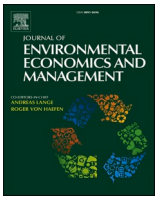
Journal of Environmental Economics and Management 121 (2023) 102867

Contents lists available at ScienceDirect

Journal of Environmental Economics and Management

journal homepage: www.elsevier.com/locate/jeem



The impact of the clean air act on particulate matter in the 1970s

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ARTICLE INFO

Keywords:
Clean Air Act
NAAQS nonattainment
Impact of CAA on TSP

ABSTRACT

We examine whether counties designated as out of attainment with the National Ambient Air Quality Standards (NAAQS) under the 1970 Clean Air Act (CAA) experienced larger reductions in Total Suspended Particulates (TSP) during the 1970s than attainment counties. We answer this question using the official designation of nonattainment status which, between 1972 and 1978, was by Air Quality Control Region (AQCR). Data from balanced panels of TSP monitors in operation from 1969–78 and from 1971–78 are used to examine the impact of nonattainment status on TSP. We also examine the impact of nonattainment on TSP using the definition in the literature, which designates a county as out of attainment if any of its monitors violated the NAAQS. Using the official (AQCR) nonattainment designation, TSP, on average, fell by 10.2 μg/m3 using the 1969 panel and 9.1 μg/m3 using the 1971 panel. Using the definition of non-attainment in the literature yields smaller reductions: 6.0 μg/m3 using the 1969-78 panel and 7.7 μg/m3 using the 1971-78 panel. Using the correct definition of non-attainment in difference-in-differences (DID) models calls into question whether these results can be interpreted as causal. When counties are characterized using the official nonattainment designation, the parallel trends assumption, crucial to causal inference in the DID context, is violated.

1. Introduction

Retrospective analyses of the first decade of the 1970 Clean Air Act (CAA) have linked reductions in particulate matter to human health (Chay et al. 2003; Chay and Greenstone 2003), human capital (Isen et al., 2017) and changes in housing prices (Chay and Greenstone 2005). These studies all use nonattainment status under the CAA to instrument for changes in particulate matter, arguing that nonattainment status constituted an exogenous source of regulation imposed by the federal government. In these papers, non-attainment status is measured at the county level, using monitor readings to determine whether a county violated the National Ambient Air Quality Standards for total suspended particulates (TSP).

In this paper we examine the definition of nonattainment status used in this literature and contrast it with EPA's actual designation of nonattainment status, which was implemented by Air Quality Control Region (AQCR) rather than by county. Our goal is to see how nonattainment status, measured by AQCR, affected TSP readings during the 1970s. Did TSP decline faster in nonattainment areas than in attainment areas, when attainment is measured using the official (AQCR) designation? How do the magnitudes of these effects compare with results obtained using nonattainment status as measured in the literature?

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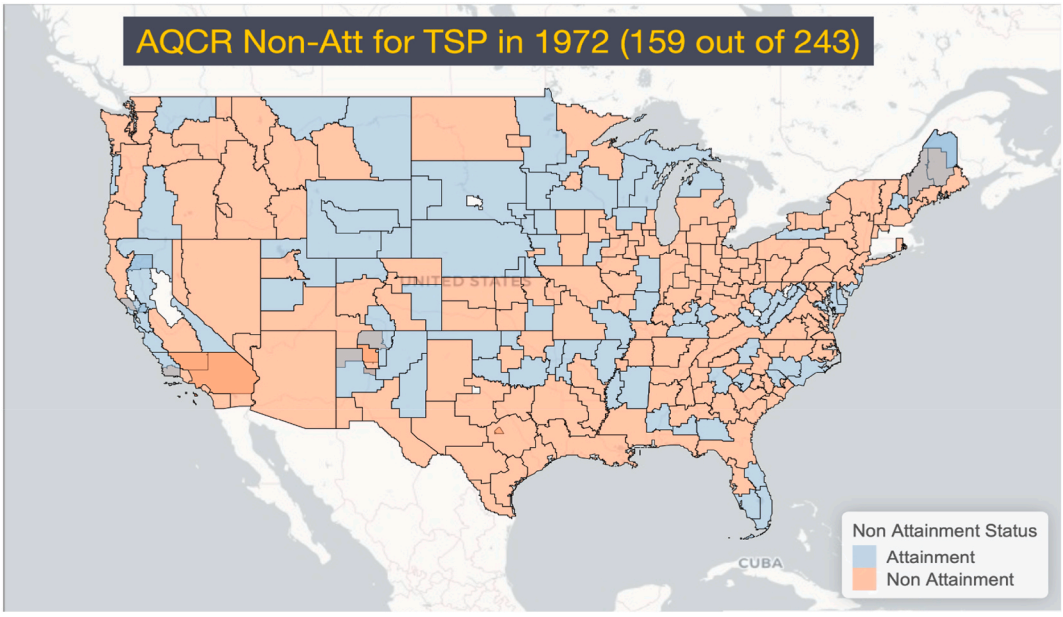
https://doi.org/10.1016/j.jeem.2023.102867
Received 24 July 2022; Received in revised form 22 May 2023; Accepted 5 August 2023
Available online 10 August 2023



Note: The figure indicates that out of 243 Air Quality Control Regions (AQCR) spanning the continental US, 159 AQCRs were out of attainment for TSP in 1972.

Fig. 1. Map of Air Quality Control Regions (AQCRs) by TSP Attainment Status in 1972
Note: The figure indicates that out of 243 Air Quality Control Regions (AQCR) spanning the continental US, 159 AQCRs were out of attainment for TSP in 1972.

We note that ours is not the first paper to discuss differences between the official designation of nonattainment status in the 1970s and the definition used in the literature. Murphy (2016, 2017) points this difference out in his dissertation and examines the implications of the official designation for the use of regression discontinuity designs in the literature (e.g., Chay and Greenstone, 2005). We extend his results by comparing the impact of the two definitions of nonattainment on the rate of decline in TSP in nonattainment v. attainment counties in the 1970s.

