NBER WORKING PAPER SERIES

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Maureen L. Cropper
Mengjia Hu
Yongjoon Park
Nicholas Z. Muller

Working Paper 33412
http://www.nber.org/papers/w33412

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
January 2025

We thank Resources for the Future for supporting this research through the Retrospective Analysis of Environmental Regulation project. We also thank the following people for helpful comments: Eric Battistin, David Evans, Art Fraas, Koichiro Ito, Ethan Kaplan, Guido Kuersteiner, Dick Morgenstern, Carl Pasurka. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 33412
January 2025
JEL No. Q52, Q53, Q58

ABSTRACT

A large literature uses nonattainment status under the U.S. Clean Air Act (CAA) to measure regulatory stringency and to instrument for air pollution in studies of the impact of the CAA on health and other endpoints. Since 1978 U.S. Environmental Protection Agency (EPA) has regulated ambient air quality at the county level; however, prior to 1978 nonattainment status was imposed on Air Quality Control Regions, contiguous counties that comprise an airshed. This is not the definition of nonattainment used in the literature. Using county-level data, we examine the impacts of EPA's definition of nonattainment status for TSP, CO, ozone, and SO2 in 1972 on ambient air quality and manufacturing employment between 1969 and 1976 and EPA's definition of nonattainment in 1978 on air quality and manufacturing employment between 1975 and 1988. Nonattainment status in 1972 had no significant impact on either ambient TSP or on the ratio of dirty manufacturing to total employment between 1969 and 1976. We do, however, find significant impacts on ambient TSP using 1978 nonattainment status, and significant impacts of TSP, CO, ozone and SO2 nonattainment in 1978 on the fraction of employment in dirty manufacturing industries from 1975 to 1988. We discuss the implications of these findings for EPA's decision regarding the geographic level at which to regulate air pollution.

Maureen L. Cropper
University of Maryland
Department of Economics
College Park, MD 20742
and Resources for the Future
and also NBER
mcropper@umd.edu

Mengjia Hu
University of Maryland
mhu12680@umd.edu

Yongjoon Park
Department of Resource Economics
University of Massachusetts Amherst
80 Campus Center Way
Amherst, MA 01003
yongjoonpark@umass.edu

Nicholas Z. Muller
Department of Engineering, and Public Policy
Tepper School of Business
Carnegie Mellon University
4215 Tepper Quad
5000 Forbes Avenue
Pittsburgh, PA 15213
and NBER
nicholas.muller74@gmail.com

1 Introduction

A common role of government in modern, developed economies is the management of environmental externalities. Environmental externalities vary in scope from globally mixed pollutants like greenhouse gases to highly localized pollutants like heavy metals in water bodies and particulate matter in the ambient air. These differences in physical dispersion and environmental fate and transport raise important questions regarding appropriate regulatory jurisdiction and policy resolution.

Questions pertaining to jurisdiction often hinge on transboundary pollution flows. One approach is to design policy such that compliance decisions reflect the full extent of pollution dispersion. Thus, if emissions from an industry influence environmental conditions within a state or province, compliance designations are accordingly made at the state or provincial level. An alternative policy design focuses on local effects, whereby compliance decisions are made at smaller spatial scales. The obvious benefit of the former approach is capturing the full extent of impacts of emissions. However, the larger the compliance region, the more limited is the regulator's ability connect impacts to specific factories, industries, or economic sectors. In contrast, while the localized strategy may omit or overlook impacts from long-range dispersion, its clear advantage is the ability to link environmental outcomes to particular polluters. A priori, both approaches have strengths and weaknesses.

This paper explores these policy design issues in the context of the United States Clean Air Act (CAA). Since 1978 the U.S. Environmental Protection Agency (EPA) has regulated ambient air quality at the county level. Counties (or portions of counties) are either in attainment or out of attainment with the National Ambient Air Quality Standards (NAAQS) which are maximum allowable concentrations of ambient air pollution. Reflecting the federalist structure of much regulation in the U.S., the NAAQS are set by the EPA and implemented by states and municipal governments. Penalties for NAAQS violations may be imposed on counties out of attainment with the NAAQS. EPA's use of counties as the geographic unit for designating compliance began, however, only in 1978.

Under the 1970 CAA, prior to the 1977 amendments, NAAQS compliance decisions were not made at the county level. Rather, EPA levied compliance decisions for Air Quality Control Regions (AQCRs). The AQCRs were groups of contiguous counties intended to reflect airsheds. While there are over 3,100 counties in the U.S., there were 247 AQCRs, and 313 AQCR-state pairs, with each AQCR that crossed a state boundary divided into a separate AQCR-state pair. Attainment with the NAAQS was determined at the AQCR level. Thus, all counties within the same AQCR-state pair were declared in nonattainment even if only one county violated the NAAQS. Beginning in 1978, after the passage of the 1977 amendments to the CAA, nonattainment status with the NAAQS was assigned at the county level.

EPA's use of AQCRs to set nonattainment status prior to 1978 has important consequences for the economics literature. There is a large literature that uses nonattainment status under the Clean Air Act to measure regulatory stringency (Becker and Henderson 2000; Greenstone (2002, 2004); Henderson 1996; List et al. 2003) and to instrument for air pollution—specifically Total Suspended Particulates (TSP)—in studies of the impact of air pollution on health and housing values (Chay et al. 2003; Chay and Greenstone 2005; Isen et al.

2017). Greenstone (2002) examines the impact of nonattainment status on employment in manufacturing plants between 1967 and 1987 and finds that nonattainment counties lost 592,000 jobs relative to attainment counties between 1972 and 1987. Chay and Greenstone (2005) find that TSP declined by 10 $\mu g/m^3$ in nonattainment relative to attainment counties between 1970 and 1980. To measure nonattainment status prior to 1978 these studies use air pollution monitor readings rather than nonattainment status as designated by the USEPA. An important question is whether these results would change using nonattainment status as designated by the EPA. Put somewhat differently, do key results about the impact of nonattainment status on ambient TSP and on manufacturing employment continue to hold when the official designation of nonattainment status is used?

We examine these questions in this paper using quasi-experimental econometric methods. First, we focus on the period from 1969 to 1976 when compliance determinations were made at the AQCR level. Specifically, we ask whether TSP fell faster in counties declared out of attainment with TSP than in attainment counties. Further, we test whether being out of attainment for any of four criteria pollutants which are subject to the NAAQS (TSP, Carbon Monoxide (CO), Ozone (O3) and Sulfur dioxide (SO2)) caused employment in pollution-intensive manufacturing industries to fall in nonattainment relative to attainment counties. Over the period when EPA used AQCR designations, we do not find evidence of differential outcomes in attainment versus nonattainment counties. Specifically, using EPA's definition of nonattainment by AQCR, we find no evidence that TSP fell faster in nonattainment than in attainment counties between 1969 and 1976, when the parallel trends assumption holds. Neither do we find a statistically significant impact of nonattainment for any of the four criteria pollutants on the ratio of pollution-intensive manufacturing employment to total employment.

We repeat these empirical tests for the period 1975 to 1988 using EPA's county-based nonattainment designations, which were assigned by EPA in 1978. Our results are very different in this context. Counties out of attainment with TSP in 1978 reduced their ambient TSP levels by 6-7 $\mu g/m^3$ more than attainment counties over the period 1975-88. When considering the impact of nonattainment for each of four criteria pollutants (TSP, CO, O3 and SO2) on the fraction of employment in pollution-intensive industries from 1975 to 1988, we find a significant reduction in the fraction of employment in these dirty industries of 0.9% in counties out of attainment with only TSP and a 1.1% reduction in the fraction of employment in dirty industries in counties out of attainment with TSP and at least one other pollutant.

We believe that these findings shed light on an important policy decision at EPA—to move from regulating air quality at the AQCR level to the county level. The intuitive appeal of AQCRs is that they mimic airsheds—areas where emissions from multiple sources mix to determine ambient air quality. Although useful from the perspective of dispersion and atmospheric chemistry, AQCRs pose problems from a regulatory perspective. Faced with newly established constraints on ambient pollution, regulators targeted abatement in the most polluted counties within the AQCRs. The resulting air quality improvements were concentrated in these counties, as our results below show.

We note an additional limitation to airshed-based regulations. Provisions of the 1977 amendments to the CAA would have been very costly to enact had the AQCR designations been retained beyond 1978. This is illustrated in Figure 1a, which shows that two-thirds (or 2069) of all counties in the coterminous U.S. were declared out of attainment for TSP in 1972, based on AQCR designation. Under the 1977 amendments, new firms that were major sources entering counties out of attainment with the NAAQS faced higher compliance costs than new sources in compliant counties. Specifically, new facilities in nonattainment areas were required to install lowest achievable emissions rate (LAER) technology and to offset their emissions by buying rights to emit pollution from existing sources (Shapiro and Walker 2024). Since the focus of these provisions lay clearly on pollution hot spots, it would not have made sense to apply them to nonattainment areas as defined by AQCRs.

Our Approach. We investigate the impact of nonattainment status on ambient particulate matter and manufacturing employment by assembling data on TSP monitor readings from 1969 through 1988 and data on manufacturing employment at the county level over the same period from County Business Patterns data (Eckert et al. 2020; Eckert et al. 2022). We construct county-level estimates of annual average TSP using a balanced panel of monitors in 309 counties from 1969-76 and a balanced panel of monitors in 402 counties from 1975-88. We use these to estimate difference-in-differences models and event studies to gauge the impact of nonattainment status on ambient TSP.

To analyze the impact of nonattainment status on manufacturing we examine the impact of being out of attainment for each of four criteria pollutants (TSP, CO, O3 and SO2) on the ratio of dirty manufacturing employment to total employment. We estimate the impact of 1972 nonattainment on employment over the 1969-76 period and 1978 nonattainment on employment over the 1975-88 period. We do this using border pair analysis and also by estimating difference-in-differences models and event studies. Because a county can be out of attainment for more than one pollutant, we estimate models that control for nonattainment status for multiple pollutants.

Our Results. This paper makes three contributions to the literature. First, we examine the impact of EPA's official designation of nonattainment status in 1972 on ambient air quality and manufacturing employment. The existing literature used an imputed definition of nonattainment status prior to 1978 that reflects EPA's approach after 1978 by declaring a county out of attainment if its monitoring readings in the previous year exceeded the maximum ambient levels stated in the NAAQS (Greenstone 2002; Chay et al. 2003; Chay and Greenstone 2003; Isen et al. 2017). These studies are useful in examining the impact of nonattainment designations in particular "hot spots" (heavily polluted areas) on ambient air quality and manufacturing employment, but do not capture the impact of EPA's official designations.

Second, we demonstrate that EPA's official designation of nonattainment status did not have a significant impact on ambient TSP and manufacturing employment until after the 1977 CAAA when nonattainment status was declared by county, and more stringent regulations were imposed on manufacturing firms in nonattainment counties.[1] Interestingly, we find a negative impact on employment similar to Greenstone (2002)'s estimate for the 1972-87 period—a loss of approximately 500,000 jobs in nonattainment counties relative to attainment counties. However, we find that this loss occurred between 1978 and 1988. That the adverse effects on employment of the CAA were concentrated after 1978 agrees with our air quality analysis. We find that ambient annual average TSP levels in counties designated out of attainment with the TSP standard fell by 6-7 $\mu g/m^3$ more than in

[1] We note that the NAAQS themselves did not change between 1972 and 1978.

attainment counties over the 1975-88 period.

Finally, we believe that our findings have implications for the geographic resolution at which air pollution is regulated and the stringency with which it is regulated. While the management of pollution externalities according to the area over which concentrations are affected has a strong scientific basis, we note several concerns with this approach. First, regulators facing incentives to comply with ambient standards tend to target high pollution areas. The result of this, for the case of air pollution, was heterogeneity within the airshed both in terms of air quality changes and compliance costs. Second, this intra-airshed variation despite uniform compliance designations, may obscure empirical inferences about policy effectiveness. Finally, airshed-based compliance determinations limit the ability of regulations to nudge economic growth toward compliant geographies especially if, as was the case in the U.S. in the 1970s, most areas are noncompliant.

The remainder of this paper is structured as follows. Section 2 summarizes salient facts about EPA's regulation of air pollution under the 1970 CAA and the 1977 CAA amendments. Section 3 describes our data and econometric methods. In Section 4 we report the impact of nonattainment status on ambient TSP and manufacturing employment. Section 5 summarizes our results and concludes.

