables.

Here, the identifying assumption is that $E[D_{i4} \eta_{it}| X_{ib}, P_{ib}, \theta_t] = 0$ or that 4th year nonattainment status is independent of potential pollution concentrations, <u>conditional</u> on the covariates. Recall, the EPA's exact selection rule is unknown but it seems sensible to assume that it is a function of lagged pollution levels, economic activity, and its cognizance of a county's overall air quality (measured by the nonattainment designations for other pollutants). If the EPA relies on other variables that also determine post-period SO_2 concentrations, the assumption will be violated and the estimated treatment effect will be inconsistent.

Propensity Score Matching. Equation (2) relies on a linear model to control for the covariates X_{ib} and P_{ib}. This may be unappealing since their true functional form is unknown. An alternative is to compare the change in SO_2 concentrations of attainment and nonattainment counties that have identical values of X_{ib} and P_{ib}. This would obviate all functional form concerns. Of course, this method is not feasible when there are many variables or even a few continuous variables, because it becomes impossible to match nonattainment and attainment counties. This problem is known as the "curse of dimensionality."

As a solution, Rosenbaum and Rubin [20] suggest matching on the propensity score—the probability of receiving the treatment conditional on covariates.[13] This probability is an index of all covariates and effectively compresses the multi-dimensional vector of covariates into a simple scalar. The advantage of the propensity score approach is that it offers the promise of providing a feasible method to control for the observables in a more flexible manner than is possible with linear regression.

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[12] These data are obtained from the Bureau of Economic Analysis.

Just as with linear regression, the identifying assumption is that assignment to the treatment is associated only with <u>observable</u> pre-period variables. This is often called the ignorable treatment assignment assumption or selection on observables [15].

I implement the propensity score matching strategy in three steps. First, the propensity score is obtained by fitting logits for SO_2 nonattainment status, using X_{ib} and P_{ib} as explanatory variables. Thus, I try to replicate the EPA's selection rule with the observed covariates. I then conduct two tests. The first examines whether the estimated propensity scores of the nonattainment and attainment counties are equal within strata (e.g., quintiles). The second tests whether the means of the covariates are equal in the nonattainment and attainment counties within strata. If the null hypothesis is not accepted for either test, I divide the strata and/or estimate a richer logit model by including higher order terms and interactions.[14] Once the null is accepted for both tests, I proceed to the next step.

Second, the treatment effect is calculated by comparing the change in SO_2 concentrations between a post-period year and year t-1 of nonattainment and attainment counties with similar or "matched" values of the propensity score. In particular, a treatment effect is calculated for each nonattainment county for which there is at least one attainment county with a propensity score "suitably close" to the value for the nonattainment county. In the subsequent results, I define suitably close in two ways—within calipers of 0.05 and 0.10. In cases where multiple attainment counties fall into one of these calipers, I average the outcome across all of these counties. Further, this matching is done with replacement so that individual attainment counties can be used as controls for multiple nonattainment counties.[15]

Third, a single treatment effect is estimated by averaging the treatment effects across all the nonattainment counties for which there was at least one suitable match. An attractive feature of this

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[13] An alternative is to match on a single (or possibly a few) "key" covariate(s). See Angrist and Lavy [2] or Rubin [22] for applications.
[14] See Dehejia and Wahba [9] and Rosenbaum and Rubin [21] for more details on how to implement the propensity score method.
[15] See Dehajia and Wahba [9] and Heckman, Ichimura, and Todd [13] on propensity score matching algorithms.

approach is that the estimated treatment effect is based on comparisons of nonattainment and attainment counties with "similar" values of the index. This has the desirable property that it focuses the comparisons where there is overlap in the distribution of the propensity scores in the nonattainment and attainment samples.[16]

VI. Empirical Results

A. 1975-1980

Here, I present evidence on the relationship between 1978 SO_2 nonattainment status and SO_2 concentrations in 1978, 1979 and 1980. Table III A contains the linear regression results. The entries are the parameter estimate from the 1978 nonattainment indicator, its estimated standard error (in parentheses), and the R-squared statistic. Each set of entries is from a separate regression. In the first, second, and third panels, the dependent variables are the 1978-77, 1979-77, 1980-77 change in mean SO_2 concentrations.

Column (1) reports the unadjusted first difference estimate from the fitting of equation (1). These estimates indicate that SO_2 concentrations declined by .00259 ppm, .00290 ppm, and .00477 ppm more in nonattainment counties than attainment counties in 1978, 1979, and 1980 (relative to the regulation selection year), respectively. These results suggest that by the end of the period (i.e., 1980) nonattainment status is associated with a 17% decline in SO_2 concentrations. The important limitation of the first difference estimator is that it does not adjust for time-varying factors (e.g., the pre-existing trends in the two sets of counties). As Table II and Figure 2A demonstrated, the pre-period trends in these two sets of counties are starkly different.

The entries in the remaining columns are from the estimation of equation (2) and they progressively control for more potential confounders. In the column (2) specification the lagged measures of SO_2 are included, while in column (3) the measures of nonattainment status for the other

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[16] If there are heterogeneous treatment effects, this strategy produces an estimate of the average "effect of the treatment on the treated" when there are suitable matches for all nonattainment counties [1, 4, 14, 22].

pollutants are added. The column (4) specification includes the economic activity controls and lastly column (5) adds a full set of state fixed effects. The exact controls are noted at the bottom of the table.[17]

The key finding from columns (2)-(5) is that, once the lagged pollution levels are included as covariates, the nonattainment designation is associated with modest <u>increases</u> in SO_2. However, none of these estimates would be judged statistically significant at conventional levels.[18] The R-squared statistics highlight that the addition of these variables greatly improves the fit of the regressions. Appendix Table I reports the coefficients on the covariates from the fitting of the column (4) specification when the dependent variable is the difference in the 1980 and 1977 SO_2 concentrations.

Table III B presents the results from the propensity score matching routine. This is done with two different specifications of the logit. In "Logit Specification 1", the covariates in the logit are the lagged SO_2 measures (including the 1977 mean SO_2 concentration), while "Logit Specification 2" adds the county level nonattainment designations for the other criteria pollutants and the economic activity controls. The set of covariates in the logits correspond to those in Columns (2) and (4) of Table III A, respectively. For each specification of the logit, the Table reports the estimated treatment effects and their standard errors based on calipers of 0.10 and 0.05.[19] The bottom two rows report the number of nonattainment counties for which at least one match is available and the number of attainment counties that fall within the calipers, respectively.

The first panel reports the results from a test of whether SO_2 concentrations in the regulation selection year are equal among the matched comparisons. These results are presented, because this is the most important difference between the two groups before the assignment of the nonattainment designation. They indicate that even after matching on the propensity score, the 1977 SO_2 concentrations

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[17] In this period the lagged pollution variables enter linearly but higher order terms are not included due to the small sample size.

[18] In all three periods, results are qualitatively unchanged when the regressions are weighted by the county population.

[19] The standard errors are calculated according to the standard two-sample formula. These are generally considered to be conservative estimates of the standard error for the estimated treatment effect, because they treat the matched treatments and controls as being independent of each other. However, the

are higher in the nonattainment counties, although these differences would not be judged statistically different from zero at conventional levels. The differences range between .0011 ppm and .0054 ppm, depending on the specification of the logit and the size of the caliper. Notably, these differences are substantially smaller than the average difference of .0103 ppm across attainment and nonattainment counties in the complete sample. Thus, the matching has been relatively successful on this dimension.

Before proceeding to the main matching results, Figure 4A displays the overlap in the distributions of the estimated propensity scores of the nonattainment and attainment counties based on Logit Specification 2. The figure contains the fraction and number of counties in each quintile, as well as the means of the propensity score by attainment status. The overlap is less than ideal here. For example, the highest quintile is entirely comprised of nonattainment counties and the mean propensity score among these counties is 0.97. Further, 39 of the 44 attainment counties are in the lowest quintile. It is evident that it will not be possible to find suitable matches for many of the nonattainment counties.

