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Three-City Air Study

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Abstract

This study analyzes the local regulatory and non-regulatory determinants of ambient air quality in Allegheny, Baltimore, and Cuyahoga Counties over the period 1972-1992. Mandated pollution control investments appear to have often had a statistically significant effect in reducing maximum concentrations of suspended particulates and tropospheric ozone in these areas. The effects of regulatory air quality controls, however, generally have been overshadowed by the impacts of non-regulatory factors. In general, local regulatory and non-regulatory factors failed to account for a majority of the variation in local air quality. This underscores the importance of regional or national factors in determining local air quality.

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Three-City Air Study

*Mark R. Powell**

1. INTRODUCTION

This study analyzes the effects of mandated pollution control investments and non-regulatory factors (e.g., level of manufacturing activity) on ambient air pollutant concentrations in three Rust Belt metropolitan counties over the period 1972-92. The pollutants analyzed are suspended particulates and tropospheric ozone. The focus of the analysis is on changes occurring in the high-end of the annual distribution of ambient concentrations (reported maxima) where exceedances of National Ambient Air Quality Standards (NAAQS) would be expected to occur. The counties studied are Allegheny, PA (which includes the city of Pittsburgh); Baltimore, MD (Baltimore); and Cuyahoga, OH (Cleveland). These counties were selected because they are metropolitan areas where the level and composition of economic activity substantially changed concurrently with the implementation of NAAQS. In all three cities, steel manufacturing was, and to some extent remains, an important industry.

Previous econometric studies have concluded that there is little evidence of an association between pollution control investments and air quality. Broder (1986) examined changes in Total Suspended Particulates (TSP) concentrations between 1973 and 1977 in a sample of 93 metropolitan areas. The study attempted to control for weather, the level and composition of industrial activity, and the pollutant content in the fuels burned by households and electric utilities. No correlation was found between either pollution control investment or the pollutant content of fuels on the one hand and air quality on the other.¹ However, when the analysis was restricted to the eastern U.S., increased pollution control investments were associated with decreased TSP levels. MacAvoy (1987) attempted to relate total pollutant emissions by industry to each industry's investments in pollution control, annual coal usage, output price, and total investment in plant and equipment. The study concluded that pollution control investment plays a limited role in explaining pollutant emissions by industry, and that economic variables like coal usage, total investment, and product price have much greater explanatory power.

There are important limitations to these two studies. Broder's study covers many geographic areas, but it is based on a limited period of time early in the development of national air pollution controls. While this early period may have offered some "low hanging fruit" in terms of air pollution control efforts, it may not reflect the later benefits of institutional learning regarding the implementation of national ambient air quality standards. MacAvoy's

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¹ A possible explanation for the failure of Broder's study to detect a fuel quality effect is that, according to Energy Information Administration officials, data available prior to 1985 on the consumption of various fuels by power plants are unreliable.

study suffers from the same limitation of all efforts to evaluate the determinants of air pollution emissions. Unlike ambient concentrations, reported emissions are not actually measured. Instead, they are based on engineering estimates (i.e., formulae). Therefore, reported emissions may be predicted with absolute certainty, if only the investigator has access to the equations that were used to develop the estimates. If the engineering estimates assume that pollution controls have a limited effect on emissions, then analyzing reported emissions data can lead to no other conclusion.

More recently, Henderson (1995), evaluating data from 1977-87, concluded that a 1% increase in annual state pollution abatement expenditures leads to about a .04% improvement in local ambient ozone readings and that increased local efforts to control ozone have resulted in spreading out economic activity geographically (moving into areas classified as in attainment with the NAAQS) and through time (stretching activity over the day to dampen peaks in ozone inducing activity).

Casual observation of Rust Belt cities such as Pittsburgh suggests that air quality has improved dramatically over the past few decades. At least in Pittsburgh, this trend is often attributed to the decline of the steel manufacturing sector in the city. However, as evidenced by the disposal of their residuals, stationary source air pollution control technologies undeniably prevent some emissions of particulates and their precursors. The question is whether the signal of the pollution controls can be discerned through the noise of economic, meteorological, demographic, and other changes that contribute to changing ambient pollutant levels. If the effects of mandated pollution control investments can be detected in urban areas where economic changes have been stark, then we arguably would have more confidence that significant regulatory effects have occurred where changes in the level and composition of economic activity have been less dramatic.