We begin by describing the official designation of nonattainment status by AQCR in 1972 and then map AQCR nonattainment status to counties. We contrast the AQCR definition with Michael Greenstone's definition of nonattainment status in 1972 (Greenstone personal communication 2020). The papers cited above all use Greenstone's definition of nonattainment for the early 1970s, which, hereafter, we refer to as the imputed definition of nonattainment. Using each definition, we compare nonattainment and attainment counties in terms of population, employment, per capita income, and population density.

To examine the effect of nonattainment status on TSP we must focus on counties with TSP monitors. We have comprehensive data on all TSP monitors in operation in the US from 1969 to 1980 obtained from a Freedom of Information Act Request.[1] We select two sets of counties: the 226 counties having a balanced panel of TSP monitors from 1969 through 1978, and the 413 counties having a balanced panel of TSP monitors from 1971 through 1978. We focus on counties with the same set of monitors operating each year due to evidence reported by Murphy (2016), which we corroborate, that newly introduced monitors had, on average, lower TSP readings than existing monitors. We estimate difference-in-differences models to examine the effect of nonattainment status in 1972 on annual average TSP in 1969 (1971) through 1978.

We find that actual AQCR nonattainment status resulted in a statistically significant and greater average reduction in TSP than the imputed nonattainment designation. Specifically, TSP fell by approximately 10.2 μg/m3 more between 1969 and 1978 in AQCR nonattainment counties than in AQCR attainment counties. The difference, using the imputed definition, is approximately 6.0 μg/m3. Using the 1971 panel, TSP fell by approximately 9.1 μg/m3 more between 1971 and 1978 in AQCR nonattainment counties than in AQCR attainment counties. The difference, using the imputed definition is approximately 7.7 μg/m3. The AQCR definition results in a larger drop in TSP in part because many of the counties officially categorized as nonattainment are incorrectly designated as attainment counties using the imputed definition. But, TSP was falling significantly in these counties; since in fact they were in nonattainment, polluters would have been compelled to change behavior to reduce emissions. When incorrectly designated as being in attainment using the imputed definition, the difference in TSP between attainment and nonattainment counties is substantially reduced.

Additionally, using the correct definition of nonattainment in difference-in-differences (DID) models calls into question whether these results can be interpreted as causal. When counties are characterized using the official (AQCR) nonattainment designation, the

[1] We thank Karen Clay for sharing this dataset with us (Clay et al., 2022).

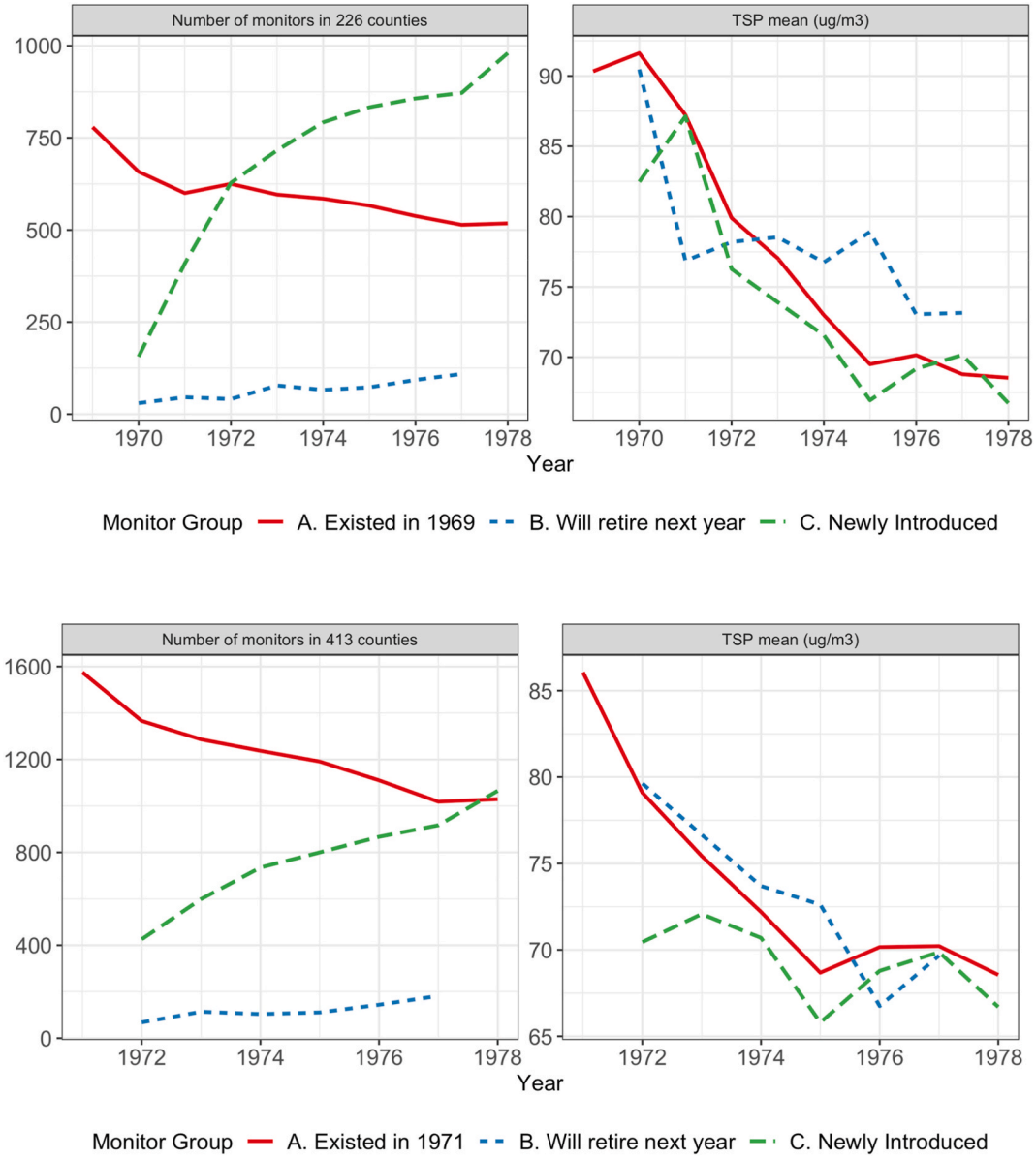


Fig. 2. Number of Monitors and Average TSP by Monitor Status
[Upper Panel]: Counties with balanced monitors 1969–1978, The figure's left panel illustrates the change over time in the number of monitors in counties that had balanced monitors between 1969 and 1978, categorized into three groups — A. monitors that were present in 1969; B. monitors that will be retired in the next year; and C. monitors that have recently been introduced in the current year. The right panel displays the average TSP level of monitors over 1969 and 1979, with the monitors classified into the aforementioned groups. [Lower Panel]: Counties with balanced monitors 1971–1978, The figure's left panel illustrates the change over time in the number of monitors in counties that had balanced monitors between 1971 and 1978, categorized into three groups — A. monitors that were present in 1971; B. monitors that will be retired in the next year; and C. monitors that have recently been introduced in the current year. The right panel displays the average TSP level of monitors over 1971 and 1979, with the monitors classified into the aforementioned groups.