2 Regulation of Ambient Air Pollution Under the 1970 and 1977 Clean Air Acts

The 1970 CAA required EPA to establish ambient air quality standards for common (or "criteria") air pollutants, and required states to draft state implementation plans (SIPs) to describe how they would come into compliance with these standards (USEPA 1973). In 1971 EPA issued National Ambient Air Quality Standards (NAAQS) for TSP, CO, nitrogen dioxide, SO2, and O3 (USEPA 1971). The Agency also defined 247 AQCRs, spanning the continental US, Alaska and Hawaii, the Virgin Islands and Guam (USEPA 1972b). Each AQCR was a group of contiguous counties located in the same airshed. There were 313 AQCR-state pairs, with each AQCR that crossed a state boundary divided into a separate AQCR-state pair.

In May of 1972 counties within each AQCR were determined to be in attainment or out of attainment with each of the criteria pollutants (USEPA 1972a). Attainment status was determined based on 1971 monitor readings; however, TSP monitors operated in only 765 counties in 1971. EPA also used air quality modeling to determine attainment status. All counties within the same AQCR-state pair were assigned the same attainment status. Figure 1a shows the boundaries of the AQCRs in the continental US and their attainment status for TSP in 1972. When AQCRs are mapped to counties, 2,069 counties were designated as TSP nonattainment counties and 1,044 as attainment counties.[2]

Nonattainment status for other pollutants in 1972 are shown in Table 1. (Maps showing nonattainment counties for these pollutants appear in Appendix Figures A1a–A3a). In 1972, 997 counties were declared out of attainment for SO2, 651 counties for O3 and 271 counties for CO. Many counties were out of attainment for

[2] We are happy to share the data describing AQCR status by county upon request.

multiple pollutants. While 2,069 counties were designated as out of attainment for TSP, 1,189 counties were out of attainment for TSP and at least one other pollutants. There were 932 counties in attainment with all four pollutants.

Beginning in 1978, assignment of attainment status was conducted at the county level. Figure 1b shows the 433 counties designated as nonattainment for TSP in 1978. (Maps showing nonattainment counties for other pollutants appear in Appendix Figures A1b–A3b.) The number of counties designated as out of attainment for TSP and SO2 fell sharply when NA status was assigned county by county—from 2,069 to 433 for TSP and from 997 to 93 for SO2 (see Table 1). The number of counties declared out of attainment also declined for CO though by a much smaller margin than for SO2 and TSP (from 271 to 167). Only in the case of ozone nonattainment did the number of counties increase, from 651 to 685. This demonstrates that for two key pollutants—TSP and SO2—the number of counties subject to the consequences of NA under the 1977 CAAA fell significantly.

In addition to changing the resolution of nonattainment designations, the 1977 CAAA strengthened air quality regulations in important ways that affected stationary sources in nonattainment counties. Major sources that entered or expanded operations in a nonattainment county were not allowed to increase emissions of nonattainment pollutants.[3] To avoid increases in emissions, proposed emissions increases had to be balanced by equivalent or greater reductions from existing sources. This was often achieved by purchasing offsets from existing sources (Shapiro and Walker 2024). Major sources were also required to achieve the Lowest Achievable Emissions Rate (LAER) for nonattainment pollutants. LAER is the most stringent emission limit included in the SIP of any state, or the most stringent emissions limit achieved in practice (USEPA nd).[4] As stated above, our empirical results indicate that nonattainment designations affected air quality and employment only after the 1977 amendments. Clearly, two aspects of the CAA changed that may have driven our findings: the stringency of the regulations governing new sources, as well as the use of counties rather than AQCRs as nonattainment units.

3 Data and Econometric Methods

This section describes our econometric approach to testing the impact of the CAA on ambient pollution levels and manufacturing employment. This section also discusses the data sources used and provides summary statistics. Sub-section (a) focuses on our ambient air quality analyses. Sub-section (b) centers on the manufacturing employment models and data.

3.1 The Impact of Nonattainment Status on Ambient TSP, 1969-1988

We examine the impact of nonattainment status on ambient TSP using two balanced panels of monitors, 606 monitors in 309 counties for 1969-76 to study the impact of 1972 NA status on ambient TSP and 763 monitors

[3] A major source was a facility estimated to produce more than a threshold number of tons per year (often 100 tons) of a pollutant for which the county was out of attainment.

[4] Minor sources were not required to purchase offsets or achieve the LAER. They were subject to less stringent Reasonable Available Control Technology (RACT) standards (USEPA nd).

in 402 counties for 1975-88 to study the impact of 1978 NA status. The need to use a balanced panel of monitors (i.e., requiring that the same monitors be in operation each year) is well established, given evidence that newly cited monitors often have lower pollution readings than existing monitors (Cropper et al. 2023; Grainger et al. 2019; Muller and Ruud 2018).[5]

We examine the impact of nonattainment status in 1972 using both EPA's official designation of nonattainment based on AQCR and the imputed definition of nonattainment used in the literature, which is based on monitor readings in 1971 (Greenstone 2020). In 1978 and thereafter, nonattainment status is based on EPA's official designation, by county. Descriptive statistics for these counties appear in Appendix Table A1. Figures A4a and A4b in the Appendix show the location of attainment and nonattainment counties in 1972 and 1978 based in EPA-designated attainment status.

To examine the impact of nonattainment on ambient TSP we estimate difference-in-differences and event study models for 1969-76 and 1975-88. In our difference-in-differences models, equation (1), $Post_t = 1$ for $year \geq 1972$ or $year \geq 1978$. Our difference-in-differences models for 1969-76 contain county and year fixed effects and state-by-year fixed effects. For the 1975-88 period, when nonattainment status is defined by county, we alternatively include AQCR-by-year fixed effects.

$$TSP_{ct} = \beta_1 Post_t \times NonAtt_c + \delta_c + \tau_t + \gamma_{st} + \epsilon_{ct}, \tag{1}$$

Table 2 shows the number of nonattainment and attainment counties for each sample based on EPA's official designation of nonattainment status and the imputed definition. We note that by EPA's designation, only 47 of 309 counties were in attainment. Using the definition in the literature, 182 counties were in attainment. The difference reflects the fact that all counties in the same AQCR-state-pair were labeled nonattainment even though some may not have violated the NAAQS. (Table A1 of the Appendix presents summary statistics for both groups of counties.)

Figure 2 shows the implications of the difference in the two definition. Using the AQCR definition of nonattainment, mean TSP in nonattainment counties in 1972 is 78.85 $\mu g/m^3$, barely above the annual average TSP standard of 75 $\mu g/m^3$. This is because many counties labeled nonattainment are not violating the NAAQS. In contrast, for nonattainment counties under the imputed definition, mean TSP in 1972 is 96.90 $\mu g/m^3$.

Another difference between the behavior of nonattainment counties under the AQCR and imputed definitions is that, using the AQCR definition, nonattainment and attainment counties do not obey parallel trends. This is not surprising. The 47 counties out of the 309 that EPA characterized as being in attainment are largely rural. Their average TSP levels prior to 1972 were flat and below 60 $\mu g/m^3$. In contrast, counties labeled nonattainment began to decrease their TSP levels prior to 1972.

[5] The fact that so few counties have the same monitor(s) in operation during this period reflects the size of the ambient monitoring network.

3.2 Impact of Nonattainment Status on Manufacturing Employment, 1969-1988

In a seminal article, Greenstone (2002) examined the impact of nonattainment status for four criteria pollutants (TSP, CO, O3 and SO2) on employment in dirty manufacturing industries from 1967 to 1987, using plant-level data from the Survey of Manufacturers.[6] Dirty manufacturing industries were defined, for each pollutant, to be industries that were major emitters of that pollutant. Greenstone estimated that 592,000 jobs were lost in nonattainment counties over the 1972-1987 period. The largest impacts were found in counties out of attainment with CO and ozone.

We examine the effect of nonattainment status on manufacturing employment using county-level employment data over the period 1969-1988 (Eckert et al. 2020; Eckert et al. 2022). Specifically, we examine the impact of nonattainment status for TSP, CO, O3 and SO2 on dirty manufacturing employment using two approaches: a border-pair analysis and a difference-in-differences approach. We define a manufacturing industry as "dirty" if it is classified by Greenstone (2002) as a major emitter of TSP, CO, VOCs or SO2.[7] Table A2 in the Appendix lists industries classified as major emitters of each pollutant, by six-digit NAICS category. Dirty manufacturing employment is defined as the union of employment in these industries.

When examining impacts on dirty manufacturing employment we normalize dirty manufacturing employment by total employment. The distribution of manufacturing employment across counties is skewed, but the use of a logarithmic transformation is not advisable (Chen and Roth 2024) in difference-in-differences analyses. We normalize by employment to assess the average treatment effects in proportional terms. This approach also facilitates causal inference as parallel trends are more likely to hold when the dependent variable is expressed in this manner, given differences in the levels of manufacturing employment between treatment and control counties.

This is followed by difference-in-differences models which measure the impact of each pollutant on the ratio of dirty manufacturing employment to total employment. In the difference-in-differences (DiD) analyses all counties in attainment for a given pollutant serve as the control group and all counties out of attainment for that pollutant as the treated group. This is followed by DiD models which control for the impact of multiple pollutants on manufacturing employment.

Border-Pair Models. Our border-pair analysis estimates the impact of nonattainment status for each pollutant on the ratio of dirty manufacturing employment to total employment by comparing nonattainment counties for a particular pollutant in 1972 to attainment counties sharing the same border, over the period 1969-76. A similar comparison is made over the period 1975-88. Figures 3a and 3a show border pair counties for TSP in 1972 and 1978. Figures A5–A7 of the Appendix present border-pair maps for CO, O3 and SO2.

The advantage of the border-pair analysis is that each nonattainment county is matched with an attainment

[6] Specifically, Greenstone examined the percentage change in plant employment, for each five-year period, as a function of dummy variables indicating whether a plant emitted each one of the four pollutants and whether it was located in a nonattainment county for that pollutant, where nonattainment was defined at the beginning of each period.

[7] We have also examined dirty employment separately for each pollutant (e.g., dirty-TSP employment, dirty-CO employment); however, many industries are major emitters of multiple pollutants (see Table A2), leading to double-counting of employment effects.

county with which it shares a border, thus controlling for unmeasured factors that may affect labor markets. Figure 3 shows border pair counties for TSP based on EPA's official nonattainment status in 1972 (Figure 3a) and in 1978 (Figure 3b). In our border-pair analysis we measure the impact of each pollutant individually on the ratio of dirty manufacturing employment to total employment.

EPA's definition of nonattainment in by AQCR has implications for the number of nonattainment counties that share borders with attainment counties in 1972. Many nonattainment counties are not adjacent to attainment counties, as a comparison of Figures 1a and 3a illustrates. Only 657 out of 2,069 counties out of attainment for TSP in 1972 share a border with an attainment county, giving us 1,308 unique border pairs. The situation is similar for O3 and SO2 nonattainment counties: only 380 out of 651 counties out of attainment for O3 and 435 out of 997 out of attainment for SO2 share a border with an attainment county.

The situation is different when attainment status is defined by county. In 1978, 90 percent or more of counties out of attainment with TSP, CO and SO2 have adjacent attainment counties—on average, each county in nonattainment has between 3 and 4 adjacent counties.[8]

Table 3 shows key employment statistics for TSP border pairs in both periods of our analysis, 1969-76 for 1972 nonattainment status and 1975-88 for 1978 nonattainment status. (Corresponding tables for CO, O3 and SO2 are Tables A3–A5 in the Appendix.) Nonattainment counties are, on average, larger in terms of population and these areas have larger labor markets. Further, nonattainment counties have more workers employed in dirty industries than attainment counties.

Our regression specification for the border-pair analysis is shown in (2):

$$y_{ct} = \beta_1 Post_t \times NonAtt_c + \delta_c + \tau_t + \gamma_{pt} + \epsilon_{ct}, \tag{2}$$

which is similar to the equation (1) but we restrict our sample to pairs of nonattainment and attainment counties that share the same border. The dependent variable is the ratio of dirty manufacturing employment to total employment (y_{ct}). Our border pair model contains county (δ_c) and year (τ_t) fixed effects and county pair-by-year fixed effects (γ_{pt}).

DiD Models Using All Nonattainment Counties. We next consider models that incorporate all nonattainment counties. In these analyses, counties in attainment for all four pollutants in a given year are in the control group. We begin with models that examine pollutants one at a time and then models which control for multiple pollutants. Since these samples contain far more counties than the border-pair analysis, we briefly discuss summary statistics here.

Table 3, panel (a) indicates that, according to the AQCR definition of TSP nonattainment in 1972, nonattainment counties are, on average, more populous and have larger labor markets than counties in attainment. This is true for total employment levels and for employment in dirty industries. Further, the ratio of employment in dirty industries to total employment is 50% larger in nonattainment counties.

[8] This is not, however, true for ozone. Counties out of attainment for ozone in 1978 are clustered in the Northeast and Middle Atlantic states, or in California. (See Figure A2 in the Appendix.)