While visible forms of air pollution such as smoke, soot, and ash may have declined along with traditional, heavy manufacturing in the Rust Belt, tropospheric ozone is invisible and is most closely associated with vehicular emissions, which, absent controls, may be expected to track with sprawling suburbanization (and perhaps also with a transition to a regional economy based on geographically dispersed light manufacturing and the service sector). If less tangible air pollutants have not diminished over time, then the casually perceived improvement in overall air quality in Rust Belt urban areas may be somewhat overstated.

2. DATA

a. Dependent Variables: Ambient Air Monitoring Data

Because reported air pollutant emissions are based on engineering estimates (as discussed above), this study only analyzes data measured at ambient air monitoring sites. Furthermore, the data analyzed cover a period of up to 20 years, coinciding with the early and more mature developmental stages of national regulatory air pollution controls. The data entered into the analysis are restricted, however, to the highest pollutant concentrations

recorded in each of the counties in a given year. (See discussion of EPA's "Quick Look Report" below.)²

The USEPA Region 5/Air and Radiation Division/Ambient Monitoring Section retrieved ambient air monitoring data on suspended particulate matter (total suspended particulates (TSP) and PM₁₀) and tropospheric ozone in Allegheny, Baltimore, and Cuyahoga counties for the period 1972-92 from the USEPA Aerometric Information Retrieval System/Air Quality Subsystem (AIRS/AQS). The TSP and PM₁₀ data are reported in units of micrograms per cubic meter ($\mu\text{g}/\text{m}^3$). PM₁₀ indicates particulate matter smaller than 10 microns in diameter. PM₁₀ replaced TSP as the basis of the NAAQS for particulates in 1987. The ozone data are reported in units of parts per million (ppm). EPA retrieved the data by generating a Quick Look Report, which summarizes the four worst air quality days for each monitoring site-year.³ The report extracts from the AIRS database the first through fourth maximum observations for each monitoring site in each year (i.e., site-year) in the selected geographic area. For particulates, the reported maxima are maximum 24-hour values. For ozone, the reported maxima are valid daily 1-hour maxima. This snippet of the high-end tail of the annual distribution of air quality data is where one would expect to find exceedances of the NAAQS for particulates and ozone, if they occur in the metropolitan area. It is not indicative of typical ambient air quality levels.

Data extracted by the Quick Look Report were eliminated from the analysis if they were coded as not satisfying EPA's data quality criteria for summary statistics. PM-10 data measured by low-volume suspended particulate samplers were also eliminated from the analysis.⁴ Despite these efforts to assure the quality of the ambient air data used in the analysis, two principal concerns remain. First, the report provided no TSP data at all for Allegheny County and no ozone data for the county prior to 1978.⁵ Secondly, it was unclear from the report how observations were determined not to satisfy EPA's data quality criteria, and there may have been errors in coding the data as satisfying or not satisfying EPA's data quality criteria.⁶ In addition, the observations used in the analysis do not represent a random

² It should be noted that air quality planning areas and airsheds often encompass multiple counties; therefore, while the county is a convenient geographic unit of analysis for the purposes of analyzing the impact of local economic factors, it may be smaller than optimal for the purposes of analyzing local ambient air quality trends.

³ Reporting the four worst air quality days for each year permits calculation of the expected number of exceedances of the NAAQS to determine whether an area is in or out of compliance with the standards. The Quick Look Report provides an estimate of the central tendency (the geometric mean) of the TSP site-year data but not for the ozone data.

⁴ Low-volume samplers reportedly generate more variable measurements than do high-volume samplers.

⁵ It remains unclear whether the data does not exist in any form, the AIRS database lacks the data, or the database manager was simply unable to extract it from AIRS.

⁶ It was particularly troubling that *none* of the ozone data were coded as not satisfying summary criteria despite some apparently wide gaps between the indicated number of measurements for a site-year (as low as 12) and the required number of measurements (214 for the ozone season). Discussions with EPA Region 5 personnel were unsuccessful in shedding much light on these problems. For example, it was considered plausible that

sample of air quality in each of the three counties.⁷ Furthermore, the data do not permit treatment of the monitoring sites themselves as the geographic unit of analysis.⁸

TSP: The Quick Look Report extracted a total of 500 TSP records for Baltimore and Cuyahoga counties for 1972-92. TSP data from 1972 were not used in the analysis because air pollution abatement and control expenditures data at the state level were not available until 1973. After eliminating unsatisfactory observations, a total of 290 observations were used in the analysis. (Baltimore--1973-89, 116 observations, 3-8 valid observations per year. Cuyahoga--1973-92, 187 observations, 2-16 valid observations per year.)