parallel trends assumption, crucial to causal inference in the DID context, is violated. When using the imputed definition of non-attainment, the parallel trends assumption holds although attainment status is mischaracterized. This suggests that the official designation must be used carefully when making causal statements about the impact of the 1970 CAA on air quality.

2. Nonattainment status under the 1970 CAA

The 1970 CAA required EPA to establish ambient air quality standards for common (or "criteria") air pollutants, and required states

Table 1
Number of counties by attainment status and definition of nonattainment.

Counties with balanced monitors 1969-78			
AQCR 1972 NA status	Imputed 1972 NA status		Total
	Attainment	Nonattainment	
Attainment	33	0	33
Nonattainment	102	91	193
Total	135	91	226
Counties with balanced monitors 1971-78			
AQCR 1972 NA status	Imputed 1972 NA status		Total
	Attainment	Nonattainment	
Attainment	74	6	80
Nonattainment	192	141	333
Total	266	147	413

The table presents the number of counties based on their AQCR nonattainment (NA) status and imputed NA status, considering only those counties that had balanced monitors between 1969 and 1978 (upper panel) and between 1971 and 1978 (lower panel).

to draft 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 particulate matter, carbon dioxide, nitrogen dioxide, sulfur dioxide, hydrocarbons, and photochemical oxidants (USEPA 1971). The Agency also defined 247 AQCRs, spanning the continental US, Alaska and Hawaii, the Virgin Islands and Guam (USEPA 1972a). AQCRs are groups of contiguous counties, located in the same airshed.

In May of 1972 each AQCR was determined to be in attainment or out of attainment with each of the criteria pollutants (USEPA 1972b). 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. Fig. 1 of the paper shows the boundaries of the AQCRs in the continental US and their attainment status for TSP. When AQCRs are mapped to counties, 2,035 counties were designated as non-attainment counties and 1,028 as attainment counties.[2]

The imputed nonattainment status categorized attainment status in 1972 based on monitoring readings in each county in 1971 (Chay et al. 2003; Greenstone 2020). A county that violated the annual average TSP standard or the 24-h standard in 1971 was designated as a nonattainment county in 1972. By this definition, 288 counties were designated as nonattainment counties in 1972.

EPA required states to submit plans to achieve the NAAQS by May of 1975 (USEPA 1973).[3] In 1976 attainment status by AQCR was reassigned (USEPA 1976). For TSP, 1,392 counties were declared to be in attainment and 1,671 designated out of attainment. Based on 1975 monitoring readings, 271 counties were out of attainment in 1976. EPA's assignment of attainment by AQCR ended in 1978. Beginning in that year, attainment status was assigned by county (USEPA 1978), a practice which continues to this day.

3. The impact of attainment status on TSP

3.1. Counties used in the analysis

To examine the impact of attainment status on TSP levels we must restrict the analysis to counties with TSP monitors. In 1969 only 490 counties had at least one TSP monitor.[4] Only 349 of these counties had at least one monitor each year from 1969 through 1978, although not necessarily the same set of monitors each year. In total, 226 counties had a balanced panel of monitors from 1969 through 1978; i.e., they had at least one monitor which operated each year during this period. If we begin the analysis in 1971, there are 413 counties that have a balanced panel of monitors operating from 1971 through 1978.

Our analysis focuses on a balanced panel of monitors because TSP readings from monitors added during this period are, on average, lower than readings at monitors continuously in operation. Monitors removed during the period have, on average, higher readings than monitors continuously in operation. This is illustrated by Fig. 2, which show monitors added and retired during the period of our analysis in the 1969 and 1971 panels of counties. The graph on the left side of each figure shows the cumulative number of monitors added and retired, by year. The graph on the right side of each figure shows average TSP, by year and class of monitor. Average TSP for newly introduced monitors (the dashed green lines) lies below average TSP based on monitors continuously in operation (the red lines) in most years. The converse is true for monitors to be retired next year (the dashed blue lines). Fig. 2 suggests the possibility of strategic placement of monitors to reduce TSP readings, a point noted by Murphy (2016), which is consistent with findings by Grainger et al. (2019) and Muller and Ruud (2017).

The number of counties in the 1969 and 1971 panels that are in attainment with the NAAQS is much smaller when the official

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

[3] Some of the 247 AQCRs cross state boundaries. There are 313 AQCRs counting AQCRs in individual states separately. As a referee notes, enforcement of State Implementation Plans may not have been uniform within AQCRs.

[4] The number of counties with at least one TSP monitor is 565 counties in 1970, 765 counties in 1971 and 1,059 counties in 1972.