Returning to Table III B, the remaining panels present the results from tests of whether nonattainment status is associated with relative declines in SO_2 concentrations in the post-treatment years. Due to the difference in the regulation selection year SO_2 concentrations across the matched counties, the outcome is equal to the post treatment value of SO_2 minus the value in the regulation selection year. Again, separate results are reported for 1978, 1979, and 1980.

The results differ dramatically from the linear regression approach. They suggest that nonattainment status is associated with <u>declines</u> in SO_2 pollution in this period. Logit Specification 1 indicates that by 1980, SO_2 concentrations in 1978 SO_2 nonattainment counties declined by roughly .003 ppm, while the specification 2 estimates indicate a decline that ranges from .003 ppm to .009 ppm. However, conventional criteria imply that all of the estimated declines are indistinguishable from zero in the 3rd post-period year. And, the small number of matched counties in Logit 2 limits the generality of the findings. Nevertheless, the contrast between these estimated treatment effects and those from linear

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matching process likely creates some positive dependence between them and this dependence is not accounted for.

regression is striking and underscores the poor reliability of linear regression when there is little overlap in the distributions of the covariates.[20]

B. 1981-1986

Tables IV A and IV B and Figure 4B are structured identically to Tables III A and III B and Figure 4A. The only difference with the analysis of the previous period is that the sample sizes are large enough to adjust for the lagged SO_2 concentrations with a more flexible functional form. In particular, the adjusted first difference estimates (in columns 2-5) and both of the logit specifications include quadratics and cubics of the lagged mean SO_2 concentrations and quadratics of the extreme values measures. Otherwise, the specifications are identical.

The results based on linear adjustment imply that nonattainment status is associated with modest reductions in SO_2 concentrations. Almost the entire post-period decline has occurred in the first post-treatment year. Interestingly, the estimates are roughly constant in columns (2) through (4).[21] The estimates are also insensitive to the inclusion of a full set of state fixed effects as in column (5). Overall, the linear regression results suggest that nonattainment status is associated with a 6%-9% decline in SO_2 concentrations by the end of the period. Again, none of the estimated parameters are statistically significant.

A few points emerge from the propensity score matching procedure. First, the matching almost completely eliminates the differences in regulation selection year SO_2 concentrations. Second, there is more overlap in the distribution of the propensity scores than in the 1975-80 period but there are still substantial differences in the two distributions. For example, 11 of the 12 counties in the highest quintile

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[20] There are at least two explanations for the differences between the estimated treatment effects from the linear regression and propensity score approaches. First, the propensity score approach nonparametrically controls for observable variables while the linear regression is necessarily parametric. Second, the matching estimate is not based on the full set of nonattainment counties due to the poor overlap in the distributions of the propensity scores.

[21] The parameter estimates and standard errors from the other covariates in the column (4) specification when the dependent variable is the difference in the 1986 and 1983 SO_2 concentrations are reported in Appendix Table I. This table also reports this information for the analogous regression from the 1987-1992 period.

are nonattainment. Third, the treatment effects are smaller than the ones from linear regression and imply that nonattainment status had little effect on SO_2 concentrations in this period.

C. 1987-1992

The 1987-92 period results are presented in Tables V A and V B and Figure 4C. The estimates based on linear adjustment suggest that nonattainment status is associated with a .0009 ppm to .0014 ppm reduction in SO_2 pollution by the end of the period. These estimates would generally be considered statistically different from zero. Interestingly, the largest estimate comes from the specification that includes state fixed effects when the estimate is identified from comparisons among nonattainment and attainment counties within the same state. These estimates suggest that 1990 nonattainment status reduced SO_2 concentrations by 7%-11% in nonattainment counties by 1992.

Figure 4C demonstrates that the overlap of the distributions is better in this period than the other two. Although there are not any attainment counties in the two highest quintiles, 14 of the 19 nonattainment counties are in the lowest three quintiles where the entire attainment distribution is located. The estimated treatment effects are about half the magnitude of the linear regression treatment effects and are not statistically distinguishable from zero. This is likely driven by the inability to find suitable comparisons for the nonattainment counties with the highest probability of being designated nonattainment. Overall, the estimates from this period suggest that 1992 SO_2 nonattainment status modestly reduced SO_2 concentrations in the post-period.

VII. Interpretation

The goal of the CAAAs is to bring all counties into compliance with the NAAQS. The EPA's primary tool to achieve this goal is its ability to designate counties nonattainment and strictly regulate emitters in these areas. This paper has documented that by the late 1970s practically the entire U.S. had achieved the SO_2 standard. Its most surprising finding is that a substantial number of counties with SO_2 concentrations below the federal standard are designated SO_2 nonattainment.

Through extensive conversations with EPA staff, I received a number of explanations for this seeming anomaly but none of them are completely satisfying.[22] The most plausible explanation has two parts. First, it is the states' responsibility to petition to get a county redesignated from nonattainment to attainment and this redesignation process is more difficult than might be expected. For example, this process frequently requires states to develop a local air pollution model that demonstrate that all areas within a county (not just the areas covered by the monitors) have SO_2 concentrations below the federal threshold. These models are often necessary even when all the local pollution monitors record concentrations that are below the federal standard. Importantly, these models are expensive to develop and states do not always have the necessary resources.

Second, the federal EPA staff suggested that they are receptive to requests to lessen the intensity of regulatory oversight in nonattainment counties that do not exceed the NAAQS. It may be easier to lessen the regulatory burden with these requests than by following all of the steps involved in obtaining a formal redesignation to attainment status.

Consequently, the stringency of regulations aimed at reducing a county's SO_2 pollution may depend on a county's nonattainment designation and whether its ambient SO_2 concentration exceeds the federal standards. If this is the case, this paper's mixed results on the effectiveness of the SO_2 nonattainment designation at reducing concentrations may not be surprising. However, it must be emphasized that this is a qualitative explanation of the results and cannot readily be subject to a rigorous test. Further, it does not explain why recent research has found that the TSPs and ozone nonattainment designations are associated with reductions in the ambient concentrations of these pollutants [6, 7, 16].

VIII. Conclusion

This study has used regulation categories specified by the Clean Air Act Amendments to empirically test whether this legislation contributed to the dramatic 80% decline in sulfur dioxide air

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[22] This section draws on conversations with Matthew Witosky of the EPA Region 6 office and a number of people at the national EPA office.

pollution that occurred over the last 30 years. Under this legislation, the EPA annually assigns every county a nonattainment or attainment designation. Stricter regulations apply in the nonattainment counties. Two primary findings are that the statutory selection rule that should have determined nonattainment status is not followed and that there are important observable differences between nonattainment and attainment counties. These findings make the evaluation problem especially difficult.

Linear regression and propensity score matching are used to control for the likely confounding caused by these differences. Notably, the matching appears to be especially useful when the observable differences between the nonattainment and attainment counties are greatest. The results indicate that SO_2 nonattainment status is associated with modest reductions in SO_2 air pollution, but a null hypothesis of zero effect generally cannot be rejected. In summary, the paper finds that the SO_2 nonattainment designation played a minor role in the dramatic reduction of SO_2 concentrations over the last three decades.

The source of the dramatic reduction in ambient SO_2 remains a mystery. The most likely candidates are other features of the CAAAs or state and local regulations. In support of the latter possibility, there were large declines in SO_2 concentrations that pre-dated the implementation of the 1970 CAAAs in a sample of 10 counties with monitors from 1969-1971. However, this extremely small sample may not be representative of the rest of the country. Overall, there is little evidence available to support or contradict alternative explanations.