In panel (b) of Table 3, which uses the 1978 county-level attainment designations, it is clear that nonattainment counties are also more populous and have larger labor markets than counties in attainment. Further, the difference between the attainment and nonattainment counties is more pronounced. This is intuitive since, under the county-level nonattainment designations, counties out of compliance with the NAAQS tend to be urban core counties; thus, more densely populated with larger labor supply.

Our regression specification for the one-pollutant-at-a-time models is shown in (3):

$$y_{ct} = \beta_1 Post_t \times NonAtt_c + \delta_c + \tau_t + \gamma_{st} + \epsilon_{ct}, \tag{3}$$

which is similar to the equation (2), but we use all nonattainment counties for this model.

We also estimate multipollutant DiD models, as shown in (4):

$$\begin{aligned} y_{ct} =& \beta_1 Post_t \times (\text{NonAtt for TSP Only})_c + \beta_2 Post_t \times (\text{NonAtt for Other Only})_c \\ &+ \beta_3 Post_t \times (\text{NonAtt for TSP and Other})_c + \delta_c + \tau_t + \gamma_{st} + \epsilon_{ct}. \end{aligned} \tag{4}$$

This model includes three treatments: (a) counties out of attainment only for TSP; (b) counties out of attainment only for another pollutant; (c) counties out of attainment for TSP and at least one other pollutant. Controls are counties in attainment for all pollutants. Figure 4a and Figure 4b, which show trends in dirty manufacturing employment for the 1969-76 and 1975-88 periods for each of the four groups, foreshadow our econometric results which are reported below in section 4. (Summary statistics describing each group of counties for each time period appear in Table A6 of the Appendix.)

Figure 4a suggests no sign of dirty manufacturing employment declining as a result of 1972 nonattainment status. There is a gradual decline in dirty manufacturing employment from 1969 to 1971 and then an increase in dirty manufacturing employment until 1974. After a slight decrease during the 1974 recession, dirty manufacturing employment continues to rise. In accord with Figure 4a, our subsequent econometric analysis finds no significant reduction in dirty manufacturing employment associated with 1972 nonattainment status.

The situation is quite different for the impact of 1978 nonattainment status on dirty manufacturing employment, as Figure 4b suggests. Dirty manufacturing employment is rising from 1975 through 1979 for all groups of counties. It begins to decline thereafter, rising only slightly at the end of the 1982 recession. In light of these patterns, it is not surprising that our econometric analyses find a negative impact of 1978 nonattainment status on dirty manufacturing employment for counties out of attainment with TSP only and counties out of attainment with TSP and another pollutant.

4 Empirical Results

This section of the paper covers three sets of analyses. First, we report the empirical results from the air quality analyses. Next, we discuss the border-pair models. And third, the DiD models that include all counties are covered.

Ambient Air Quality. Table 4 reports the results of the regression analyses that test whether attainment status affected ambient TSP levels. These models are fit to the data in Figures 2a and 2b. We find statistically significant evidence that counties in nonattainment for TSP exhibited a reduction in ambient TSP levels over the 1969-1976 period. The effect size varies in magnitude between 6 and 9 $\mu g/m^3$, depending on the definition of nonattainment status and the set of fixed effects included. Crucially, the parallel trends assumption fails to hold when using EPA's official, AQCR-based nonattainment status. Thus, we cannot interpret the effects in columns (1) and (2) as causal relationships. In contrast, the parallel trends assumption does hold when using the imputed definition of nonattainment status. We interpret these results as indicating that, in highly polluted counties, the 1970 CAA indeed induced a drop in emissions of TSP relative to counties that were truly in attainment, *and those within the AQCR that had observed pollution levels below the NAAQS*. We also interpret these results as an indication that abatement activities were targeted in highly polluted counties.

To examine the impact of nonattainment status in 1978 on ambient TSP levels we use a different group of counties. Included in this sample are the 402 counties that comprise a balanced panel of TSP monitors in operation every year between 1975 and 1988 (see Table 2); 56% of these counties were designated out of attainment with the 1978 TSP NAAQS. Trends in TSP for attainment and nonattainment counties in this group are shown in Figure 2c.

The fitted DiD models are reported in columns (6) through (8) of Table 4. The 1978 designation of nonattainment status reduced ambient TSP levels by 6 to 8 $\mu g/m^3$ relative to attainment counties for the 402 counties in our sample. Importantly, the parallel trends assumption holds in two of the three fitted models. Specifically, the assumption holds in the models that control for county, year and either state-by-year or AQCR-by-year fixed effects, shown in columns (7) and (8). The effect sizes reported in these models are quite similar, within 10% of each other. Without fixed effects that interact geography and year, we do not find evidence of a causal relationship between nonattainment status and TSP levels. Further, the effect size is somewhat larger in this specification (26% larger than in column (8)).

The fact that we do find causal evidence of a relationship between the official EPA nonattainment designation and subsequent TSP levels may reflect *either or both* the strengthening of emissions regulations under the 1977 Amendments to the CAA and the focus on counties as the unit of regulation. We cannot disentangle these two effects. We also note that the consequences of these differences in concentrations for exposures, which were caused by nonattainment designations under the CAA, were quite likely large as these 402 counties contained 54% of the US population in 1980.

As argued in Section 1, the use of AQCRs, or airshed-based nonattainment designations has a firm grounding in the natural sciences. However, our failure to identify a causal impact of the CAA in columns (1) and (2), together with the results in columns (3) through (5), provide evidence that, despite the spatially-extensive AQCR nonattainment designations, abatement activities were concentrated in counties that exhibited relatively high pollution levels. This conclusion is bolstered by the results in columns (6) through (8) which reflect outcomes after adoption of the county-based attainment designations.

Effects of Nonattainment on Employment. To test whether the CAA adversely affect employment in dirty manufacturing industries, we estimate DiD models and event studies. In these models, we specifically test whether nonattainment status affects the ratio of employment in dirty industries to total employment, by pollutant.

Border Pair Analysis. Table 5 presents the DiD models applied to the sample of border pair counties. All models include county and county-pair-by-year fixed effects. The p-values reported in the bottom row indicate the probability of a Type I error if the null hypothesis of parallel trends is rejected.

Columns (1) through (4) focus on the years during which nonattainment status for each of the four criteria pollutants was determined using the AQCR approach. The results indicate that counties in nonattainment in 1972 have a lower ratio of dirty to total employment over the period 1972-76 relative to counties in attainment. However, only the impact of nonattainment for CO is statistically significant. In the case of TSP, the assumption of parallel trends is rejected, whereas this assumption holds for O3, CO, and SO2. The situation is quite different for 1978 nonattainment status. In columns (5) through (8), the models for each of the four criteria pollutants show a statistically significant negative impact of nonattainment status on the ratio of dirty manufacturing employment to total employment. This effect is largest for SO2 (1.4%) and TSP (0.9%). Further, for SO2, TSP, and O3 the effect of nonattainment status on employment is causal, as the parallel trends assumption holds in each case. In contrast, though nonattainment status for CO also appears to adversely impact employment in dirty manufacturing industries, the parallel trends assumption does not hold. We emphasize that these coefficients must be interpreted with some caution. The models focusing on the impact of nonattainment status for each pollutant do not control for the attainment status for other pollutants. We note, however, that the coefficients in columns (5) through (8) imply large employment losses over the 1975-88 period: approximately 350,000 in 393 TSP nonattainment counties and 168,000 in 97 SO2 nonattainment counties (see Appendix Table A7).

We comment briefly here on the statistical significance of nonattainment status for CO in both time periods. Our explanation for this result, which stands in contrast to each of the other pollutants, is based on the composition of the AQCRs for CO. Recall from Table 1 that the change in attainment designations from AQCR to counties resulted in dramatic reductions in the number of nonattainment counties for TSP (80%) and SO2 (90%). In contrast, the number of CO nonattainment counties fell by only 40%. One reason this may have occurred is a more uniform distribution of ambient CO levels *within CO AQCRs*. Such a distribution would have implied that abatement activities were also more evenly distributed within the CO nonattainment AQCRs than for TSP and SO2. And, if that was the case, one would expect adverse employment effects in the nonattainment AQCRs, relative to attainment AQCRs. In contrast, since TSP reductions were concentrated in counties with particularly high ambient levels (see Table 4), the statistical tests fail to detect significant reductions in employment for the TSP AQCR models (see column 1 of Table 4).

The results in Table 5 support our central argument that the use of AQCRs as nonattainment designations did not align with implementation of activities to achieve NAAQS compliance. We argued this from the perspective of TSP levels above. Here, we note that consistent evidence that employment in pollution intensive industries contracted relative to total employment is found only when nonattainment designations moved to the county level of resolution. With abatement concentrated in high pollution areas, under the AQCR system, there aren't discernible employment effects from nonattainment since firms in many of the counties within nonattainment AQCRs were not required to conduct abatement.

Analysis of Employment Effects Using All Nonattainment Counties. Table 6 reports the results from the regression models that include all counties with monitoring data, not just matched border pairs. These models contain county and year fixed effects and either state-by-year or AQCR-by-year fixed effects. The results are similar to those in the border pair models, even though both the treatment and control groups differ. In the eight models presented for the 1969-76 period, no coefficient on nonattainment status post 1972 is statistically significant for any pollutant when parallel trends hold. Five of the models violate the parallel trends assumption. In sum, there is no evidence that AQCR-based nonattainment for any of the four pollutants affected dirty manufacturing employment in treatment relative to control counties.

In marked contrast, the analysis of county-based nonattainment status between 1975 and 1988 suggests that being out of attainment for TSP, O3, or SO2 in 1978 significantly reduced the ratio of dirty manufacturing to total employment. The magnitudes of the coefficients are similar to those in the border pair models. Results for CO are sensitive to our use of fixed effects; the CO coefficient is not statistically significant when AQCR-by-year fixed effects are included. All models satisfy the parallel trends assumption.

As in the border pair analysis, the magnitude of the employment effect of SO2 nonattainment employment is largest, followed by the effect of TSP nonattainment. However, when interpreting the total effect of nonattainment status for these two pollutants, it is critical to note that fewer counties are out of attainment for SO2 (98) than for TSP (433). Similarly, the employment effect of O3 nonattainment is smaller than the coefficient of TSP, yet more counties (685) were out of attainment for ozone in 1978 than for TSP. We return to the issue of tabulated total job loss due to the CAA below.

We emphasize a note of caution when interpreting the parameter estimates in Table 6 since these are estimated using models that account only for attainment status for one pollutant. For example, it is certainly possible that the impact of TSP nonattainment may capture the effects of being out of attainment with other pollutants, given that 313 of the 433 counties out of attainment with TSP in 1978 were also out of attainment with at least one other pollutant. To control for such effects, we estimate the models in Table 7 which specify three treatments: being out of attainment only for TSP; being out of attainment only for a pollutant other than TSP; being out of attainment for both TSP and at least one other pollutant. The control groups consist of counties designated by EPA as in attainment with the NAAQS for all pollutants.

Table 7 confirms our previous findings that 1972 nonattainment status did not reduce the ratio of dirty manufacturing to total employment.[9] Though column (1) displays a significant and negative coefficient for nonattainment only for TSP, the parallel trends assumption is not satisfied. In column (2), the coefficients for being out of attainment for TSP and at least one other pollutant and the coefficient for being out of attainment only for a non-TSP pollutant are both positive. However, these effects are not statistically significant. Thus, even

[9]The one exception to this, noted above, is the impact of 1972 nonattainment status for CO in the border pair model.

in the multi-pollutant models, there is no evidence of 1972 nonattainment reducing manufacturing employment among pollution intensive industries in nonattainment relative to attainment counties in this period.

In accord with our results in Tables 5 and 6, we do detect evidence of an adverse effect of nonattainment status on employment when using the county-based designations after 1978. Specifically, counties out of attainment in 1978 only for TSP, or for TSP and another pollutant, suffer a loss in employment relative to attainment counties. The coefficients for nonattainment only with pollutants other than TSP are not significant. As Table 7 shows, the estimated coefficients are not sensitive to whether we include state-year or AQCR-year fixed effects. Recall that our results in Tables 5 and 6 suggest nonattainment status for each pollutant exerted adverse effects on employment. However, when we simultaneously control for attainment status across all pollutants, it appears that TSP is the primary driver of job loss. We next use the parameter estimates from Table 7 to make a series of provisional calculations of total manufacturing job loss from the CAA during the 1978-88 period.

The coefficients in columns (3) and (4) on being out of attainment only for TSP and being out of attainment for TSP and another pollutant imply a loss in employment of approximately 525,000 jobs in the 433 counties out of attainment with TSP in 1978. These are average annual losses over the period 1978-88.[10] These total job loss estimates, although estimated using very different data than Greenstone (2002), are quite similar to Greenstone's estimated job losses of 592,000 over the period 1972-1987. There are, however, two important differences. We find no causal effects of EPA designated nonattainment status in 1972 in reducing manufacturing employment, and our major effects associated with 1978 nonattainment status are associated with TSP nonattainment, rather than Greenstone's finding that it was nonattainment with CO or O3 that drove job loss.