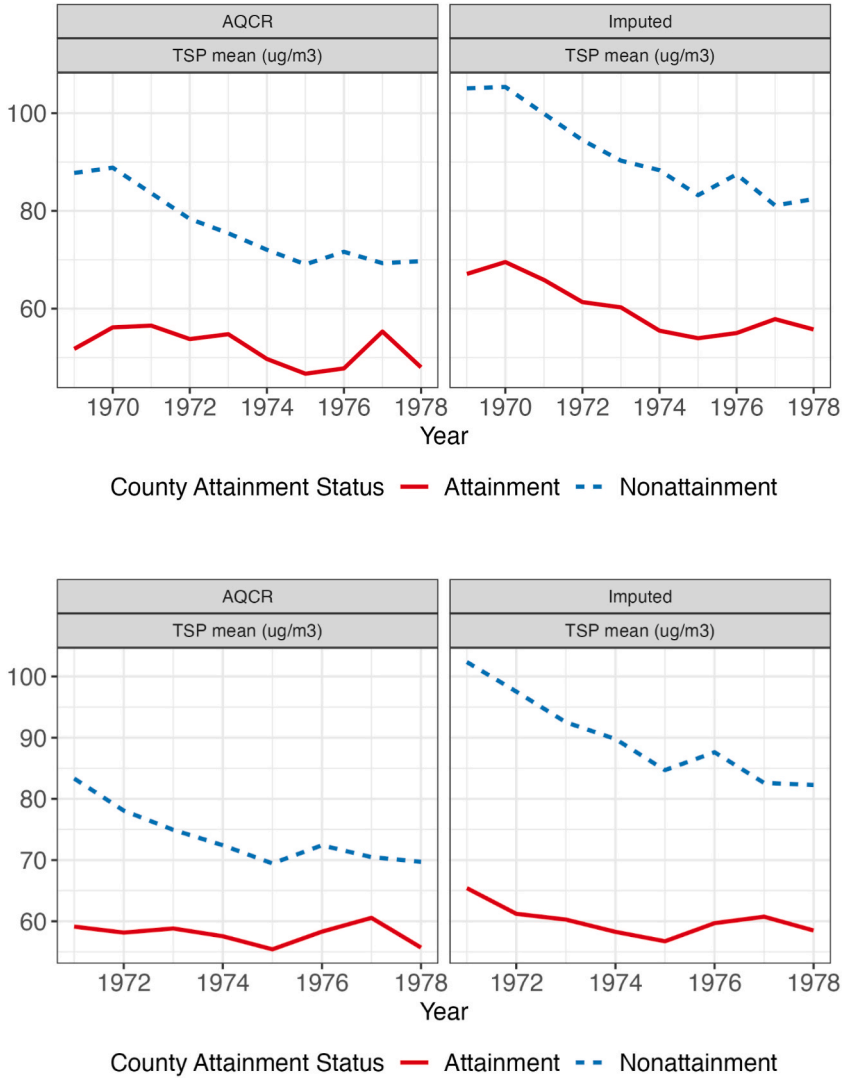


Fig. 3. Average TSP Levels by Attainment Status and Definition of Nonattainment
[Upper Panel]: Counties with balanced monitors 1969–1978: The figure's left panel depicts the variation over time in the average TSP level of counties categorized as being in nonattainment or attainment based on AQCR. In contrast, the right panel displays the same information, but the county's attainment status is determined by imputation. [Lower Panel]: Counties with balanced monitors 1971–1978: The figure's left panel depicts the variation over time in the average TSP level of counties categorized as being in nonattainment or attainment based on AQCR. In contrast, the right panel displays the same information, but the county's attainment status is determined by imputation.

definition of attainment status is used. Table 1 lists the number of counties by attainment status using the AQCR and imputed definitions of attainment in the 1969 and 1971 panels. Using the AQCR definition, only 33 out of 226 (14.6%) counties are in attainment in the 1969 panel; only 80 out of 413 (19.4%) counties are in attainment in the 1971 panel. In contrast, the imputed definition assigns over half of counties as being in attainment. Using the imputed definition, 135 (59.7%) counties in the 1969 panel and 266 (64.4%) counties in the 1971 panel are in attainment. Figure A.1 and Figure A.2 in the Appendix show the locations of the counties in each panel, by attainment status. This difference stems from the fact that, under the actual designation, all counties in an AQCR are out of attainment if any county in an AQCR violates the standard.

How do attainment and nonattainment counties differ? We obtain county level population and earnings statistics from the U.S. Bureau of Economic Analysis. All monetary values are converted to 1974 dollars using the personal consumption expenditure index (USBEA PCE). By either definition, nonattainment counties are, on average, more populous, more densely populated, contain more workers, and have higher per capita incomes than attainment counties. Appendix Table A.1 and Table A.2, which present summary statistics for the 1969 and 1971 panels by attainment status, using both of definitions of nonattainment, illustrate this point. For this reason, we control for population, employment, and per capita income in the models reported below.

Average annual TSP readings were falling for both attainment and nonattainment counties in the 1969 and 1971 panels using both

Table 2
County-level difference-in-differences models for TSP.

	Counties with balanced monitors 1969-78					
	AQCR Nonattainment			Imputed Nonattainment		
	(1)	(2)	(3)	(4)	(5)	(6)
NA x After 1972	−10.154 *** (1.907)	−10.630 ***(2.064)	−8.672 ***(1.738)	−5.988 ***(2.302)	−6.538 ***(2.432)	−4.113 * (2.352)
N	2230	2007	1784	2230	2007	1784
Years Excluded?	No	1972	1977–78	No	1972	1977–78
R^2	0.782	0.777	0.798	0.781	0.776	0.797
	Counties with balanced monitors 1971-78					
	AQCR Nonattainment			Imputed Nonattainment		
	(1)	(2)	(3)	(4)	(5)	(6)
NA x After 1972	−9.060 *** (1.904)	−9.890 *** (2.014)	−7.954 *** (1.812)	−7.694 *** (2.258)	−8.982 *** (2.357)	−5.254 ** (2.295)
N	3176	2779	2382	3176	2779	2382
Years Excluded?	No	1972	1977–78	No	1972	1977–78
R^2	0.787	0.784	0.816	0.787	0.785	0.815

***p < 0.01; **p < 0.05; *p < 0.1.
In all models the dependent variable is annual county-level average TSP. County-level population, per capita income, and employment are controlled for, together with time and county level fixed effects. 3 counties (upper panel) and 16 counties (lower panel) were dropped due to missing economics data. Standard errors are in parentheses and clustered at the county level.

definitions of nonattainment, as shown in Fig. 3. For both panels, average TSP levels are higher for both nonattainment and attainment counties using the imputed definition of nonattainment. This is to be expected: as noted above, counties in nonattainment AQCRs may have TSP levels lower than the annual standard, which will lower the average TSP level for nonattainment counties using the AQCR definition compared to the imputed definition. The fact that TSP levels are higher for attainment counties using the imputed definition reflects the fact that approximately 75% of these attainment counties are designated as being in nonattainment according to the official designation.