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Table I: Trends in EPA's SO_2 Monitoring and Regulatory Programs, 1969-1997

| Year | Monitors | Counties | Population (in millions) | SO_2 Concentrations (ppm) | | | Counties with Monitor Readings Exceeding Standard for: | | | SO_2 Nonattainment Counties | |
| | | | | Annual Mean (Unweighted) | Annual Mean (Pop. Weighted) | Mean of 2nd Highest Daily | Year | 24 Hrs | Year or 24 Hrs | Monitored | Total |
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1969	43	16	23.4	0.0380	0.0359	0.1904	8	8	9	-----	-----
1970	30	17	22.6	0.0301	0.0266	0.1493	6	8	8	-----	-----
1971	73	44	34.5	0.0224	0.0210	0.1121	9	14	18	-----	-----
1972	107	57	44.9	0.0206	0.0190	0.1009	6	14	15	-----	-----
1973	144	87	53.1	0.0185	0.0172	0.0970	12	17	20	-----	-----
1974	271	146	70.2	0.0172	0.0149	0.0833	11	20	25	-----	-----
1975	319	168	68.3	0.0150	0.0136	0.0746	10	21	23	-----	-----
1976	425	204	88.0	0.0143	0.0131	0.0728	11	22	23	-----	-----
1977	447	205	84.4	0.0142	0.0121	0.0758	10	22	25	-----	-----
1978	494	225	90.3	0.0127	0.0114	0.0646	2	13	13	41	87
1979	559	252	94.3	0.0125	0.0110	0.0682	3	12	14	43	84
1980	561	274	110.3	0.0105	0.0098	0.0540	1	15	15	45	83
1981	593	287	114.7	0.0098	0.0093	0.0558	1	8	8	47	80
1982	588	299	113.2	0.0093	0.0085	0.0479	0	6	6	42	60
1983	629	331	117.1	0.0089	0.0083	0.0461	1	4	4	36	53
1984	640	329	116.9	0.0094	0.0087	0.0521	2	6	7	31	48
1985	577	305	114.6	0.0088	0.0085	0.0474	0	6	6	34	51
1986	562	309	120.4	0.0084	0.0083	0.0449	0	3	3	36	49
1987	523	299	120.6	0.0076	0.0080	0.0388	1	4	4	29	48
1988	528	309	124.5	0.0079	0.0079	0.0413	1	3	4	30	49
1989	533	309	119.9	0.0078	0.0079	0.0392	0	1	1	30	49
1990	523	310	122.5	0.0072	0.0074	0.0363	1	1	2	29	46
1991	535	315	125.6	0.0070	0.0073	0.0363	0	2	2	28	46
1992	522	308	123.4	0.0064	0.0066	0.0338	0	1	1	25	46
1993	524	320	125.5	0.0061	0.0064	0.0314	0	2	2	-----	-----
1994	516	309	120.3	0.0059	0.0062	0.0331	0	1	1	-----	-----
1995	537	320	126.2	0.0048	0.0050	0.0255	0	0	0	-----	-----
1996	532	320	127.8	0.0048	0.0050	0.0265	0	1	1	-----	-----
1997	511	310	122.1	0.0048	0.0050	0.0250	0	1	1	-----	-----

Notes: The data sources are the EPA's SO_2 monitoring network and the Code of Federal Regulations (CFR). The EPA considers a monitor "representative" of the prevailing ambient SO_2 concentration if it records at least 6570 (out of a maximum of 8760) hourly concentrations in a year. The sample is restricted to monitors that meet this definition of representativeness in columns (1) - (9). Counties with at least 1 monitor satisfying this sample restriction form the universe of counties in column (7), but data from all monitors within those counties is used to determine whether the 24 hour SO_2 air quality standard is exceeded. Column (10) reports the number of nonattainment counties in the entire U.S. Nonattainment status was published annually in the CFR beginning in 1978 and is unavailable before this year. The post-1992 data is currently unavailable in electronic form. The 1970 Census' population counts were used for the population measues from 1969 through 1975. The 1980 Census was used for 1976 through 1985 and the 1990 Census for 1986 through 1997. See the Data Appendix for more details.

Table II: Pre-Period Characteristics of Counties, by Nonattainment Status

	Counties	Population Year t-1	Pre-Period SO$_2$ Concentration Summary Statistics		Exceed Annual or 24 SO$_2$ NAAQS			SO$_2$ Nonattainment Summary Statistics		
			Mean Year t-1	Pre-Period Change (Year t-1 – Year t-3)	Year t-1	Year t-2	Year t-3	At Least 1 Pre-Period Year	All Pre-Period Years	Every Year 1978 Through Year t-1
	(1)	(2)	(3a)	(3b)	(3c)	(3d)	(3e)	(4a)	(4b)	(4c)
1975-1980										
Nonattainment	18	15,728,538	0.0220	-0.00268	7	6	7	---	---	---
Attainment	44	23,567,800	0.0117	0.00053	1	2	2	---	---	---
1981-1986										
Nonattainment	23	9,709,513	0.0110	-0.00369	1	3	2	23	23	20
Attainment	139	76,277,154	0.0091	-0.00083	1	2	3	10	2	2
1987-1992										
Nonattainment	19	7,719,144	0.0125	-0.00196	1	2	3	19	17	13
Attainment	184	87,390,332	0.0084	0.00008	1	2	1	5	1	1

Note: Each panel reports summary information from the samples for each of the three 6 year periods analyzed in the paper. Column (1) reports the number of counties in the attainment and nonattainment categories in 1978, 1984, and 1990, respectively. Column (2) reports the population in each set of counties. Columns (3a) through (3e) report summary information on SO$_2$ concentrations. Year t-1 refers to the regulation selection year, which is the year before the assignment of the nonattainment designation (i.e., 1977, 1983, and 1989). Years t-2 and t-3 are 2 and 3 years before the regulation selection year, respectively. Columns (4a) (4b), and (4c) report the number of counties designated nonattainment in any of the pre-period years (i.e., t-1, t-2, and t-3), each of the pre-period years, and in all years from 1978 through year t-1, respectively.

Table III: Estimated Effect of 1978 Nonattainment Status on Mean SO_2 Concentrations

A. First Differences Estimates

	(1)	(2)	(3)	(4)	(5)
$(1978\ SO_2 - 1977\ SO_2)/100$					
1978 Nonattainment	-.259	.077	.100	.121	.083
	(.138)	(.101)	(.096)	(.097)	(.098)
R-Squared	.09	.66	.71	.73	.87
$(1979\ SO_2 - 1977\ SO_2)/100$					
1978 Nonattainment	-.290	.037	.095	.139	.154
	(.181)	(.131)	(.142)	(.144)	(.175)
R-Squared	.06	.62	.64	.67	.78
$(1980\ SO_2 - 1977\ SO_2)/100$					
1978 Nonattainment	-.477	-.082	.078	.089	.100
	(.201)	(.153)	(.159)	(.173)	(.213)
R-Squared	.12	.55	.61	.64	.81
N	62	62	62	62	62
Lagged SO_2 Concentrations	No	Yes	Yes	Yes	Yes
Flexible Functional Forms of Lagged SO_2 Concentrations	No	No	No	No	No
Nonattainment for Other Pollutants	No	No	Yes	Yes	Yes
Economic Activity Controls	No	No	No	Yes	Yes
State Fixed Effects	No	No	No	No	Yes

Notes: The entries are the parameter estimates from the 1978 nonattainment indicator variable and the associated standard errors from separate regressions. The standard errors are calculated with the Eicker-White formula to account for unspecified heteroskedasticity. See the text, particularly the description of equations (2) and (3), for further details. The included covariates are reported at the bottom of the table.