In the model with AQCR-by-year fixed effects (column (4)) being out of attainment only with a pollutant other than TSP has a negative impact on dirty manufacturing employment, implying an annual average loss of 71,000 jobs in the 420 counties out of attainment only with another pollutant over the period 1978-88, but the effect is not statistically significant.

5 Conclusion

In developed economies such as the U.S., a common role of government is the management of environmental externalities. The geographic scope of environmental externalities ranges from globally mixed pollutants like greenhouse gases to pollutants with localized impacts such as water pollutants and airborne particulate matter. These differences in physical dispersion and transport raise thorny questions regarding the appropriate geographic resolution of policy. One approach is to design policy such that compliance decisions reflect the full extent of pollution dispersion. An alternative policy design focuses on local effects, whereby compliance decisions are made at smaller spatial scales. The present paper concentrates on the importance of the geographic resolution of compliance determinations.

To explore these issues, we examine the U.S. CAA over the period from the late 1960s to the late 1980s. The

[10]The estimate is 526,646 with the 95% confidence interval of (328,908, 722,530) based on column (3) of Table 7 and 524,749 with the 95% confidence interval of (280,863, 814,917) based on column (4).

CAA represents one of the most significant market interventions by the U.S. government in the post-World War II era (Greenstone 2004). Further, this period featured a substantive change, made in the 1977 amendments, to the geographic resolution at which the CAA was implemented. Prior to 1977, compliance with the ambient air quality standards established by the CAA was determined for AQCRs, or multi-county airsheds. After 1977, compliance designations were made on a county-by-county basis.

Our results clearly demonstrate that geographic design of environmental policies has significant implications for both environmental outcomes and the impact on regulated industries. Under the AQCR regime we find no evidence of differential air quality improvements or adverse employment effects for pollution intensive industries in non-compliant AQCRs. In contrast, when compliance is determined by county, we report clear evidence of differential air quality improvements and job losses in nonattainment counties.

Based on these results, we believe that EPA determined that the AQCR, or airshed, was not an appropriate geographic resolution at which to regulate. We arrive at this conclusion for two reasons. First, our results suggest that regulatory pressure and resulting abatement activities were focused on the most polluted areas within the AQCRs, despite the fact that all counties within a state-AQCR pair were ascribed the same compliance designation. While it may have been rational for regulators to mitigate pollution in the most polluted areas, this approach resulted in a disconnect or misalignment between nonattainment designations and where abatement occurred.

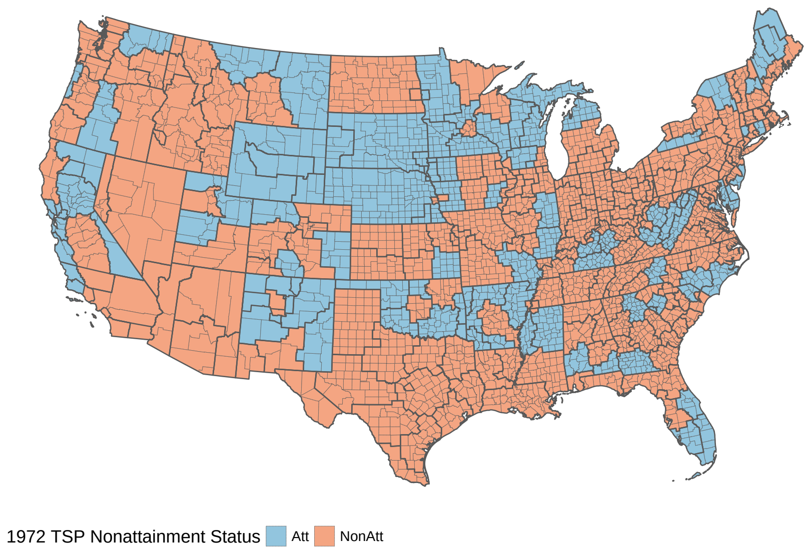
Econometrically, the implication of the AQCR designation is that the treatment group (the nonattainment AQCRs) in fact contained numerous counties that did not violate the NAAQS. Accordingly, our models either fail to detect significant post-treatment differences in pollution and employment or the assumption of parallel pre-trends is violated because of the compositional complications posed by the AQCRs. The net effect is to obscure the treatment effect of the CAA.

A second reason that we believe EPA determined the AQCRs were not a suitable geographic scale at which to levy compliance decisions relates to the management of new sources of pollution. New emitters (facilities) were deterred from entering nonattainment areas by requirements to install state-of-the-art pollution control equipment and to purchase emission offsets from existing sources. Further, because large swaths of the country were out of attainment with the NAAQS based on AQCR designations, these limits on firm entry would have curtailed growth. The transition to county-based attainment decisions reduced the number of nonattainment counties (see Table 1). This change in effect aligned efforts to mitigate pollution in nonattainment areas while not affecting growth in counties with pollution levels under the NAAQS.

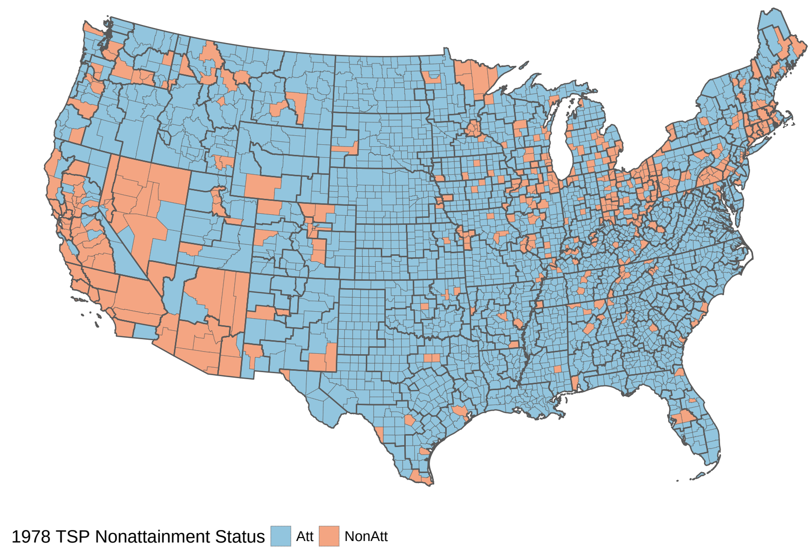
Our work has relevance to environmental policy design where questions about geographic scope and resolution are at issue. Designs that manage pollution according to flows in the natural environment have a strong and intuitive basis in the natural sciences. However, when regulations feature ambient standards, policymakers (and polluters) face incentives to prioritize abatement in highly polluted areas. If pollution is not well-mixed within the airshed or the watershed, coarsely defined compliance designations risk mischaracterizing geographic areas according to attainment or nonattainment status. The result, as our work shows, is to obscure policy effectiveness and to inefficiently manage society's joint goals of a clean environment and economic growth.

Figures and Tables

Figures



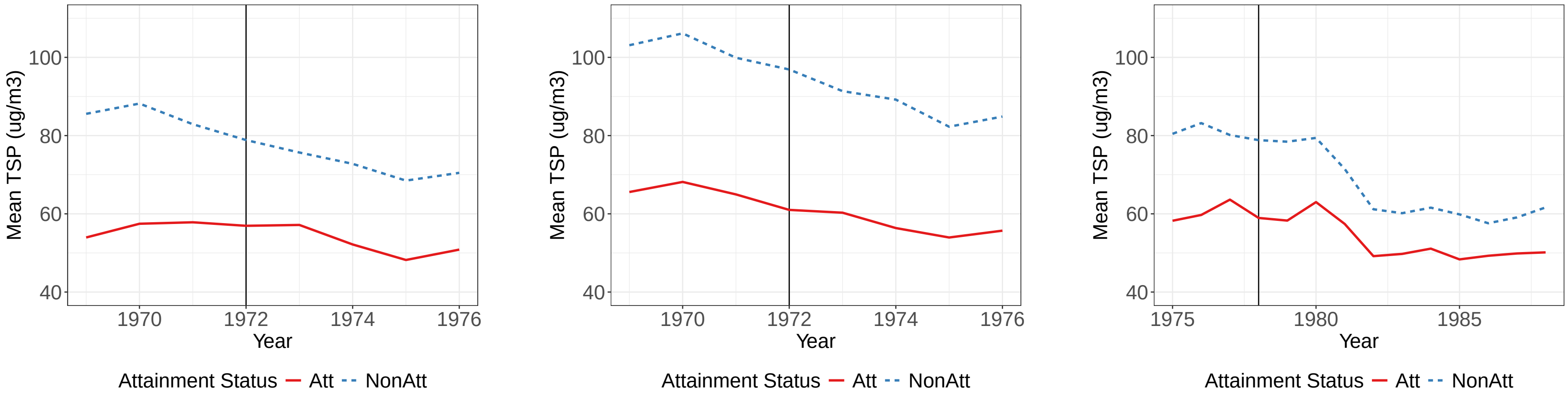
(a) EPA's Designation in 1972 by AQCR



(b) EPA's Designation in 1978 by County

Figure 1: Nonattainment Status for TSP in the Contiguous United States, 1972 and 1978

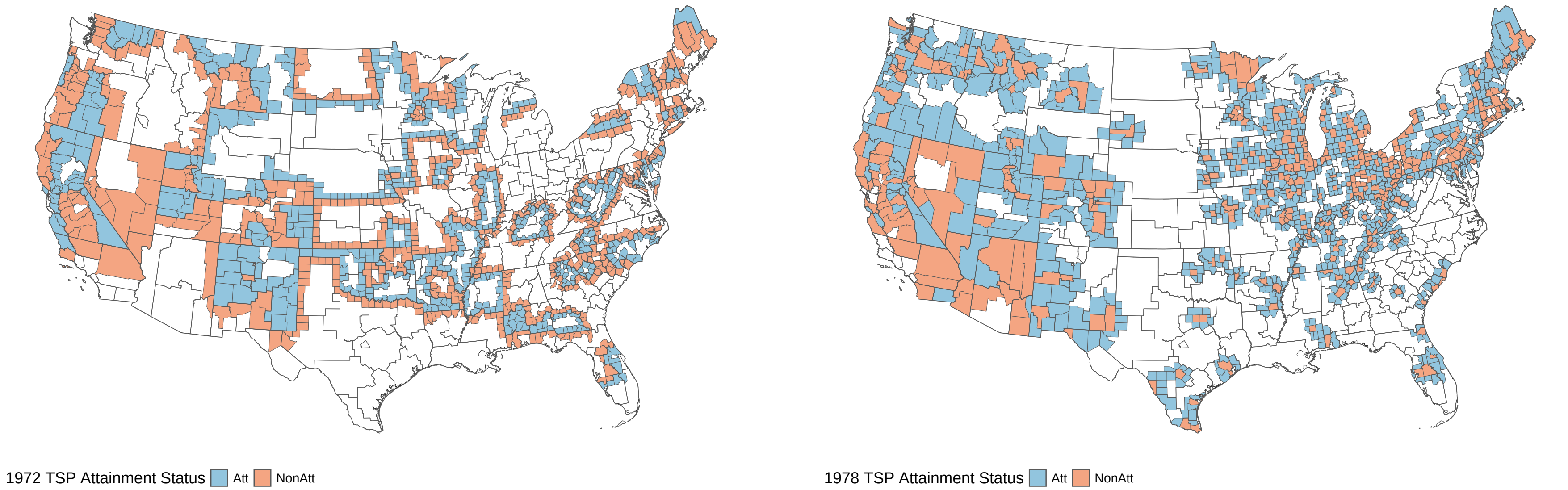
Note: This map shows the nonattainment status of counties only in the contiguous United States.



(a) EPA's Designation in 1972 by AQCR (b) Imputed Designation in 1972 by County (c) EPA's Designation in 1978 by County

Figure 2: Average TSP Levels by Attainment Status

Note: Panel (a) displays the average TSP levels for counties out of attainment and in attainment with the 1972 TSP NAAQS. Panel (b) presents the averages for counties based on the imputed nonattainment definition used in the literature, which relies on monitor readings from 1971. Panel (c) shows the averages for counties under the 1978 TSP NAAQS. The number of counties included in these averages is provided in Table 2.