3.2. Difference in differences models

Following the literature, we treat nonattainment status as exogenous and examine its effect on annual average TSP at the county level and at the monitor level using each definition of nonattainment. In county-level models the dependent variable is the arithmetic average of TSP readings across all monitors in the balanced panel in each county in each year. We also present models in which the dependent variable is TSP measured at the monitor level in each county in each year. Specifically, we estimate equations (1) and (2)

$$TSP_{ct} = \beta_1 After_t \times NA_c + X_{ct}\Gamma + \delta_c + \gamma_t + \varepsilon_{ct} \quad (1)$$

$$TSP_{mt} = \beta_1 After_t \times NA_c + X_{ct}\Gamma + \delta_m + \gamma_t + \varepsilon_{mt} \quad (2)$$

where $After_t = 1$ *if* $t > 1972$, $NA_c = 1$ if county c is out of attainment in 1972, $X_{ct} = (population_{ct}, employment_{ct}$, per capita $income_{ct})$, and δ_c (δ_m) and γ_t are county (monitor) and year fixed effects. We estimate equations (1) and (2) using all years in each panel and, as a sensitivity analysis, (a) omitting 1972 and (b) omitting years 1977–78.

At the county level, the reduction in TSP associated with nonattainment status is greater when nonattainment is measured using the AQCR designation rather than the imputed definition used in the literature, although 95% confidence intervals for the two definitions overlap. Table 2 displays results at the county level for the 1969 and 1971 panels using both definitions of nonattainment status. Using the AQCR definition of nonattainment, annual average TSP declined by approximately 10.2 μg/m3 more in nonattainment counties than in attainment counties over the 1969–1978 period and 9.1 μg/m3 more over the 1971–1978 period. The corresponding results are 6.0 μg/m3 and 7.7 μg/m3 using the imputed definition of nonattainment.[5] Omitting the years 1977–78 from each panel reduces the size of the reductions in absolute magnitude, suggesting that 1972 nonattainment status continued to exert an impact on particulate air pollution through 1978.

Results at the monitor level (Table 3) are similar to results at the county level. Point estimates of average declines for the 1969–78 and 1971–78 periods are generally within 10% of those in Table 2. Although Auffhammer et al. (2009) find significant impacts of nonattainment status for PM10 over the period 1990 to 2005 at the monitor but not at the county level, they do not use a balanced panel of monitors in their analysis. It is not surprising that our results are statistically significant at both the monitor and county levels and quantitatively similar when we use a balanced panel of monitors.

To better understand the difference in results between the two definitions of nonattainment status, we modify equation (1) to

[5] To put these numbers in context, average TSP in 1969 across all 226 counties in the 1969-78 panel was 82.4 μg/m3. It was 78.6 μg/m3 for the 413 counties in the 1971–78 in 1971.

Table 3
Monitor-level difference-in-differences models for TSP.

	Counties with balanced monitors 1969-78					
	AQCR Nonattainment			Imputed Nonattainment		
	(1)	(2)	(3)	(4)	(5)	(6)
NA x After 1972	−9.356 *** (2.088)	−11.610 *** (2.254)	−8.244 *** (1.757)	−5.371 *** (1.892)	−6.274 *** (2.236)	−4.188 ** (1.945)
N	4540	4086	3632	4540	4086	3632
Years Excluded?	No	1972	1977–78	No	1972	1977–78
R^2	0.826	0.822	0.838	0.826	0.822	0.838
	Counties with balanced monitors 1971-78					
	AQCR Nonattainment			Imputed Nonattainment		
	(1)	(2)	(3)	(4)	(5)	(6)
NA x After 1972	−8.632 *** (1.587)	−11.661 *** (1.916)	−7.683 *** (1.432)	−7.338 *** (1.379)	−7.944 *** (1.717)	−5.550 *** (1.291)
N	7624	6671	5718	7624	6671	5718
Years Excluded?	No	1972	1977–78	No	1972	1977–78
R^2	0.834	0.833	0.856	0.835	0.833	0.857

***p < 0.01; **p < 0.05; *p < 0.1.
In all models the dependent variable is annual monitor-level average TSP. County-level population, per capita income, and employment are controlled for, together with time and monitor level fixed effects. 3 counties (upper panel) and 16 counties (lower panel) were dropped due to missing economics data. Standard errors are in parentheses and clustered at the county level.

Table 4
County-level difference-in-differences models for TSP by nonattainment definition.

	Counties with balanced monitors 1969-78		
	(1)	(2)	(3)
NA Agree x After 1972	−12.292***	−13.059***	−9.891***
	(2.576)	(2.760)	(2.522)
NA AQCR only x After 1972	−8.332***	−8.601***	−7.635***
	(1.921)	(2.080)	(1.709)
p-value for H_0:	0.008	0.006	0.056
NA Agree x After 1972 = NA AQCR only x After 1972			
N	2,230	2,007	1,784
Years Excluded?	No	1972	1977–78
R^2	0.757	0.748	0.768
	Counties with balanced monitors 1971-78		
	(1)	(2)	(3)
NA Agree x After 1972	−13.242*** (2.661)	−14.817*** (2.793)	−10.797*** (2.659)
NA AQCR only x After 1972	−6.072*** (1.820)	−6.426*** (1.928)	−5.943*** (1.703)
p-value for H_0:	0.000	0.000	0.002
NA Agree x After 1972 = NA AQCR only x After 1972			
N	3,176	2,779	2,382
Years Excluded?	No	1972	1977–78
R^2	0.758	0.750	0.779

***p < 0.01; **p < 0.05; *p < 0.1.
In all models the dependent variable is annual monitor-level average TSP. County-level population, per capita income, and employment are controlled for, together with time and monitor level fixed effects. 3 counties (upper panel) and 16 counties (lower panel) were dropped due to missing economics data. Standard errors are in parentheses and clustered at the county level.

distinguish between counties designated as nonattainment according to both the AQCR and imputed definitions and those designated as nonattainment according to only the AQCR definition.[6] As Table 4 shows, TSP fell faster in counties designated as nonattainment according to both definitions than in counties designated as nonattainment according to only the AQCR definition. This difference is statistically significant. This is not surprising. Counties designated as nonattainment according to both definitions—91 counties in 1969–78 and 141 counties in 1971–78—were, on average, dirtier counties in 1972 than those designated as nonattainment using only the AQCR definition.