B. Propensity Score Matching Estimates

	Logit Specification 1		Logit Specification 2	
	Caliper=.10	Caliper=.05	Caliper=.10	Caliper=.05
	(1)	(2)	(1)	(2)
(1977 SO_2)/100				
1978 Nonattainment	.402	.538	.314	.113
	(.353)	(.426)	(.463)	(.644)
(1978 SO_2 – 1977 SO_2)/100				
1978 Nonattainment	.026	-.063	-.264	-.607
	(.127)	(.139)	(.157)	(.109)
(1979 SO_2 – 1977 SO_2)/100				
1978 Nonattainment	-.070	-.102	-.213	-.711
	(.183)	(.183)	(.239)	(.209)
(1980 SO_2 – 1977 SO_2)/100				
1978 Nonattainment	-.252	-.331	-.289	-.879
	(.231)	(.246)	(.357)	(.482)
# of 18 Treated that are Matched	11	8	6	3
# of 44 Controls that are Matched	44	43	4	2

Notes: The entries are the treatment effects and their standard errors from the propensity score matching procedure described in the text. Each nonattainment county is matched to all the attainment counties with propensity scores within the specified caliper. Logit Specification 1 includes the controls from the Column (2) specification of Table III A, plus the mean SO_2 concentration in the regulation selection year. Logit Specification 2 includes the controls from the Column (4) specification of Table III A, plus the mean SO_2 concentration in the regulation selection year.

Table IV: Estimated Effect of 1984 Nonattainment Status on Mean SO_2 Concentrations

A. First Differences Estimates

	(1)	(2)	(3)	(4)	(5)
$(1984\ SO_2 - 1983\ SO_2)/100$					
1984 Nonattainment	.010	-.054	-.065	-.058	-.061
	(.046)	(.056)	(.056)	(.058)	(.069)
R-Squared	.00	.12	.15	.17	.63
$(1985\ SO_2 - 1983\ SO_2)/100$					
1984 Nonattainment	.077	-.017	-.029	-.026	-.032
	(.061)	(.066)	(.068)	(.071)	(.071)
R-Squared	.01	.22	.24	.25	.75
$(1986\ SO_2 - 1983\ SO_2)/100$					
1984 Nonattainment	-.025	-.098	-.078	-.085	-.069
	(.053)	(.057)	(.060)	(.061)	(.070)
R-Squared	.00	.27	.28	.29	.65
N	162	162	162	159	159
Lagged SO_2 Concentrations	No	Yes	Yes	Yes	Yes
Flexible Functional Forms of Lagged SO_2 Concentrations	No	Yes	Yes	Yes	Yes
Nonattainment for Other Pollutants	No	No	Yes	Yes	Yes
Economic Activity Controls	No	No	No	Yes	Yes
State Fixed Effects	No	No	No	No	Yes

B. Propensity Score Matching Estimates

	Logit Specification 1		Logit Specification 2	
	Caliper=.10	Caliper=.05	Caliper=.10	Caliper=.05
	(1)	(2)	(1)	(2)
$(1983\ SO_2)/100$				
1984 Nonattainment	.100	.067	.071	.087
	(.167)	(.167)	(.162)	(.181)
$(1984\ SO_2 - 1983\ SO_2)/100$				
1984 Nonattainment	-.006	.003	-.013	.003
	(.072)	(.074)	(.072)	(.076)
$(1985\ SO_2 - 1983\ SO_2)/100$				
1984 Nonattainment	.041	.046	.028	.082
	(.086)	(.087)	(.084)	(.081)
$(1986\ SO_2 - 1983\ SO_2)/100$				
1984 Nonattainment	-.022	-.023	-.038	.002
	(.085)	(.086)	(.082)	(.088)
# of 23 Treated that are Matched	16	15	16	14
# of 139 Controls that are Matched	139	116	136	124

Notes: See the Notes to Tables III A and III B and the text.

Table V: Estimated Effect of 1990 Nonattainment Status on Mean SO_2 Concentrations

A. First Differences Estimates

	(1)	(2)	(3)	(4)	(5)
(1990 SO_2 – 1989 SO_2)/100					
1990 Nonattainment	.024	-.053	-.054	-.050	-.065
	(.054)	(.035)	(.037)	(.037)	(.056)
R-Squared	.00	.28	.29	.30	.58
(1991 SO_2 – 1989 SO_2)/100					
1990 Nonattainment	-.077	-.120	-.122	-.132	-.183
	(.038)	(.041)	(.043)	(.043)	(.058)
R-Squared	.02	.39	.39	.40	.68
(1992 SO_2 – 1989 SO_2)/100					
1990 Nonattainment	-.136	-.090	-.089	-.106	-.144
	(.070)	(.041)	(.042)	(.043)	(.053)
R-Squared	.03	.54	.54	.56	.80
N	203	203	203	200	200
Lagged SO_2 Concentrations	No	Yes	Yes	Yes	Yes
Flexible Functional Forms of Lagged SO_2 Concentrations	No	Yes	Yes	Yes	Yes
Nonattainment for Other Pollutants	No	No	Yes	Yes	Yes
Economic Activity Controls	No	No	No	Yes	Yes
State Fixed Effects	No	No	No	No	Yes

B. Propensity Score Matching Estimates

	Logit Specification 1		Logit Specification 2	
	Caliper=.10	Caliper=.05	Caliper=.10	Caliper=.05
	(1)	(2)	(1)	(2)
(1989 SO_2)1/100				
1990 Nonattainment	.050	.013	.119	.121
	(.151)	(.152)	(.162)	(.160)
(1990 SO_2 – 1989 SO_2)1/100				
1990 Nonattainment	.001	.001	.001	-.002
	(.042)	(.042)	(.046)	(.046)
(1991 SO_2 – 1989 SO_2)1/100				
1990 Nonattainment	-.034	-.033	-.038	-.036
	(.056)	(.055)	(.061)	(.062)
(1992 SO_2 – 1989 SO_2)1/100				
1990 Nonattainment	-.053	-.047	-.065	-.067
	(.064)	(.064)	(.070)	(.071)
# of 19 Treated that are Matched	15	15	14	14
# of 184 Controls that are Matched	184	183	181	181

Notes: See the Notes to Tables III A and III B and the text.

Appendix Table I: Estimated Effects of Determinants of Changes in SO_2 Concentrations

Dependent Variable	1980 - 1977 SO_2 Concentration (1)	1986 - 1983 SO_2 Concentration (2)	1992 - 1989 SO_2 Concentration (3)
Mean SO_2 t-2	-.300	-.780	.174
	(.145)	(.538)	(.299)
Mean SO_2 t-3	.025	.919	-.818
	(.174)	(.499)	(.302)
$(\text{Mean } SO_2 \text{ t-1})^2$	----	-39.2	-76.6
	----	(10.6)	(24.7)
$(\text{Mean } SO_2 \text{ t-2})^2$	----	84.0	.36
	----	(42.9)	(19.13)
$(\text{Mean } SO_2 \text{ t-3})^2$	----	-72.9	97.2
	----	(37.9)	(24.5)
$(\text{Mean } SO_2 \text{ t-1})^3$	----	1078.4	2534.3
	----	(358.8)	(921.5)
$(\text{Mean } SO_2 \text{ t-2})^3$	----	-2532.2	-752.6
	----	(1011.8)	(514.6)
$(\text{Mean } SO_2 \text{ t-3})^3$	----	1939.9	-1935.2
	----	(827.7)	(454.5)
Maximum 1 Hour t-1	-.004	-.0020	.0168
	(.007)	(.0059)	(.0055)
Maximum 3 Hour t-1	.004	.0071	-.0279
	(.010)	(.0099)	(.0078)
Maximum 24 Hour t-1	-.021	.0008	.0535
	(.005)	(.0238)	(.0176)
$(\text{Maximum 1 Hour t-1})^2$	----	.0053	-.0186
	----	(.0054)	(.0072)
$(\text{Maximum 3 Hour t-1})^2$	----	-.0192	.0328
	----	(.0138)	(.0123)
$(\text{Maximum 24 Hour t-1})^2$	----	.1012	-.1949
	----	(.1073)	(.0665)
CO Nonattainment t-1	.0005	-.0001	.0005
	(.0011)	(.0005)	(.0003)
TSPs Nonattainment t-1	-.0001	-.0002	.00001
	(.0012)	(.0005)	(.00035)
Ozone Nonattainment t-1	-.0045	.0006	.0000041
	(.0020)	(.0004)	(.0003164)
Per Capita Income	.00000078	.000000052	.000000018
	(.00000053)	(.000000077)	(.000000052)
Mean Hourly Wage	.0000000086	-.00000013	-.00000010
	(.0000003900)	(.00000010)	(.00000006)
Total Employment	.0000057	.00000080	.00000205
	(.0000099)	(.00000076)	(.00000083)
Total Population	-.0000000032	-.00000000051	-.00000000122
	(.0000000050)	(.00000000039)	(.00000000045)