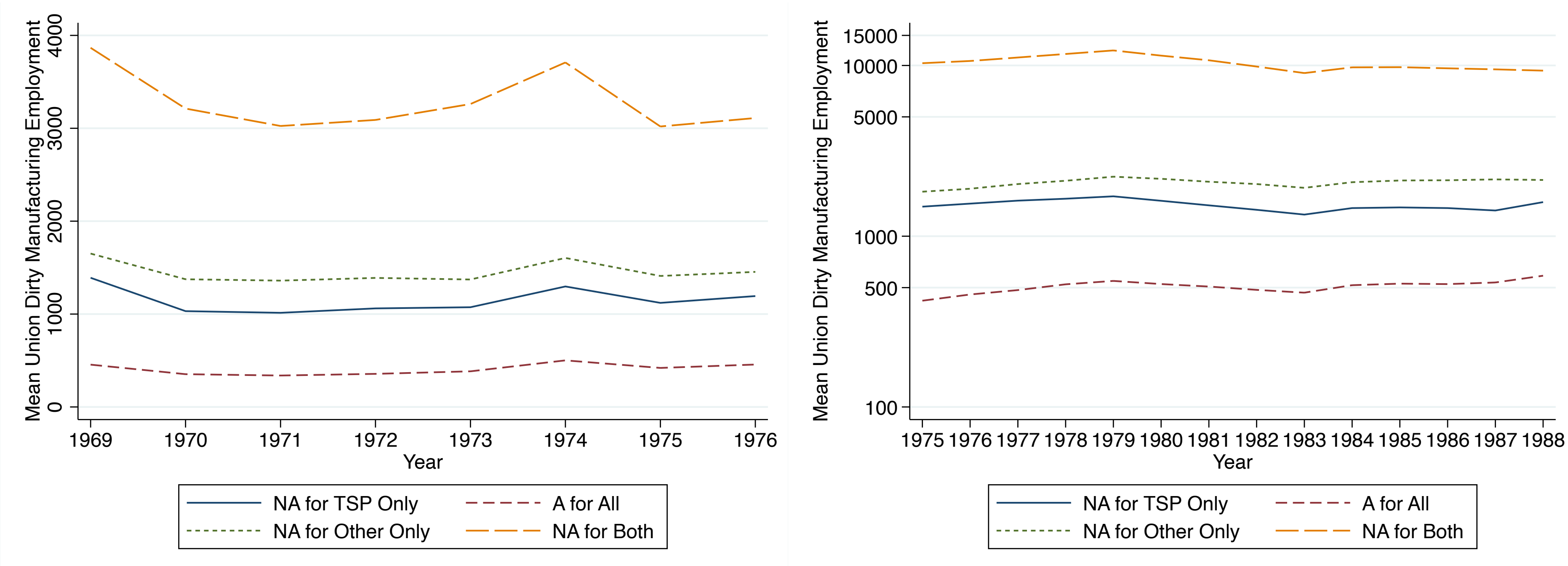


(a) EPA's Designation in 1972 by AQCR

(b) EPA's Designation in 1978 by County

Figure 3: Nonattainment Status for TSP in Counties Included in Border-Pair Analysis, 1972 and 1978

Note: This map shows the nonattainment status of counties only in the contiguous United States.



(a) EPA's Designation in 1972 by AQCR

(b) EPA's Designation in 1978 by County

Figure 4: Dirty Manufacturing Employment Trends by Attainment Status

Note: This figure shows the level of dirty manufacturing employment during 1969-1976 and 1975-1988.

Tables

Table 1: Number of Counties Designated Out of Attainment in 1972 and 1978

Detailed Attainment Statistics		
Pollutant	Out of Attainment in 1972	Out of Attainment in 1978
TSP	2069	433
CO	271	167
Ozone	651	685
SO_2	997	98
Aggregated Attainment Breakdown for TSP and Other Pollutants		
	Year	
Category	1972	1978
Out of attainment only for TSP	880	120
Out of attainment only for another pollutant	112	420
Out of attainment for TSP and at least one other pollutant	1189	313
In attainment for all four pollutants	932	2259

Table 2: Number of Counties with Balanced Monitors by TSP Attainment Status

	TSP Nonattainment Status Based on		
	EPA's Designation in 1972 by AQCR	Imputed Designation in 1972 by County	EPA's Designation in 1978 by County
Attainment	47	184	180
Nonattainment	262	125	222
Total	309	309	402

Table 3: Summary Statistics of Counties Used in Our Analysis, by TSP Nonattainment Status

(a) Year 1969-1976 (EPA's Designation in 1972 by AQCR)

	Counties Used in DiD Analysis				Counties Used in Border Pairs			
	Nonattainment (N = 2064)		Attainment (N = 929)		Nonattainment (N = 657)		Attainment (N = 580)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Population (1,000s)	85.63	277.12	26.54	61.53	65.56	139.27	34.07	80.99
Employment (1,000s)	24.76	105.45	5.41	11.59	17.17	45.68	7.28	21.82
Dirty Manufacturing Employment (1,000s)	2.38	10.30	0.41	0.89	1.51	4.26	0.60	1.88
Ratio of Dirty to Total Employment	0.09	0.11	0.06	0.09	0.09	0.11	0.07	0.09

(b) Year 1975-1988 (EPA's Designation in 1978 by County)

	Counties Used in DiD Analysis				Counties Used in Border Pairs			
	Nonattainment (N = 433)		Attainment (N = 2258)		Nonattainment (N = 393)		Attainment (N = 950)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Population (1,000s)	290.84	573.31	25.78	34.87	251.24	417.98	50.60	100.24
Employment (1,000s)	106.99	246.91	6.15	11.96	92.09	194.92	13.46	35.10
Dirty Manufacturing Employment (1,000s)	7.92	16.47	0.51	0.94	6.90	12.27	1.03	2.06
Ratio of Dirty to Total Employment	0.10	0.08	0.08	0.08	0.10	0.08	0.09	0.09

[a] Attainment group in the DiD analysis consists of the counties that are in attainment for all four pollutants.
[b] Population information is missing for some counties. Specifically, in the upper table, 35, 18, 4, and 3 counties were excluded for each of the four columns, respectively. In the lower table, 12, 0, 0, and 6 counties were excluded.
[c] The statistics are calculated for the years 1969–1976 in the upper table, and for the years 1975–1988 in the lower table.

Table 4: Impact of Nonattainment on Ambient TSP (1969-1988)

	(Balanced Monitor) Mean TSP							
	EPA's Designation in 1972 by AQCR		Imputed Designation in 1972 by County			EPA's Designation in 1978 by County		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(Year ≥ 1972) × (NonAtt)	-8.946***	-6.272**	-5.358***	-6.259***	-5.674**			
	(1.638)	(2.572)	(1.897)	(2.022)	(2.441)			
(Year ≥ 1978) × (NonAtt)						-7.660***	-6.792***	-6.133***
						(1.211)	(1.296)	(1.660)
R^2	0.807	0.853	0.807	0.853	0.926	0.766	0.839	0.915
Observations	2,472	2,472	2,472	2,472	2,472	5,628	5,628	5,628
AQCR x Year FE					✓			✓
State x Year FE		✓		✓			✓	
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
County FE	✓	✓	✓	✓	✓	✓	✓	✓
Pre-trend p-val	0.000	0.031	0.524	0.545	0.263	0.011	0.371	0.863

[a] * $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$.
[b] Standard errors are clustered at the county level.
[c] "Pre-trend p-val" refers to the p-value for the null hypothesis that TSP-levels for treatment and control groups are the same in years prior to the designation. These years are 1969–1970 for columns (1)–(5) and 1975–1976 for columns (6)–(8).

Table 5: Border-Pair Analysis Results

	y = Dirty Manufacturing to Total Employment							
	EPA's Designation in 1972 by AQCR				EPA's Designation in 1978 by County			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pollutants	TSP	CO	Ozone	SO2	TSP	CO	Ozone	SO2
(Year $\geq$ 1972) $\times$ (NonAtt)	-0.004	-0.007**	-0.004	0.000				
	(0.002)	(0.003)	(0.003)	(0.003)				
(Year $\geq$ 1978) $\times$ (NonAtt)					-0.009***	-0.008***	-0.004**	-0.014***
					(0.002)	(0.002)	(0.002)	(0.004)
R^2	0.905	0.909	0.907	0.915	0.951	0.959	0.947	0.940
Observations	20,876	8,093	14,469	15,254	42,775	17,051	31,144	13,104
N. of Border Pairs?	1,308	509	908	957	1,535	613	1,118	468
CountyPair X Year FE	✓	✓	✓	✓	✓	✓	✓	✓
County FE	✓	✓	✓	✓	✓	✓	✓	✓
Pre-trend p-val	0.006	0.379	0.256	0.382	0.172	0.089	0.352	0.307

[a] * $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$.
[b] Standard errors are clustered at the county level.
[c] "Pre-trend p-val" refers to the p-value for the null hypothesis that TSP-levels for treatment and control groups are the same in years prior to the designation. These years are 1969–1970 for columns (1)–(4) and 1975–1976 for columns (5)–(8).

Table 6: Impact of Nonattainment on Dirty Manufacturing Employment Ratio (1969-1988)

	TSP		CO		Ozone		SO_2	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: 1972 AQCR Regime								
(NonAtt)× (Year ≥ 1972)	-0.006**	0.014	-0.005	-0.007	-0.007**	-0.014	-0.002	0.012
	(0.002)	(0.013)	(0.005)	(0.015)	(0.003)	(0.013)	(0.003)	(0.015)
Observations	23913	23864	9566	9517	12581	12500	15373	15348
R-sq	0.817	0.833	0.813	0.826	0.816	0.829	0.812	0.827
Pre-trend P-values	0.0028	0.7068	0.9867	0.0000	0.0883	0.1010	0.0966	0.6550
Panel B: 1978 County Regime								
	TSP		CO		Ozone		SO_2	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(NonAtt) × (Year ≥ 1978)	-0.010***	-0.009***	-0.006**	-0.003	-0.005***	-0.005**	-0.016***	-0.019**
	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.002)	(0.006)	(0.008)
Observations	37612	37416	33880	33586	41149	41023	32942	32788
R-sq	0.880	0.887	0.872	0.881	0.877	0.885	0.874	0.882
Pre-trend P-values	0.1485	0.3102	0.9800	0.7581	0.5177	0.4799	0.3683	0.3305
County FEs	✓	✓	✓	✓	✓	✓	✓	✓
Year FEs	✓	✓	✓	✓	✓	✓	✓	✓
State × Year FEs	✓		✓		✓		✓	
AQCR × Year FEs		✓		✓		✓		✓

[a] Note: * $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$.
[b] Standard errors are clustered at the county level.
[c] "Pre-trend p-val" refers to the p-value for the null hypothesis that TSP-levels for treatment and control groups are the same in years prior to the designation. These years are 1969–1970 for columns (1)–(4) and 1975–1976 for columns (5)–(8).

Table 7: Impact of Nonattainment on Dirty Manufacturing Employment Ratio (1969-1988)

	1972 AQCR Regime		1978 County Regime	
	(1)	(2)	(3)	(4)
(NonAtt for TSP Only) × (Year ≥ 1972)	-0.007**	-0.000		
	(0.003)	(0.016)		
(NonAtt for Other Only) × (Year ≥ 1972)	0.005	0.035		
	(0.005)	(0.023)		
(NonAtt for TSP and Other) × (Year ≥ 1972)	-0.003	0.022		
	(0.003)	(0.013)		
(NonAtt for TSP Only) × (Year ≥ 1978)			-0.010***	-0.009**
			(0.003)	(0.004)
(NonAtt for Other Only) × (Year ≥ 1978)			-0.004	-0.005
			(0.003)	(0.003)
(NonAtt for TSP and Other) × (Year ≥ 1978)			-0.011***	-0.011***
			(0.002)	(0.003)
Observations	24809	24752	43495	43383
R-squared	0.817	0.832	0.880	0.886
Pre-trend P-values				
(NonAtt for TSP Only) vs. (Att for All)	0.0255	0.8419	0.1910	0.2549
(NonAtt for Other Only) vs. (Att for All)	0.5921	0.0000	0.5762	0.3231
(NonAtt for TSP and Other) vs. (Att for All)	0.0235	0.5366	0.5723	0.7401
County FEs	✓	✓	✓	✓
Year FEs	✓	✓	✓	✓
State × Year FEs	✓		✓	
AQCR × Year FEs		✓		✓

[a] Note: * $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$.
[b] Standard errors are clustered at the county level.
[c] "Pre-trend p-val" refers to the p-value for the null hypothesis that TSP-levels for treatment and control groups are the same in years prior to the designation. These years are 1969–1970 for columns (1)–(2) and 1975–1976 for columns (3)–(4).