Table 4 also explains why the average declines in TSP are smaller using the imputed definition. When the imputed definition of nonattainment is used, the counties designated as nonattainment according to only the AQCR definition (102 in 1969–78 and 192 in 1971–78) enter the control group in the DID analysis. But, TSP is falling significantly in these counties, thus reducing the magnitude of

[6] We thank a referee for suggesting this. Formally we replace $\beta_1 After_t \times NA_c$ with $\beta_1\ after \bullet NA\_agree\ + \beta_2 after \bullet NA\_AQCRonly$

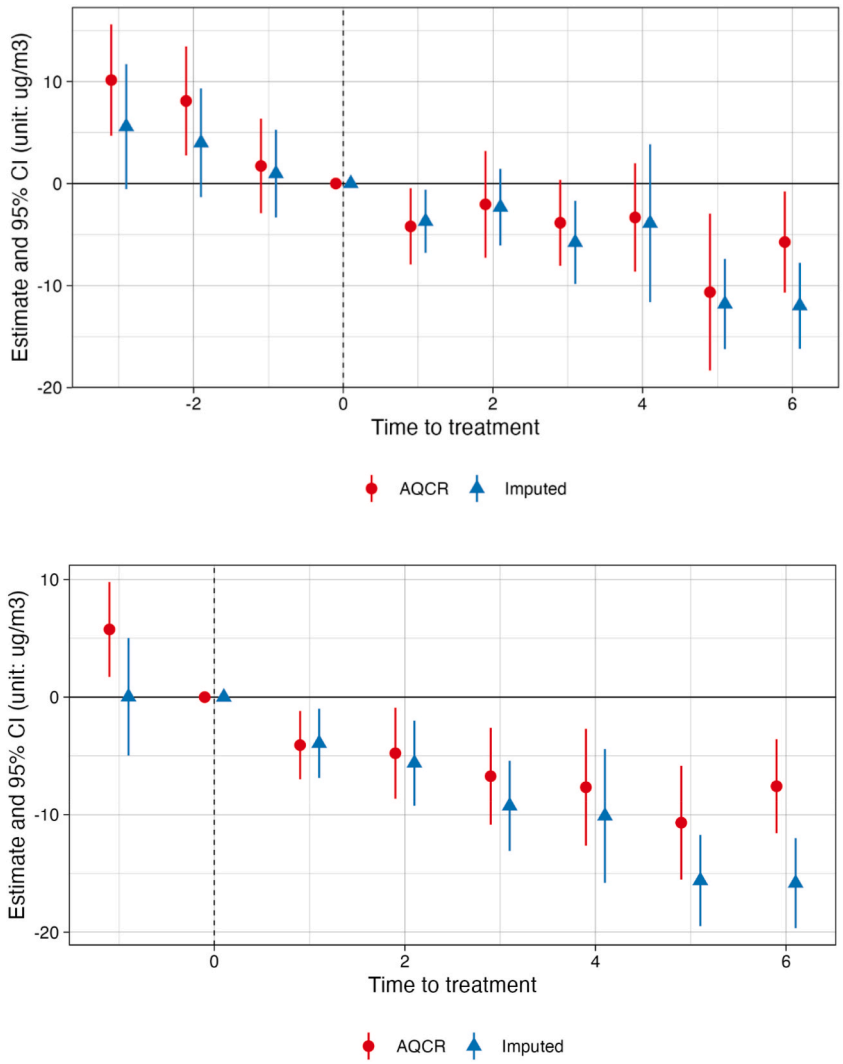


Fig. 4. Event Studies Using County-Level Data for 1969–78 and 1971–78
The figure depicts the coefficients (with 95% confidence intervals) derived from two event study regressions. The first regression (marked by a red dot) uses nonattainment counties based on AQCR as the treatment group, whereas the second regression (marked by a blue triangle) employs imputed nonattainment counties as the treatment group. The dependent variable is the average TSP level. The sample period is between 1969 and 1978 (upper panel) and between 1971 and 1978 (lower panel)

TSP declines when the imputed nonattainment definition is used.

Can the results in Table 2 through 4 be regarded as causal? Fig. 3 suggests, and an event study (Fig. 4) confirms, that the official definition of nonattainment does not satisfy the parallel trends assumption: TSP levels are falling faster in nonattainment counties prior to 1972 than in attainment counties, suggesting that nonattainment counties anticipated CAA regulations. Using the imputed definition of nonattainment results in parallel trends for TSP in attainment and nonattainment counties prior to 1972 (see Fig. 4). This suggests that, though the imputed definition of nonattainment (used so frequently in the literature) satisfies the parallel trends assumption, it does so only because it incorrectly allocates counties that were in fact in nonattainment to the control group. Further, researchers interested in whether, and by how much, the CAA caused pollution levels to fall, must do so using the official definition of nonattainment, in the context of empirical models other than DID.

4. Conclusions

This paper has two goals. The first is to examine whether counties designated as out of attainment with the NAAQS under the 1970 CAA experienced larger reductions in TSP during the 1970s than attainment counties. We ask this question using the official designation of nonattainment status which, between 1972 and 1978, was by AQCR. We answer this question by identifying AQCRs by attainment status and mapping AQCRs into counties. The second goal is to compare the effect of nonattainment status on TSP levels

during the 1970s using two definitions of nonattainment: the AQCR definition and the one used in the literature, which designates a county as out of attainment if its monitors violated the NAAQS.