Notes: The entries are the parameter estimates and heteroskedastic-consistent standard errors for the covariates from the column (4) specifications in Tables III A, IV A, and V A, respectively. See the Notes to these Tables.

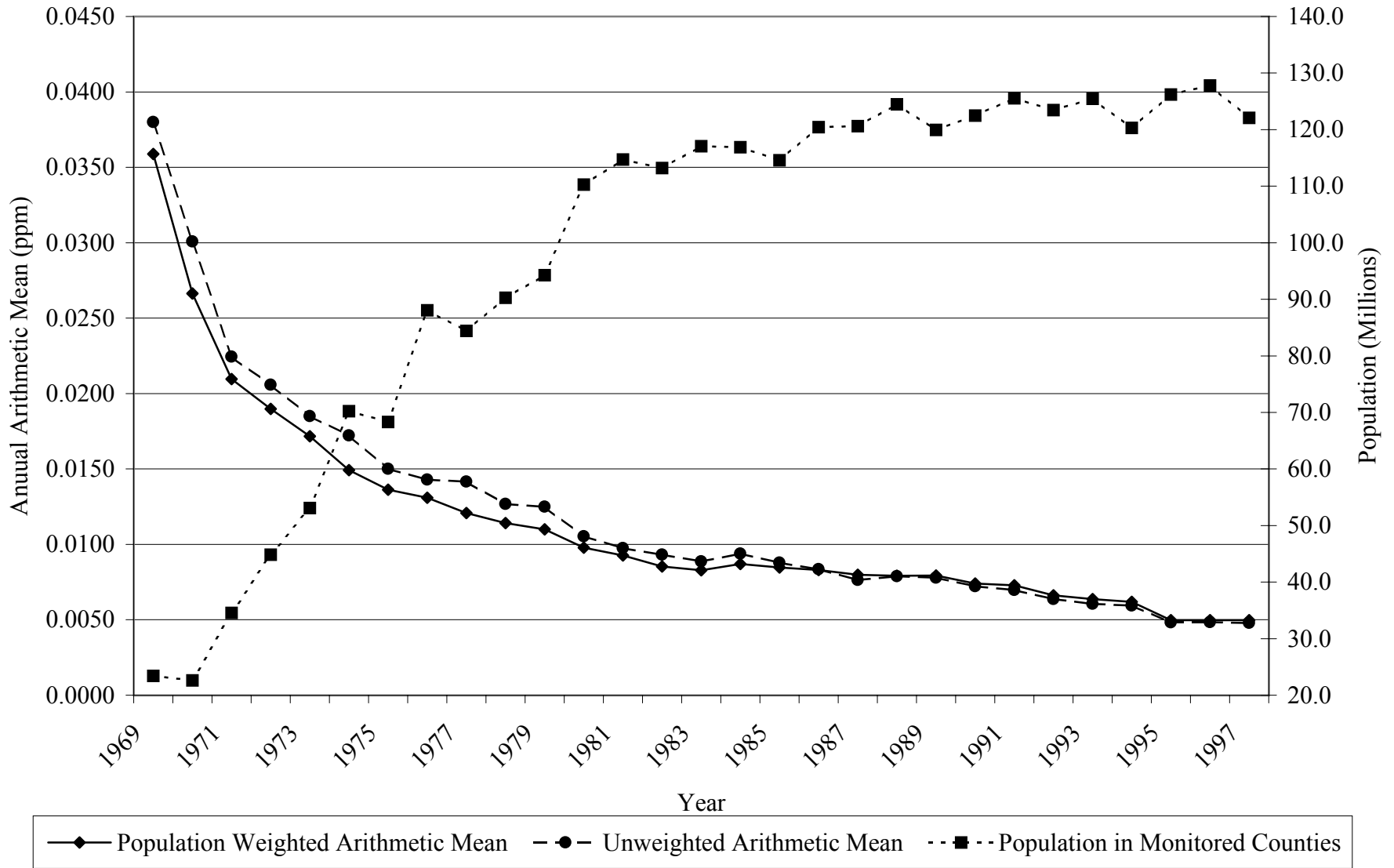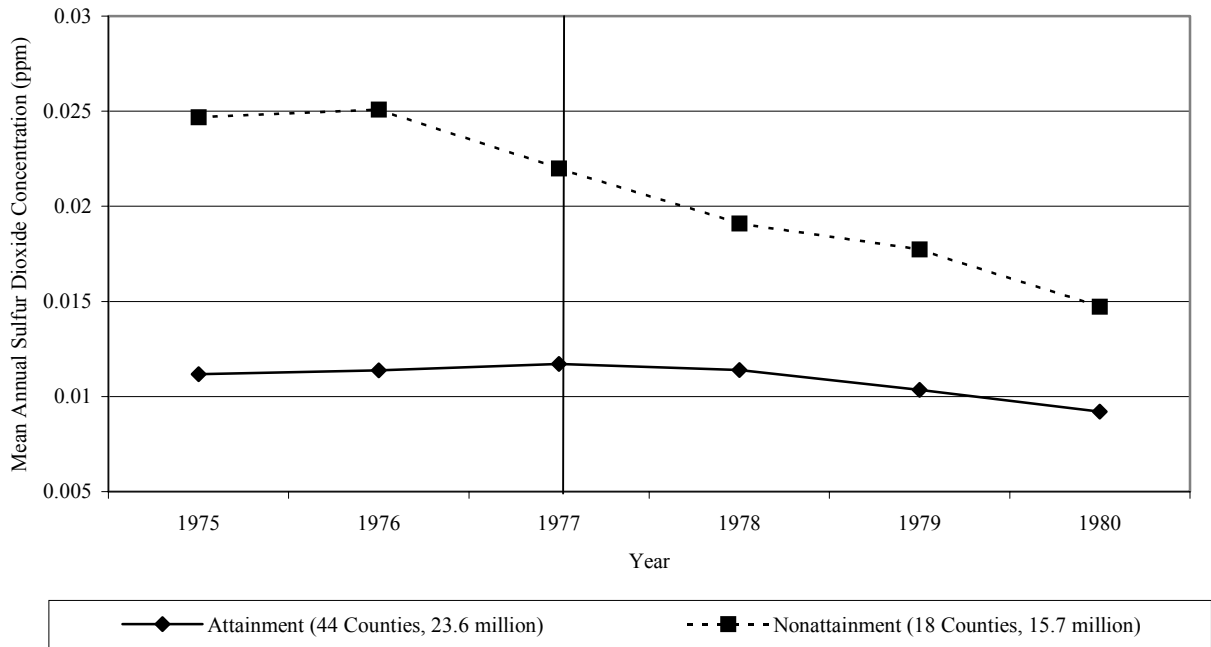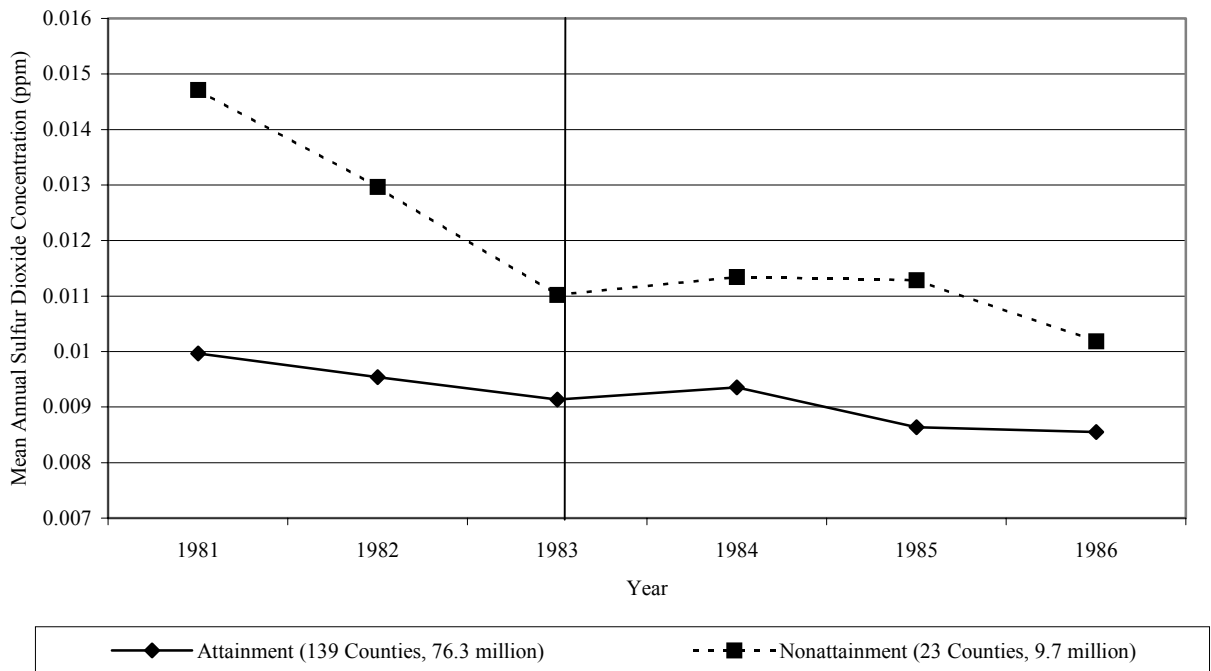Figure 1: Trends in Sulfur Dioxide Concetrations, 1969-1997