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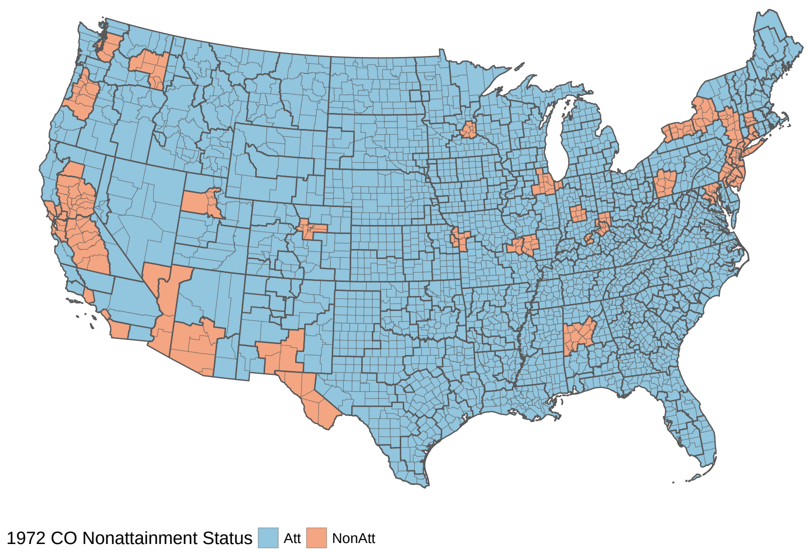
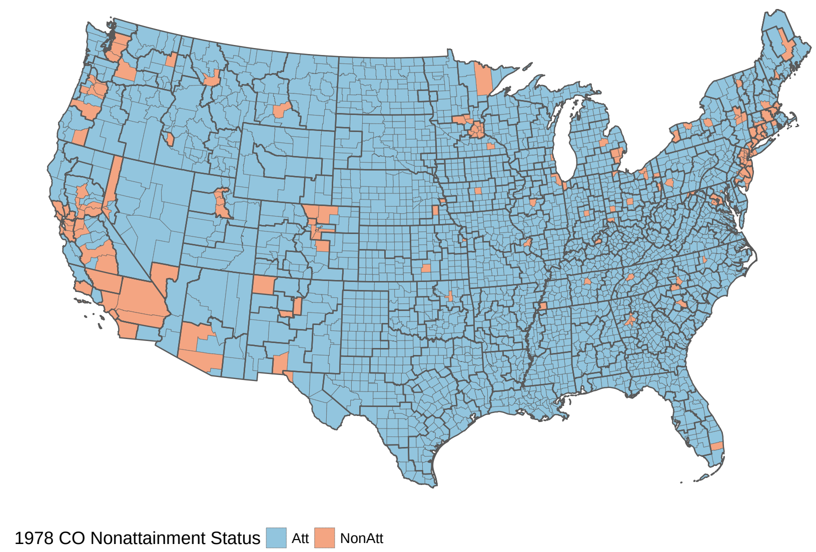
Appendices



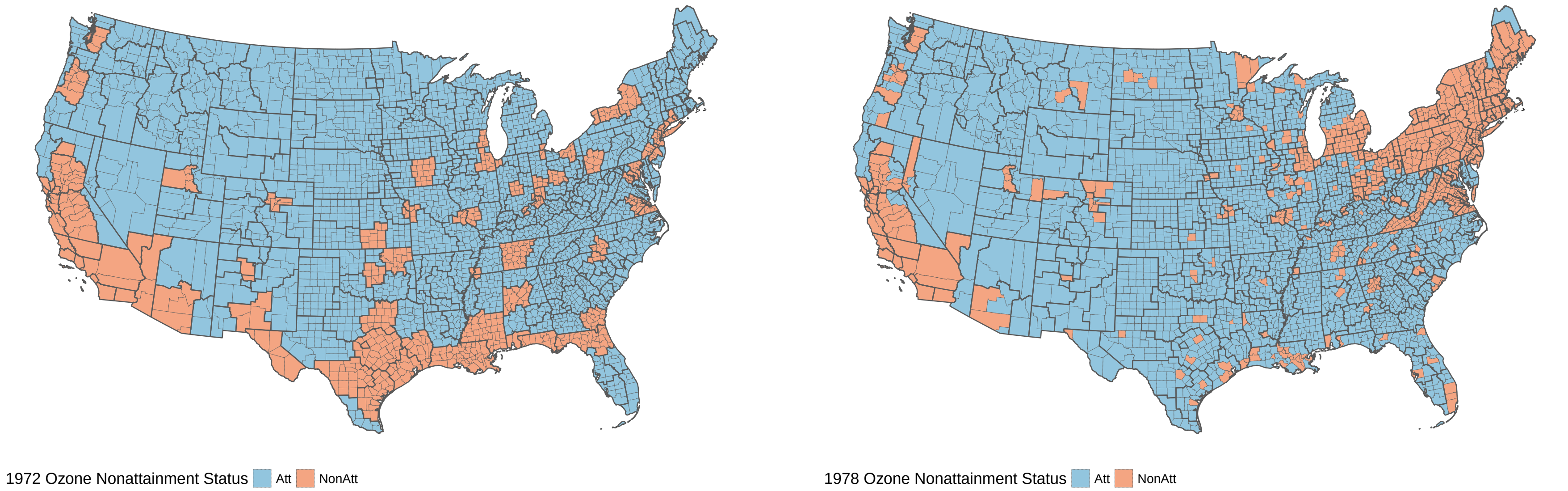
(a) EPA's Designation in 1972 by AQCR



(b) EPA's Designation in 1978 by County

Figure A1: Nonattainment Status for CO in the Contiguous United States, 1972 and 1978

Note: This map shows the nonattainment status of counties only in the contiguous United States.

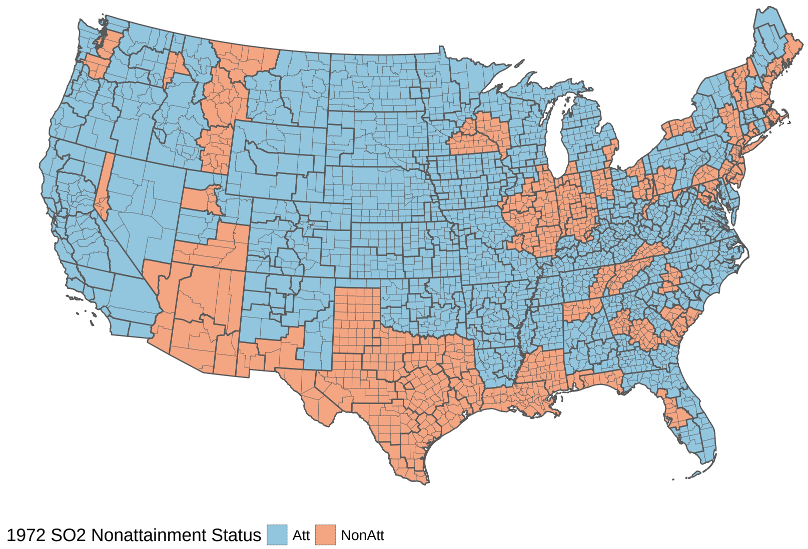


(a) EPA's Designation in 1972 by AQCR

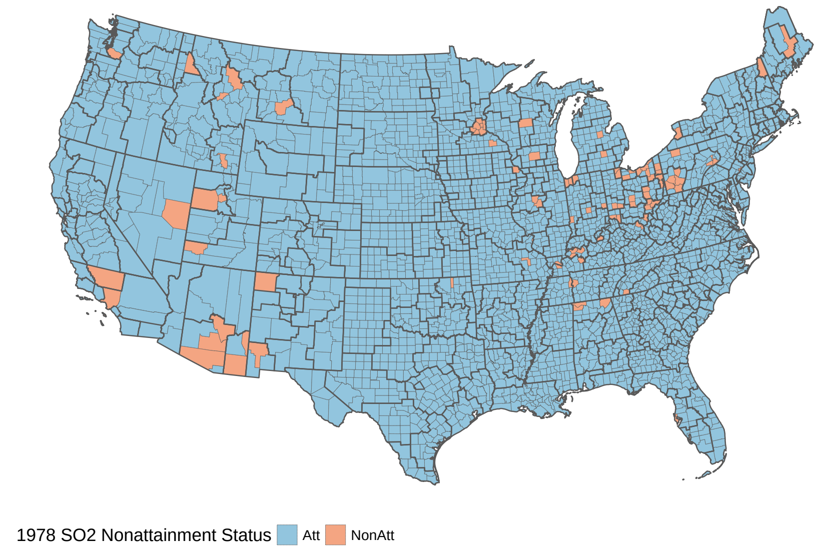
(b) EPA's Designation in 1978 by County

Figure A2: Nonattainment Status for Ozone in the Contiguous United States, 1972 and 1978

Note: This map shows the nonattainment status of counties only in the contiguous United States.



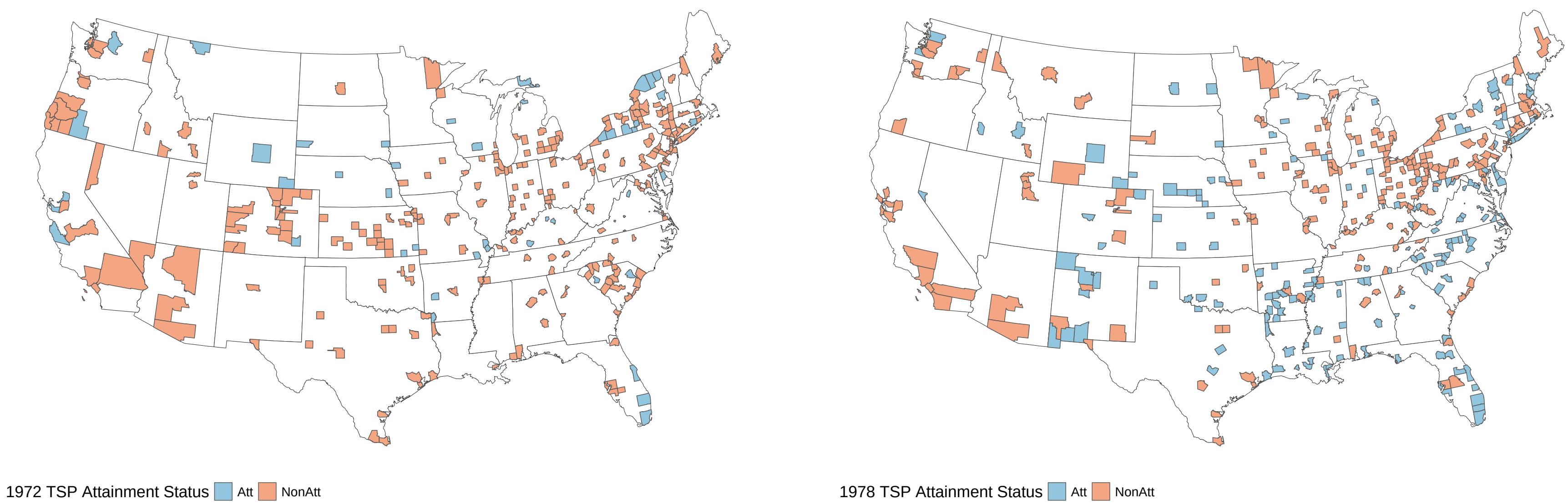
(a) EPA's Designation in 1972 by AQCR



(b) EPA's Designation in 1978 by County

Figure A3: Nonattainment Status for SO2 in the Contiguous United States, 1972 and 1978

Note: This map shows the nonattainment status of counties only in the contiguous United States.