The answer to the first question is that, using balanced panels of TSP monitors in operation from 1969–78 and in operation from 1971–78, TSP, on average, fell by over 9 μg/m3 more in nonattainment than in attainment counties. This result holds at both the county and at the monitor levels, controlling for county (or monitor) and year fixed effects, county population, employment and per capita income. The average decline is 10.2 μg/m3 using the 1969 panel and 9.1 μg/m3 using the 1971 panel. This result cannot, however, be viewed as causal: TSP fell faster in nonattainment counties than in attainment counties between 1969 and 1972, suggesting possible anticipation of the 1970 CAA.

The answer to the second question is that the definition of nonattainment in the literature yields smaller average declines in TSP: 6.0 μg/m3 using the 1969-78 panel and 7.7 μg/m3 using the 1971-78 panel. This occurs for two reasons: Many of the AQCR nonattainment counties are incorrectly designated as attainment counties using the definition in the literature, which narrows the estimated TSP decline. Secondly, the anticipation of the CAA in attainment counties using the official definition (i.e., the violation of the parallel trends assumption) increases the magnitude of the estimated impact of nonattainment using the AQCR definition.

The question that remains unanswered is what measure of nonattainment status guided policies to control TSP in the early years of the CAA. Counties classified as nonattainment counties in the literature were clearly in violation of the NAAQS, and, as we have demonstrated, the CAA did reduce TSP in these counties, relative to attainment counties (as imputed in the literature). Whether the CAA imposed pressure to reduce emissions in counties located in nonattainment AQCRs that did not have monitor readings above the NAAQS is difficult to determine, given the violation of the parallel trends assumption. This remains an open question.

Acknowledgements

We thank Michael Greenstone for sharing his data on attainment status with us and Karen Clay for providing EPA data on monitor readings. We also thank David Evans and Carl Pasurka for their help in navigating historic data, and Art Fraas and Dick Morgenstern for their encouragement in pursuing this topic. The comments and suggestions of two anonymous referees have greatly improved the paper.

Appendix

Table A.1
Summary Statistics by Attainment Status and Nonattainment Definition, Counties with Balanced Monitors 1969-78

		Attainment Counties			Nonattainment Counties		
NA Status	Variable	N	Mean	SD	N	Mean	SD
AQCR	Population (1,000s)	330	185	307	1,900	359	698
	Population density (people per square miles)	330	189	296	1,900	851	1,840
	Employment (1,000s)	330	90	154	1,900	179	362
	Per capita income (1974 dollars)	330	5,277	1,022	1,900	5,601	919
	TSP readings from balanced monitors (μg/m3)	330	52	20	1,900	77	29
Imputed	Population (1,000s)	1,330	220	301	900	500	945
	Population density (people per square miles)	1,330	441	879	900	1,214	2,414
	Employment (1,000s)	1,330	103	150	900	259	490
	Per capita income (1974 dollars)	1,330	5,439	944	900	5,722	914
	TSP readings from balanced monitors (μg/m3)	1,330	60	21	900	92	30

Statistics are based on annual values of variables in counties with balanced monitors between 1969–78.

Table A.2
Summary Statistics by Attainment Status and Nonattainment Definition, Counties with Balanced Monitors 1971-78

		Attainment Counties			Nonattainment Counties		
NA Status	Variable	N	Mean	SD	N	Mean	SD
AQCR	Population (1,000s)	616	135	239	2,560	295	601
	Population density (people per square miles)	616	345	1,683	2,560	1,073	4,263
	Employment (1,000s)	616	66	127	2,560	147	327
	Per capita income (1974 dollars)	616	5,265	1,120	2,560	5,433	998
	TSP readings from balanced monitors (μg/m3)	616	58	22	2,560	74	27
Imputed	Population (1,000s)	2,040	173	271	1,136	429	826
	Population density (people per square miles)	2,040	487	1,659	1,136	1,732	6,066
	Employment (1,000s)	2,040	80	129	1,136	224	458
	Per capita income (1974 dollars)	2,040	5,315	1,039	1,136	5,553	981
	TSP readings from balanced monitors (μg/m3)	2,040	60	18	1,136	90	29

Statistics are based on annual values of variables in counties with balanced monitors between 1971–78.

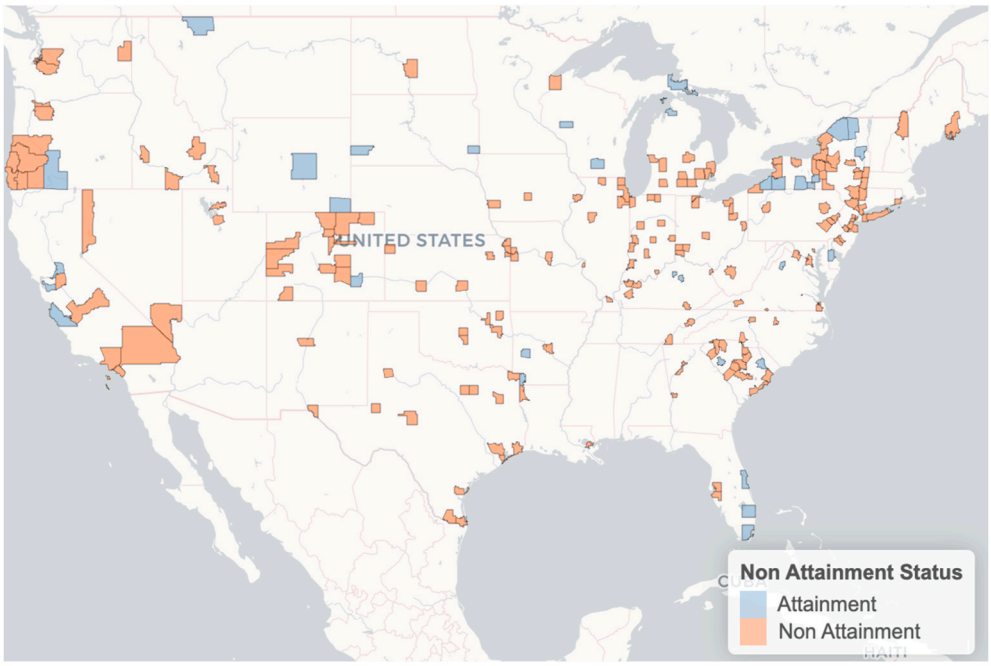


Fig. A.1. Counties with Balanced Monitors 1969–1978 by TSP Attainment Status
The figure displays the location of counties which had balanced monitors between 1969 and 1978, categorized as being either in nonattainment (highlighted in orange) or in attainment (highlighted in blue).