Figure 2: Trends in Annual Mean Sulfur Dioxide Concentrations (ppm), by Regulatory Status

A. 1978 Nonattainment Status

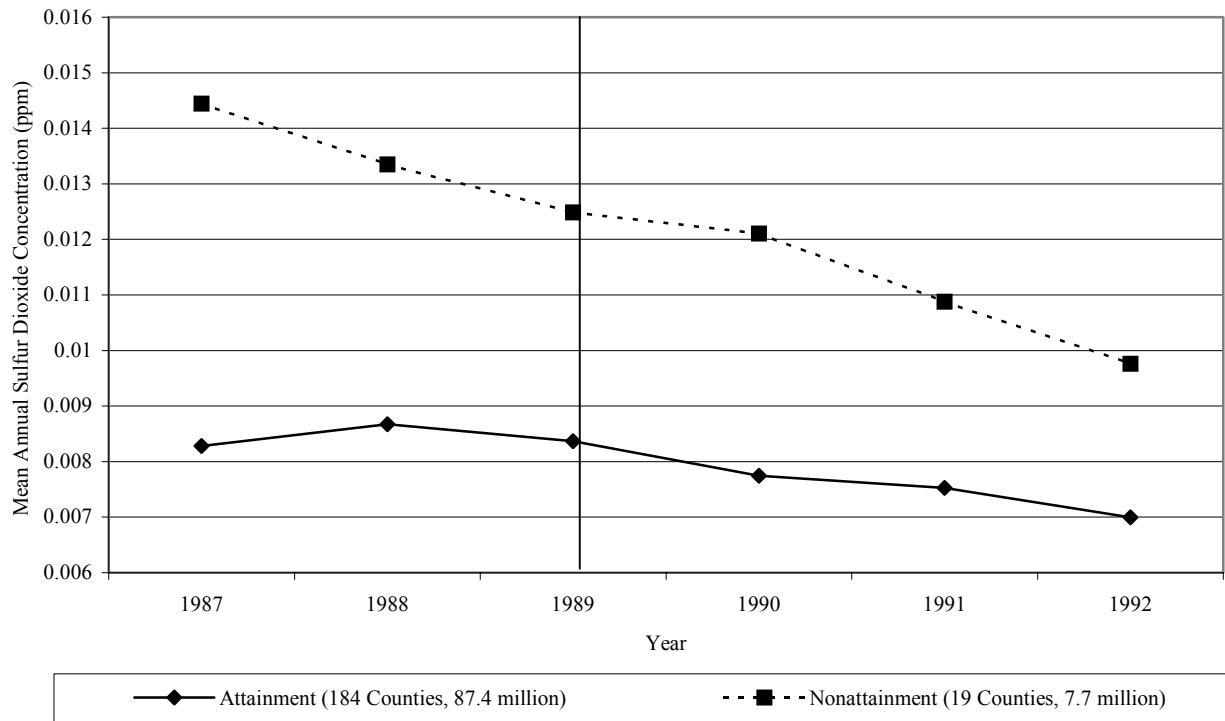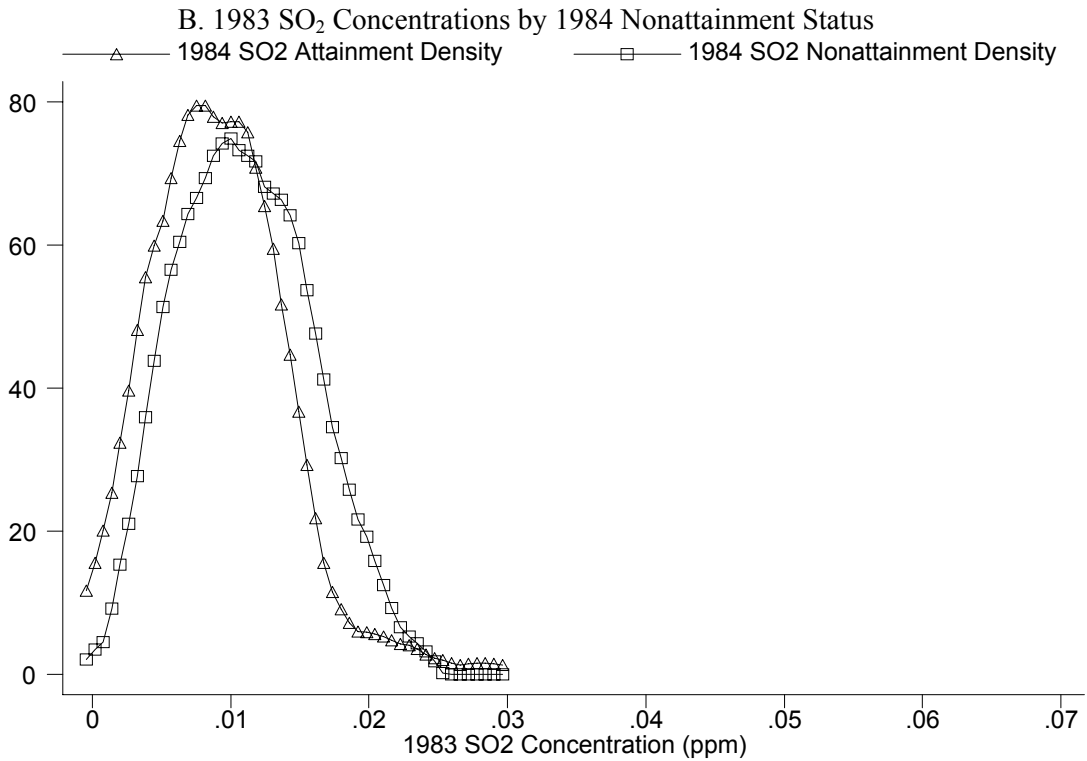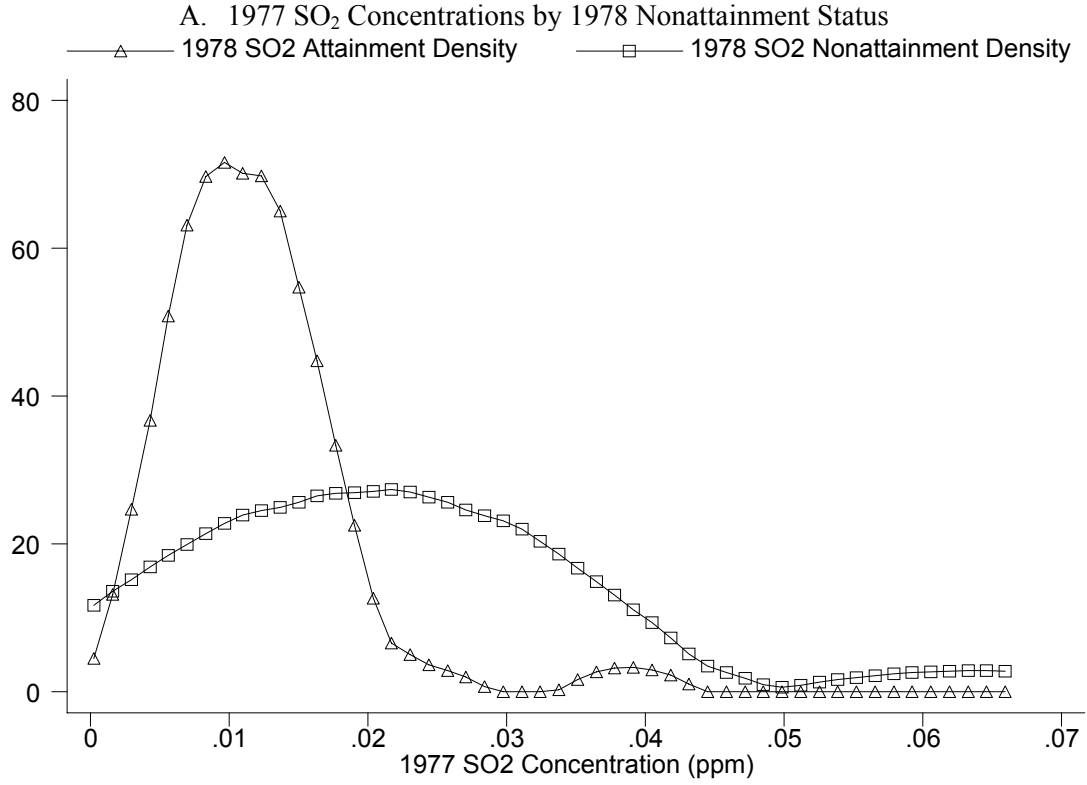B. 1984 Nonattainment Status