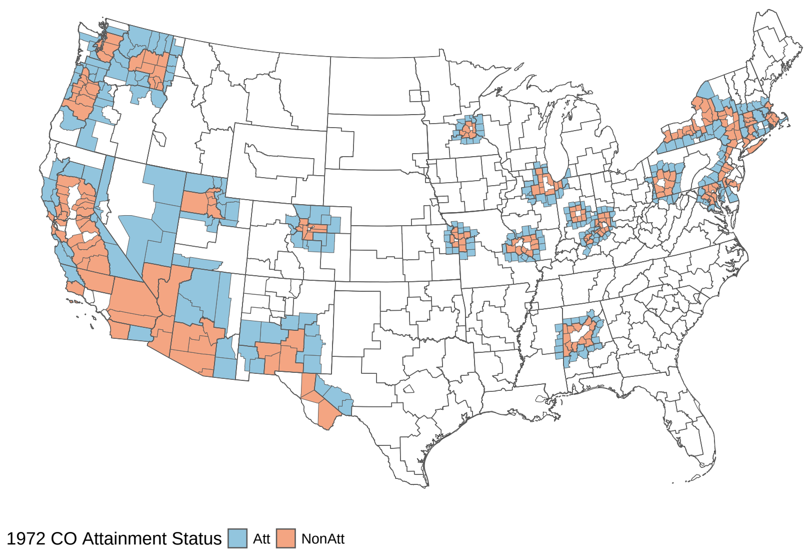


(a) EPA's Designation in 1972 by AQCR

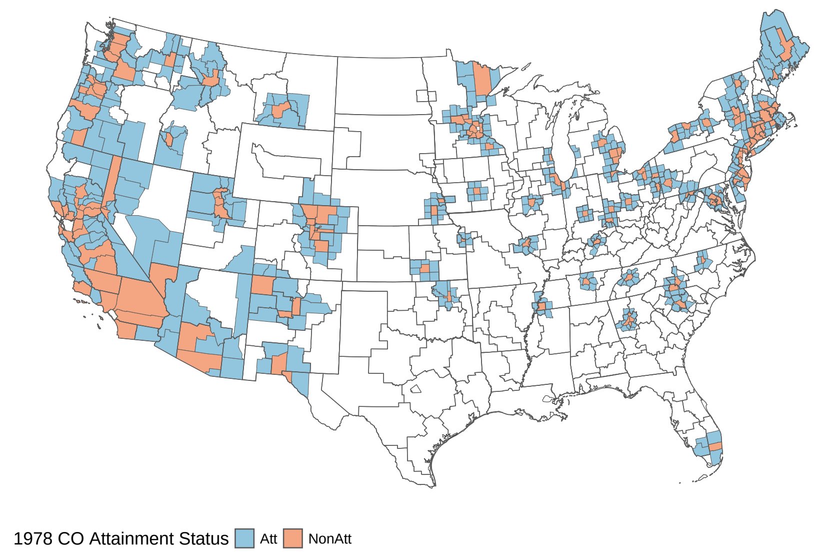
(b) EPA's Designation in 1978 by County

Figure A4: Counties With Balanced Monitors by TSP Nonattainment Status

Note: This map shows the nonattainment status of counties only in the contiguous United States.



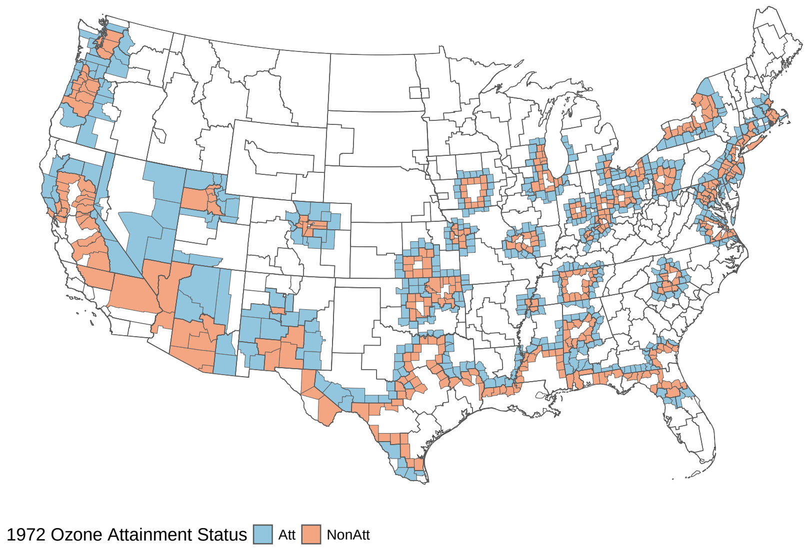
(a) EPA's Designation in 1972 by AQCR



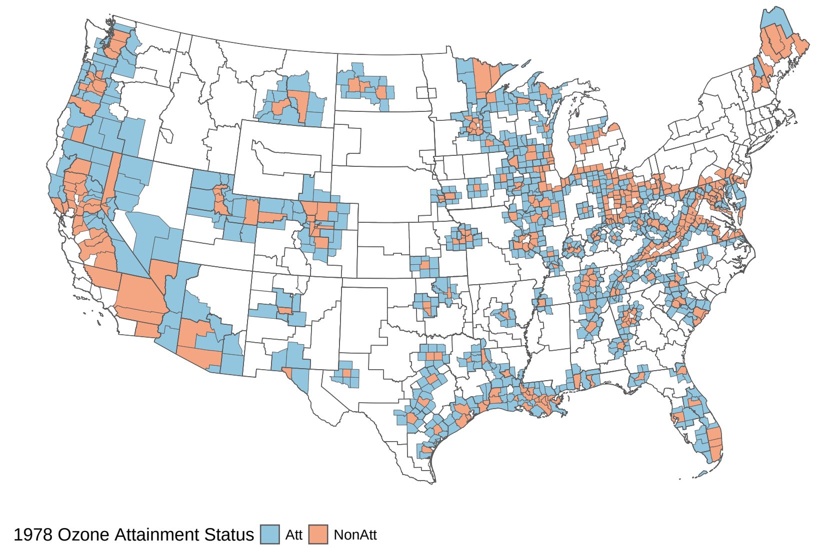
(b) EPA's Designation in 1978 by County

Figure A5: Nonattainment Status for CO in Counties Included in Border-Pair Analysis, 1972 and 1978

Note: This map shows the nonattainment status of counties only in the contiguous United States.



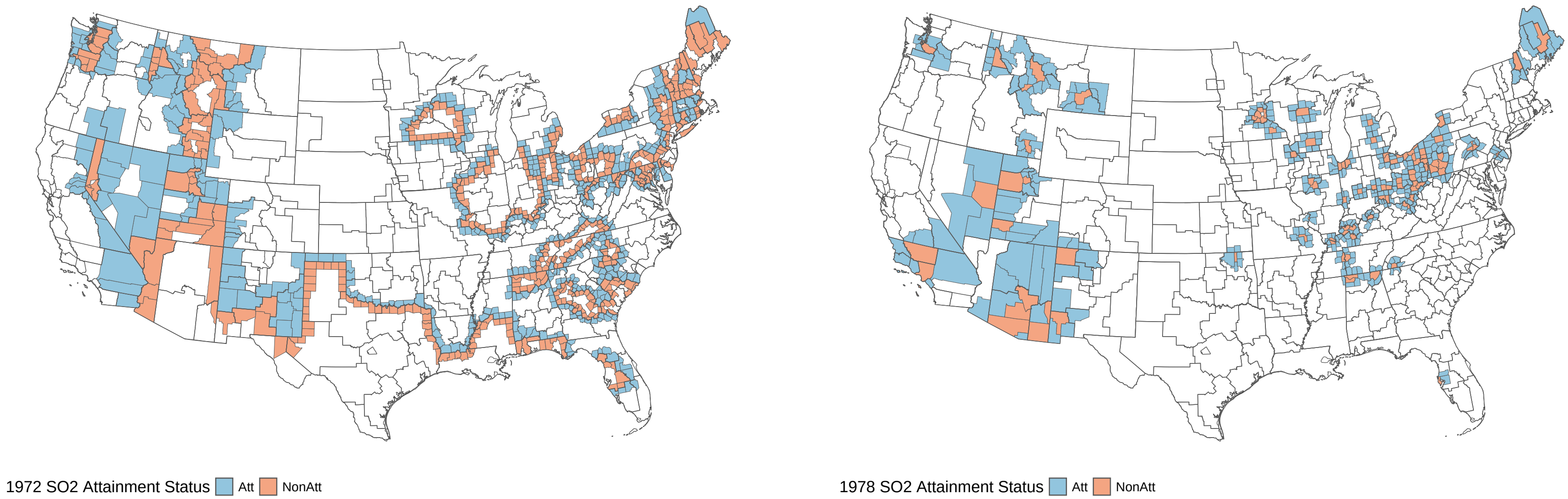
(a) EPA's Designation in 1972 by AQCR



(b) EPA's Designation in 1978 by County

Figure A6: Nonattainment Status for Ozone in Counties Included in Border-Pair Analysis, 1972 and 1978

Note: This map shows the nonattainment status of counties only in the contiguous United States.



(a) EPA's Designation in 1972 by AQCR

(b) EPA's Designation in 1978 by County

Figure A7: Nonattainment Status for SO2 in Counties Included in Border-Pair Analysis, 1972 and 1978

Note: This map shows the nonattainment status of counties only in the contiguous United States.

Table A1: Summary Statistics by Attainment Status and Nonattainment Definition, Counties with Balanced Monitors

	Nonattainment Counties			Attainment Counties		
Variable	N	Mean	SD	N	Mean	SD
Panel A: Counties with Balanced Monitors 1969-76, by EPA's 1972 Nonattainment Designation						
Population (1,000s)	257	356.71	649.90	47	164.04	271.38
Population density (people per square miles)	257	1.09	3.81	47	0.52	2.18
Employment (1,000s)	262	122.40	265.85	46	40.73	74.08
TSP readings from balanced monitors (ug/m3)	262	77.87	31.12	47	54.32	18.73
Panel B: Counties with Balanced Monitors 1969-76, by Imputed 1972 Nonattainment Designation						
Population (1,000s)	122	510.93	867.36	182	203.57	285.58
Population density (people per square miles)	122	1.74	5.36	182	0.50	1.36
Employment (1,000s)	125	185.19	359.96	183	58.72	93.84
TSP readings from balanced monitors (ug/m3)	125	94.22	32.77	184	60.75	20.14
Panel C: Counties with Balanced Monitors 1975-88, by County-level Nonattainment Designation						
Population (1,000s)	222	426.64	742.00	173	160.75	240.17
Population density (people per square miles)	222	1.17	4.32	173	0.38	0.84
Employment (1,000s)	222	167.26	324.81	179	50.95	76.51
TSP readings from balanced monitors (ug/m3)	222	69.50	21.88	180	54.78	16.31

Note: The statistics are calculated for the years 1969–1976 in Panels A and B, and for the years 1975–1988 in Panel C.

Table A2: Polluting Manufacturing Industries

NAICS 2012	NAICS Descriptions	TSP	CO	Ozone	SO_2
313320	Fabric Coating Mills			1	
321113	Sawmills	1			
321114	Wood Preservation	1			
321211	Hardwood Veneer and Plywood Manufacturing	1			
321212	Softwood Veneer and Plywood Manufacturing	1			
321213	Engineered Wood Member (except Truss) Manufacturing	1			
321214	Truss Manufacturing	1			
321219	Reconstituted Wood Product Manufacturing	1			
321911	Wood Window and Door Manufacturing	1			
321912	Cut Stock, Resawing Lumber, and Planing	1			
321918	Other Millwork (including Flooring)	1			
321920	Wood Container and Pallet Manufacturing	1			
321991	Manufactured Home (Mobile Home) Manufacturing	1			
321992	Prefabricated Wood Building Manufacturing	1			
321999	All Other Miscellaneous Wood Product Manufacturing	1			
322110	Pulp Mills	1	1	1	1
322121	Paper (except Newsprint) Mills	1	1	1	1
322122	Newsprint Mills	1	1	1	1
322130	Paperboard Mills	1	1	1	1
323111	Commercial Printing (except Screen and Books)			1	
323113	Commercial Screen Printing			1	
323117	Books Printing			1	
324110	Petroleum Refineries		1	1	1
324199	All Other Petroleum and Coal Products Manufacturing	1	1	1	1
325110	Petrochemical Manufacturing			1	
325120	Industrial Gas Manufacturing			1	1
325193	Ethyl Alcohol Manufacturing			1	
325194	Cyclic Crude, Intermediate, and Gum and Wood Chemical Manufacturing			1	
325199	All Other Basic Organic Chemical Manufacturing			1	
325991	Custom Compounding of Purchased Resins			1	
326113	Unlaminated Plastics Film and Sheet (except Packaging) Manufacturing			1	
326121	Unlaminated Plastics Profile Shape Manufacturing			1	
326122	Plastics Pipe and Pipe Fitting Manufacturing			1	
326130	Laminated Plastics Plate, Sheet (except Packaging), and Shape Manufacturing			1	
326140	Polystyrene Foam Product Manufacturing			1	
326150	Urethane and Other Foam Product (except Polystyrene) Manufacturing			1	
326160	Plastics Bottle Manufacturing			1	
326191	Plastics Plumbing Fixture Manufacturing			1	
326199	All Other Plastics Product Manufacturing			1	
326211	Tire Manufacturing (except Retreading)			1	
326220	Rubber and Plastics Hoses and Belting Manufacturing			1	
326291	Rubber Product Manufacturing for Mechanical Use			1	
326299	All Other Rubber Product Manufacturing			1	
327110	Pottery, Ceramics, and Plumbing Fixture Manufacturing	1		1	1
327120	Clay Building Material and Refractories Manufacturing	1		1	1
327211	Flat Glass Manufacturing	1		1	1
327212	Other Pressed and Blown Glass and Glassware Manufacturing	1		1	1
327213	Glass Container Manufacturing	1		1	1
327215	Glass Product Manufacturing Made of Purchased Glass	1		1	1
327310	Cement Manufacturing	1		1	1
327320	Ready-Mix Concrete Manufacturing	1		1	1
327331	Concrete Block and Brick Manufacturing	1		1	1
327332	Concrete Pipe Manufacturing	1		1	1
327390	Other Concrete Product Manufacturing	1		1	1
327410	Lime Manufacturing	1		1	1
327420	Gypsum Product Manufacturing	1		1	1
327910	Abrasive Product Manufacturing	1		1	1
327991	Cut Stone and Stone Product Manufacturing	1		1	1
327992	Ground or Treated Mineral and Earth Manufacturing	1		1	1
327993	Mineral Wool Manufacturing	1		1	1
327999	All Other Miscellaneous Nonmetallic Mineral Product Manufacturing	1		1	1