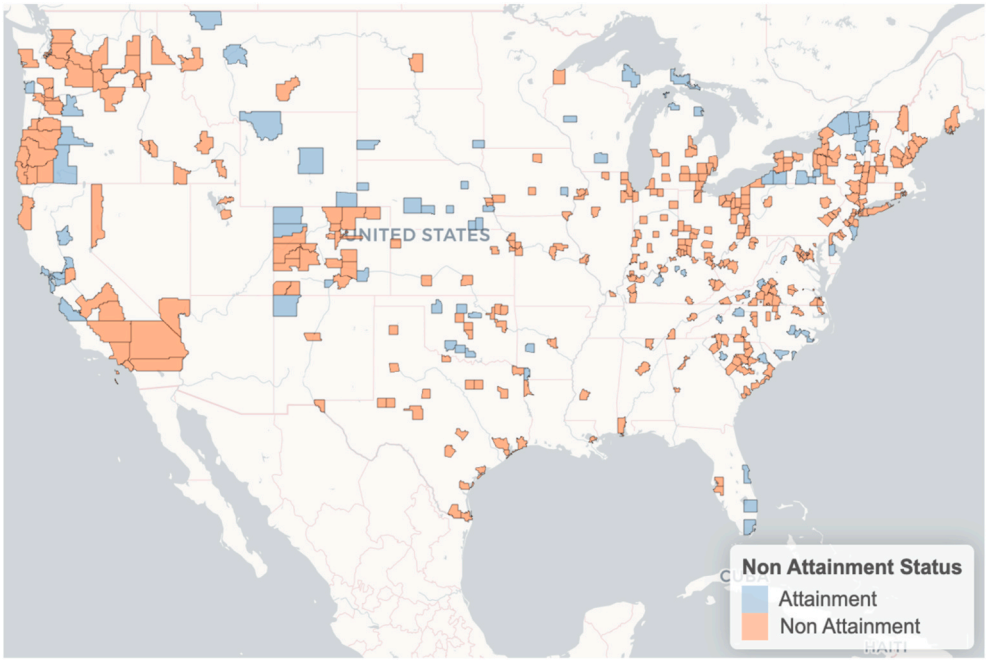


Fig. A.2. Counties with Balanced Monitors 1971–1978 by TSP Attainment Status
The figure displays the location of counties which had balanced monitors between 1971 and 1978, categorized as being either in nonattainment (highlighted in orange) or in attainment (highlighted in blue).

References

Auffhammer, M., Bento, A.M., Lowe, S.E., 2009. Measuring the effects of the clean air Act amendments on ambient PM_{10} concentrations: the critical importance of a spatially disaggregated analysis. J. Environ. Econ. Manag. 58 (1), 15–26.

Chay, K., Dobkin, C., Greenstone, M., 2003. The clean air Act of 1970 and adult mortality. J. Risk Uncertain. 27 (3), 279–300.

Chay, K.Y., Greenstone, M., 2003. Air Quality, Infant Mortality, and the Clean Air Act of 1970. National Bureau of Economic Research Working. Paper 10053.

Chay, K.Y., 2005. Does air quality matter? Evidence from the housing market. J. Polit. Econ. 113 (2), 376–424.

Clay, K., Lewis, J., Severnini, E., 2022. Canary in a Coal Mine: Infant Mortality and Tradeoffs Associated with Mid-20th Century Air Pollution." *Review Of Economics And Statistics (Forthcoming)*. National Bureau of Economic Research. Working Paper 22155.

Grainger, C., Schreiber, A., Chang, W., 2019. Do Regulators Strategically Avoid Pollution Hotspots when Siting Monitors? Evidence from Remote Sensing of Air Pollution. Department of Economics, University of Wisconsin–Madison Working Paper.

Greenstone, M., 2020. Personal communication. Nov 15, 2020.

Isen, A., Rossin-Slater, M., Walker, W.R., 2017. Every breath you take—every dollar you'll make: the long-term consequences of the clean air Act of 1970. J. Polit. Econ. 125 (3), 848–902.

Muller, N.Z., Ruud, P., 2017. What forces dictate the design of pollution monitoring networks? Environ. Model. Assess. 23 (1), 1–14. https://doi.org/10.1007/s10666-017-9553-7.

Murphy, J.D., 2016. The Benefits of Reducing Particulate Pollution: Re-e4xamining Evidence from the Clean Air Act. Mimeo. May 6, 2016.

Murphy, J.D., 2017. The Costs, Benefits and Efficiency of Air Quality Regulations. Ph.D. Dissertation, University of Toronto.

U.S. Bureau of Economic Analysis. Economic profile by county, 1969-2020. https://apps.bea.gov/regional/downloadzip.cfm. (Accessed 23 February 2022).

U.S. Bureau of Economic Analysis. Personal Consumption Expenditures (USBEA PCE), retrieved from FRED, Federal Reserve Bank of St. Louis. https://fred.stlouisfed.org/series/PCE. (Accessed 29 June 2022).

U.S. Environmental Protection Agency (USEPA), 1971. National ambient air quality standards. Fed. Regist. 37 (67), 10842–10906, 2.

U.S. Environmental Protection Agency (USEPA, 1972a. *Federal Air Quality Control Regions*. PB229-701. January 1972.

U.S. Environmental Protection Agency (USEPA), 1972b. Air programs – approval and promulgation of implementation plans. Fed. Regist. 37 (105), 6680–6701, 3.

U.S. Environmental Protection Agency (USEPA, 1973. State Air Pollution Implementation Plan Progress Report, January 1, 1973 to June 30, 1973. EPA450/2-73-005. September 1973.

U.S. Environmental Protection Agency (USEPA), 1976. State Air Pollution Implementation Plan Progress Report, January 1, 1976 to June 30, 1976. EPA450/2-76-026. October 1976.

U.S. Environmental Protection Agency (USEPA), 1978. National ambient air quality standards. Fed. Regist. 43 (43), 8962–9059. Part 3.