C. 1990 Nonattainment Status

Chart showing Mean Annual Sulfur Dioxide Concentration (ppm) vs Year (1987–1992), with two series: Attainment (184 Counties, 87.4 million) and Nonattainment (19 Counties, 7.7 million).

Figure 3: Kernel Density Plots of the Distribution of SO_2 Concentrations
in the Regulation Selection Years

A. 1977 SO_2 Concentrations by 1978 Nonattainment Status

B. 1983 SO_2 Concentrations by 1984 Nonattainment Status
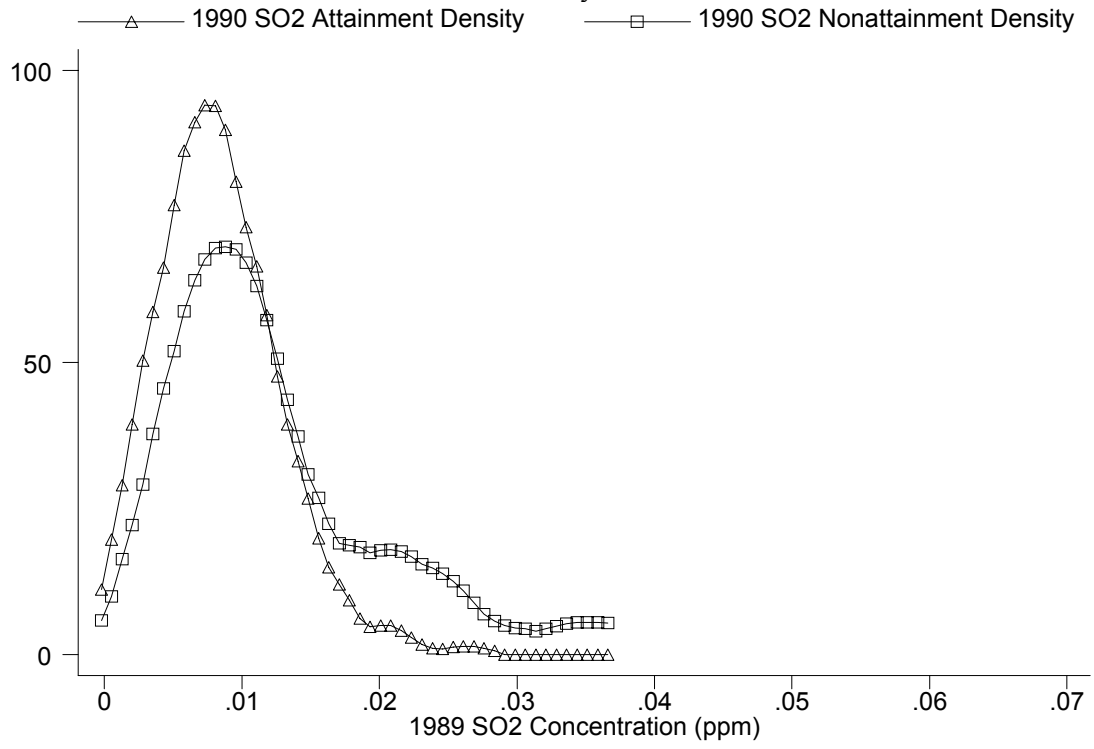