331110	Iron and Steel Mills and Ferroalloy Manufacturing	1	1	1	1
331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel	1	1	1	1
331221	Rolled Steel Shape Manufacturing	1	1	1	1
331222	Steel Wire Drawing	1	1	1	1
331313	Alumina Refining and Primary Aluminum Production		1		1
331314	Secondary Smelting and Alloying of Aluminum		1		1
331410	Nonferrous Metal (except Aluminum) Smelting and Refining	1	1	1	1
331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (except Copper and Aluminum)		1		1
331511	Iron Foundries	1	1	1	1
331512	Steel Investment Foundries	1	1	1	1
331513	Steel Foundries (except Investment)	1	1	1	1
332111	Iron and Steel Forging			1	
332112	Nonferrous Forging			1	
332114	Custom Roll Forming			1	
332117	Powder Metallurgy Part Manufacturing			1	
332119	Metal Crown, Closure, and Other Metal Stamping (except Automotive)			1	
332215	Metal Kitchen Cookware, Utensil, Cutlery, and Flatware (except Precious) Manufacturing			1	
332311	Prefabricated Metal Building and Component Manufacturing			1	
332312	Fabricated Structural Metal Manufacturing			1	
332313	Plate Work Manufacturing			1	
332321	Metal Window and Door Manufacturing			1	
332322	Sheet Metal Work Manufacturing			1	
332323	Ornamental and Architectural Metal Work Manufacturing			1	
332410	Power Boiler and Heat Exchanger Manufacturing			1	
332420	Metal Tank (Heavy Gauge) Manufacturing			1	
332431	Metal Can Manufacturing			1	
332439	Other Metal Container Manufacturing			1	
332510	Hardware Manufacturing			1	
332613	Spring Manufacturing			1	
332618	Other Fabricated Wire Product Manufacturing			1	
332721	Precision Turned Product Manufacturing			1	
332722	Bolt, Nut, Screw, Rivet, and Washer Manufacturing			1	
332812	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers			1	
332911	Industrial Valve Manufacturing			1	
332912	Fluid Power Valve and Hose Fitting Manufacturing			1	
332913	Plumbing Fixture Fitting and Trim Manufacturing			1	
332919	Other Metal Valve and Pipe Fitting Manufacturing			1	
332992	Small Arms Ammunition Manufacturing			1	
332993	Ammunition (except Small Arms) Manufacturing			1	
332994	Small Arms, Ordnance, and Ordnance Accessories Manufacturing			1	
332996	Fabricated Pipe and Pipe Fitting Manufacturing			1	
332999	All Other Miscellaneous Fabricated Metal Product Manufacturing			1	
336111	Automobile Manufacturing			1	
336112	Light Truck and Utility Vehicle Manufacturing			1	
336120	Heavy Duty Truck Manufacturing			1	
336211	Motor Vehicle Body Manufacturing			1	
336212	Truck Trailer Manufacturing			1	
336213	Motor Home Manufacturing			1	
336310	Motor Vehicle Gasoline Engine and Engine Parts Manufacturing			1	
336330	Motor Vehicle Steering and Suspension Components (except Spring) Manufacturing			1	
336340	Motor Vehicle Brake System Manufacturing	1		1	1
336350	Motor Vehicle Transmission and Power Train Parts Manufacturing	1		1	1
336370	Motor Vehicle Metal Stamping			1	
336612	Boat Building			1	
336992	Military Armored Vehicle, Tank, and Tank Component Manufacturing			1	
337125	Household Furniture (except Wood and Metal) Manufacturing	1			
339920	Sporting and Athletic Goods Manufacturing			1	
339991	Gasket, Packing, and Sealing Device Manufacturing			1	
325130	Synthetic Dye and Pigment Manufacturing				1
325180	Other Basic Inorganic Chemical Manufacturing				1

Note: This table presents important polluters (classified by NAICS 2012) for each criteria pollutant. A "1" for a pollutant indicates that the industry is a polluter for that specific pollutant.

Table A3: Summary Statistics of Counties Used in Our Analysis, by CO Nonattainment Status

(a) Year 1969-1976 (EPA's Designation in 1972 by AQCR)

	Counties Used in DiD Analysis				Counties Used in Border Pairs			
	Nonattainment (N = 269)		Attainment (N = 929)		Nonattainment (N = 202)		Attainment (N = 284)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Population (1,000s)	321.86	644.84	26.54	61.53	221.51	458.80	61.22	114.76
Employment (1,000s)	100.82	255.96	5.41	11.59	63.63	174.54	15.78	38.14
Dirty Manufacturing Employment (1,000s)	8.44	21.86	0.41	0.89	5.94	18.71	1.69	4.03
Ratio of Dirty to Total Employment	0.09	0.09	0.06	0.09	0.10	0.09	0.10	0.11

(b) Year 1975-1988 (EPA's Designation in 1978 by County)

	Counties Used in DiD Analysis				Counties Used in Border Pairs			
	Nonattainment (N = 167)		Attainment (N = 2258)		Nonattainment (N = 149)		Attainment (N = 458)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Population (1,000s)	577.10	814.54	25.78	34.87	536.57	826.57	85.18	143.25
Employment (1,000s)	220.39	352.24	6.15	11.96	202.86	338.65	22.28	42.61
Dirty Manufacturing Employment (1,000s)	13.63	23.72	0.51	0.94	13.47	24.79	2.17	4.53
Ratio of Dirty to Total Employment	0.07	0.05	0.08	0.08	0.07	0.05	0.09	0.08

[a] Attainment group in the DiD analysis consists of the counties that are in attainment for all four pollutants.
[b] Population information is missing for some counties. Specifically, in the upper table, 18, 0, 0, and 0 counties were excluded for each of the four columns, respectively. In the lower table, 12, 1, 1, and 2 counties were excluded.
[c] The statistics are calculated for the years 1969–1976 in the upper table, and for the years 1975–1988 in the lower table.

Table A4: Summary Statistics of Counties Used in Our Analysis, by Ozone Nonattainment Status

(a) Year 1969-1976 (EPA's Designation in 1972 by AQCR)

	Counties Used in DiD Analysis				Counties Used in Border Pairs			
	Nonattainment (N = 646)		Attainment (N = 929)		Nonattainment (N = 377)		Attainment (N = 500)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Population (1,000s)	180.20	461.49	26.54	61.53	140.50	346.33	56.05	146.75
Employment (1,000s)	54.12	178.02	5.41	11.59	38.75	129.91	14.35	49.38
Dirty Manufacturing Employment (1,000s)	4.66	15.60	0.41	0.89	3.98	14.34	1.83	9.46
Ratio of Dirty to Total Employment	0.10	0.10	0.06	0.09	0.10	0.11	0.10	0.10

(b) Year 1975-1988 (EPA's Designation in 1978 by County)

	Counties Used in DiD Analysis				Counties Used in Border Pairs			
	Nonattainment (N = 684)		Attainment (N = 2258)		Nonattainment (N = 341)		Attainment (N = 725)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Population (1,000s)	249.93	493.59	25.78	34.87	208.41	291.88	37.01	37.74
Employment (1,000s)	83.31	203.46	6.15	11.96	68.63	120.53	8.49	11.69
Dirty Manufacturing Employment (1,000s)	5.88	13.53	0.51	0.94	4.57	7.17	0.80	1.30
Ratio of Dirty to Total Employment	0.10	0.08	0.08	0.08	0.10	0.08	0.10	0.09

[a] Attainment group in the DiD analysis consists of the counties that are in attainment for all four pollutants.
[b] Population information is missing for some counties. Specifically, in the upper table, 16, 18, 7, and 0 counties were excluded for each of the four columns, respectively. In the lower table, 12, 45, 14, and 1 counties were excluded.
[c] The statistics are calculated for the years 1969–1976 in the upper table, and for the years 1975–1988 in the lower table.

Table A5: Summary Statistics of Counties Used in Our Analysis, by SO2 Nonattainment Status

(a) Year 1969-1976 (EPA's Designation in 1972 by AQCR)

	Counties Used in DiD Analysis				Counties Used in Border Pairs			
	Nonattainment (N = 994)		Attainment (N = 929)		Nonattainment (N = 434)		Attainment (N = 482)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Population (1,000s)	108.27	299.63	26.54	61.53	97.42	211.84	51.40	106.64
Employment (1,000s)	32.56	122.30	5.41	11.59	27.51	72.77	13.26	35.66
Dirty Manufacturing Employment (1,000s)	3.08	12.56	0.41	0.89	3.15	11.50	1.58	4.84
Ratio of Dirty to Total Employment	0.09	0.10	0.06	0.09	0.10	0.11	0.10	0.11

(b) Year 1975-1988 (EPA's Designation in 1978 by County)

	Counties Used in DiD Analysis				Counties Used in Border Pairs			
	Nonattainment (N = 98)		Attainment (N = 2258)		Nonattainment (N = 97)		Attainment (N = 355)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Population (1,000s)	313.22	829.63	25.78	34.87	311.63	833.75	95.96	332.46
Employment (1,000s)	117.47	336.62	6.15	11.96	116.31	338.15	29.68	136.43
Dirty Manufacturing Employment (1,000s)	10.03	22.65	0.51	0.94	9.99	22.77	2.50	9.65
Ratio of Dirty to Total Employment	0.13	0.10	0.08	0.08	0.13	0.10	0.11	0.09

[a] Attainment group in the DiD analysis consists of the counties that are in attainment for all four pollutants.
[b] Population information is missing for some counties. Specifically, in the upper table, 10, 18, 1, and 4 counties were excluded for each of the four columns, respectively. In the lower table, 12, 0, 1, and 0 counties were excluded.
[c] The statistics are calculated for the years 1969–1976 in the upper table, and for the years 1975–1988 in the lower table.

Table A6: Summary Statistics of Counties Used in Multi-Pollutant DID Models

(a) Year 1969-1976 (EPA's Designation in 1972 by AQCR)

	TSP Only (N = 880)		Other Only (N = 112)		TSP and Other (N = 1184)		Control Group (N = 929)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Population (1,000s)	39.74	77.84	86.15	183.34	119.87	356.13	26.54	61.53
Employment (1,000s)	10.21	25.66	21.70	60.09	35.54	136.40	5.41	11.59
Dirty Manufacturing Employment (1,000s)	1.15	3.59	1.45	4.04	3.29	13.17	0.41	0.89
Ratio of Dirty to Total Employment	0.09	0.11	0.07	0.09	0.09	0.10	0.06	0.09

(b) Year 1975-1988 (EPA's Designation in 1978 by County)

	TSP Only (N = 120)		Other Only (N = 419)		TSP and Other (N = 313)		Control Group (N = 2258)	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Population (1,000s)	54.33	54.30	116.64	187.06	380.70	650.50	25.78	34.87
Employment (1,000s)	14.94	16.54	32.04	59.10	141.96	282.12	6.15	11.96
Dirty Manufacturing Employment (1,000s)	1.52	1.95	2.06	3.09	10.36	18.75	0.51	0.94
Ratio of Dirty to Total Employment	0.11	0.10	0.10	0.09	0.10	0.07	0.08	0.08

[a] Attainment group in the DiD analysis consists of the counties that are in attainment for all four pollutants.
[b] Population information is missing for some counties. Specifically, in the upper table, 13, 0, 22, and 18 counties were excluded for each of the four columns, respectively. In the lower table, 0, 45, 0, and 12 counties were excluded.
[c] The statistics are calculated for the years 1969–1976 in the upper table, and for the years 1975–1988 in the lower table.

Table A7: Employment Losses Due to EPA's Designation in 1978 (Based on Border-Pair Analysis)

Pollutants	Number of Nonattainment Counties	Employment Losses (95% C.I. in Parenthesis)
TSP	392	354,746 (237,513, 471,979)
CO	148	248,111 (138,032, 358,190)
Ozone	341	97,894 (10,589, 185,200)
SO2	97	167,803 (74,912, 260,695)

Note: To calculate employment losses, we use the estimates from the border-pair analysis in columns 5–8 of Table 5. These estimates are multiplied by the post-treatment average employment across counties in the treatment group and then by the number of nonattainment counties.