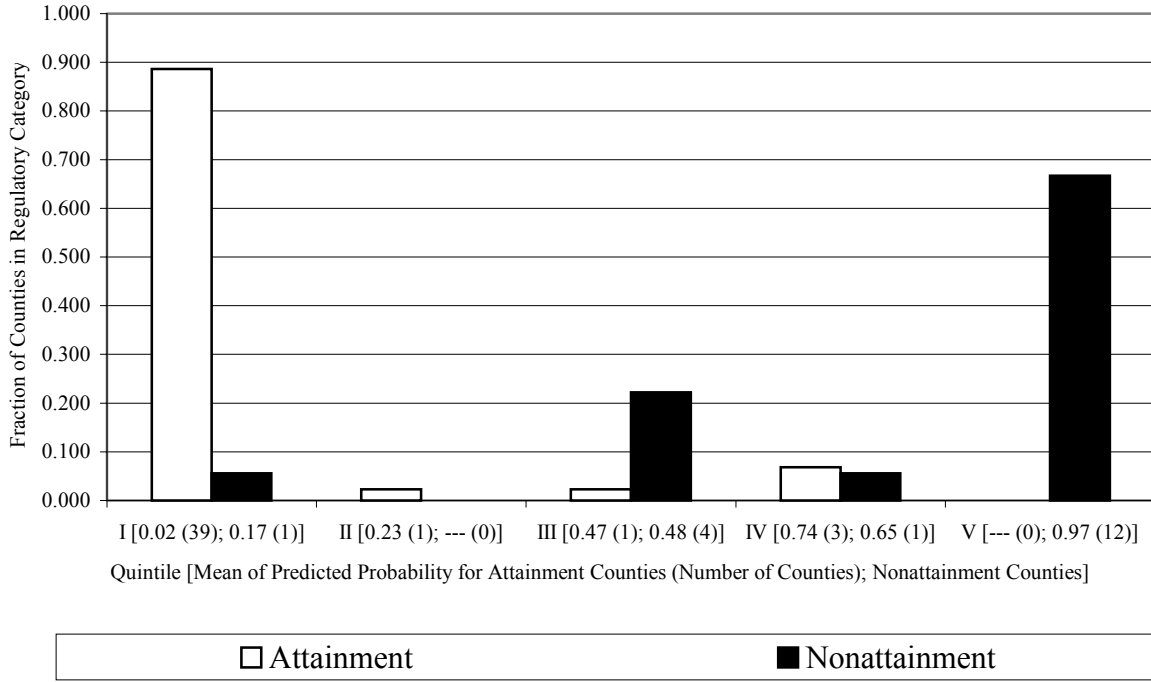C. 1989 SO₂ Concentrations by 1990 Nonattainment Status
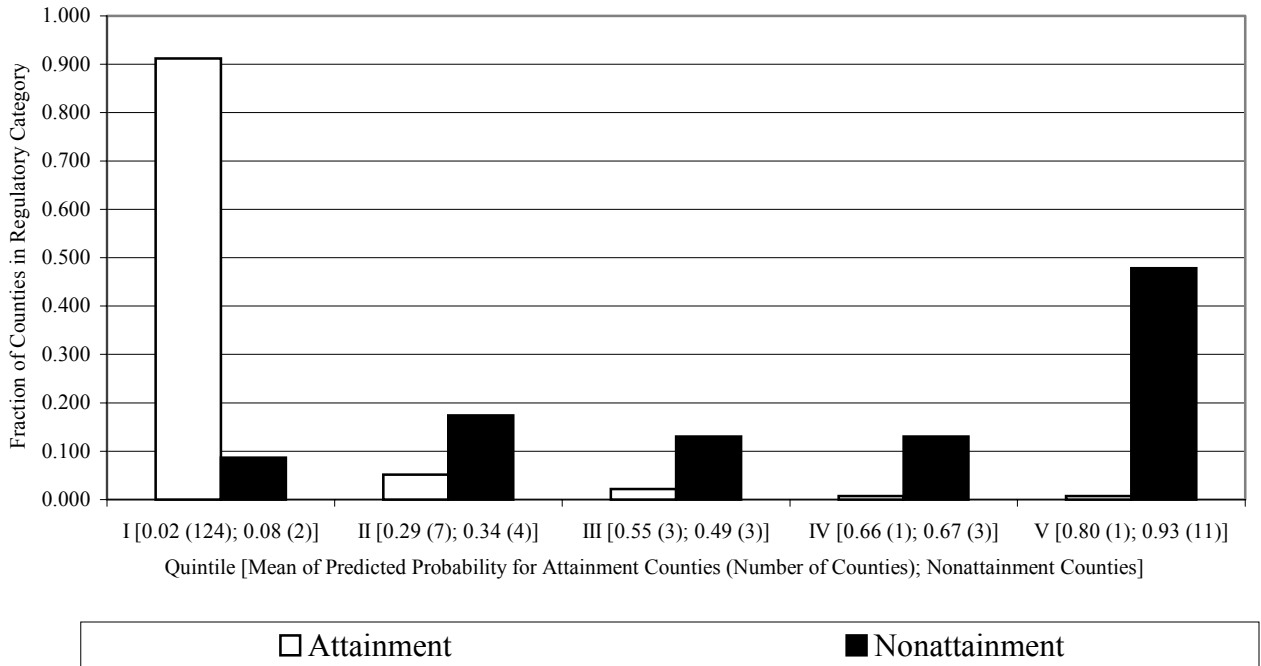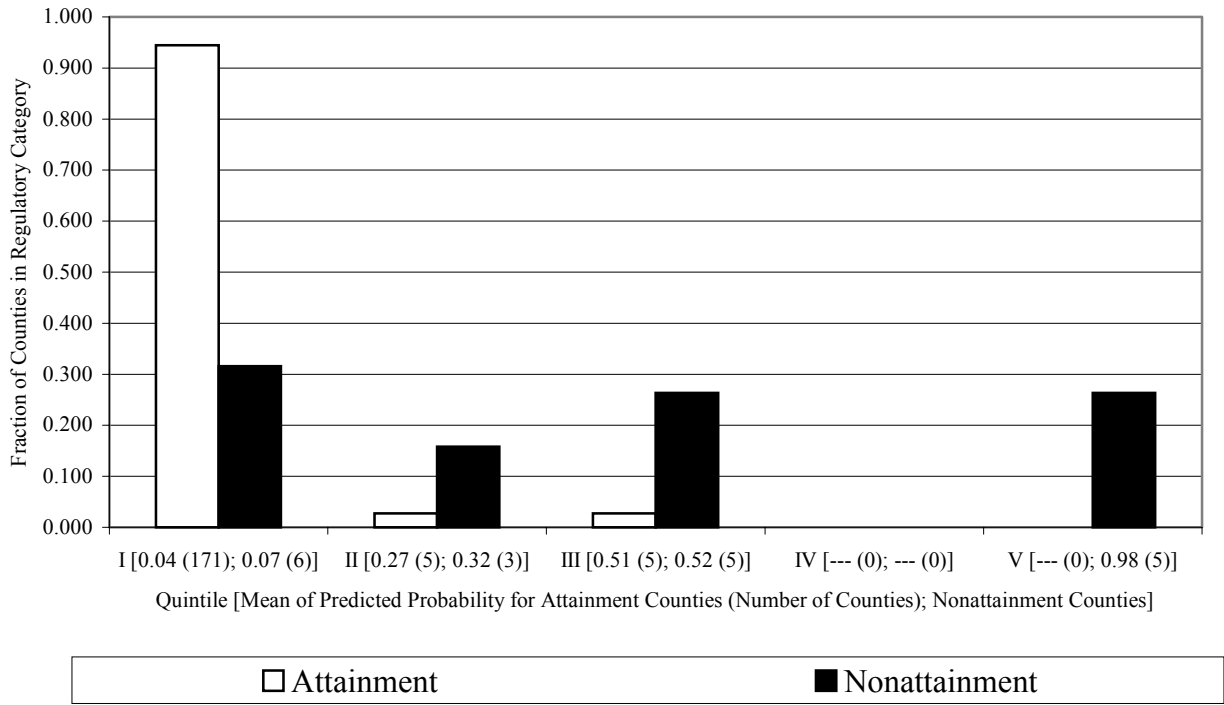
Figure 4: Distribution of Predicted Probability of SO$_2$ Nonattainment Status,
by Observed SO$_2$ Nonattainment Status
A. 1978 Nonattainment Status

B. 1984 Nonattainment Status

C. 1990 Nonattainment Status

Notes: The predicted probabilities are based on logit specification 2. See the text for more details.