PM-10: The Quick Look Report extracted a total of 137 PM-10 records for Allegheny, Baltimore, and Cuyahoga counties for 1984-92. After eliminating unsatisfactory observations, a total of 63 observations were used in the analysis. (Allegheny--1985-92, 20 observations, 0-5 valid observations per year. Baltimore--1984-92, 24 observations, 0-7 valid observations per year. Cuyahoga--1984-92, 19 observations, 0-7 valid observations per year.)

Ozone: The Quick Look Report provided 106 observations for Allegheny, Baltimore, and Cuyahoga counties for 1972-92.⁹ (Allegheny--1978-92, 29 observations, 1-2 observations per year. Baltimore--1972-92, 54 observations, 1-4 observations per year. Cuyahoga--1972-92, 23 observations, 1-2 observations per year.) Yosie *et al.* (1994) report that ozone data obtained before 1979 suffer from a calibration error. Therefore, in addition to analyzing the data pooled over the 1972-92 period, the pre-1979 and post-1978 ozone data were analyzed separately.¹⁰

b. Independent Variables

In examining changes observed in suspended particulate concentrations, this study attempted to assess the effects of county-level estimates of the level of manufacturing activity,

most or all of the ozone site-years would satisfy EPA summary criteria and that some of the lowest reported number of measurements could be erroneous.

⁷ Ambient air quality monitors are supposed to be placed on sites within air quality planning zones where exceedances of ambient air quality standards are expected to occur. It remains unclear, however, whether monitoring sites are, in fact, located where air quality is poorest.

⁸ The location and number of observations (valid or otherwise) from monitoring sites in the three counties varies considerably over time. It is unclear whether this could have biased the results of the analysis, and if so, whether the bias would be non-negligible. At a minimum, however, this, along with the other deficiencies noted in the data, reduces confidence in the results of the analysis.

⁹ Although none of the data were coded as not satisfying summary criteria, for 14% of the ozone site-years, the number of 1-hour measurements indicated in the Quick Look Report are less than half the number required (214).

¹⁰ The Quick Look Report, however, indicated no discontinuity or pattern in the ozone sampling method coding in the neighborhood of 1979. Thus, it remains unclear whether the reported measurements are actually based on the pre-1979 measurement protocol or the later protocol. It seems plausible that there could have been some local variability or lag in implementing the new protocol.

electric power generation and fuel consumption, and cumulative pollution control expenditures. For ozone, this study attempted to assess the effects of local weather, vehicular travel, and cumulative pollution control expenditures.

Manufacturing Activity: The level of manufacturing activity was estimated from the value of shipments (VOS) for each county reported in the Commerce Department's Census of Manufacturers Geographical Area Statistics.¹¹ County-level reports are available for 1972, 77, 82, 87, and 92. Linear interpolation was used to estimate VOS for years between reports. VOS was expressed in constant 1987 dollars using the implicit price deflator (*1995 Economic Report of the President*, Table B-6). The Census of Manufacturers Geographical Area Statistics reports were also the source of state-level (Pennsylvania, Maryland, and Ohio) VOS data used to derive imputed estimates of other independent variables described below.

Electric Power: Data on aggregate electric utility power generation (thousands of kilowatt-hours) for all plants (with capacity greater than 10 megakilowatt-hours) in each of the three counties for the period 1972-92 were compiled from annual reports (Form EIA-767) supplied by the Department of Energy/Energy Information Administration (EIA).¹² Coal consumption (thousands of tons) data were also compiled from the EIA reports, but only for the period 1985-92.¹³

Meteorological Data: Reports obtained from the Department of Commerce National Climatic Data Center provided data for 1972-92 for each of the three counties on the number of days in each year with temperatures exceeding 90° F.¹⁴

Vehicle Miles Traveled (VMT): Limited VMT (millions of annual vehicle miles) data were available at the county-level.¹⁵

¹¹ Changes in the composition of manufacturing activity over time were not included in the analysis because the county-level Census of Manufacturers reports frequently do not disclose VOS and other economic information at highly aggregated industrial sector levels (i.e., 2-digit SIC codes).

¹² The Allegheny and Cuyahoga County Health Departments and the Maryland Department of the Environment (for Baltimore county) were consulted to assure that all local utility plants that contribute significantly to criteria air pollutant emissions in the three counties were captured in the analysis. In a few cases, for example, electric power plants operated by utilities serving a county were included in the EIA reports but were actually located just outside the county border. After consulting with local environmental and public health officials, data from these plants were included in the analysis.

¹³ EIA officials suggested that data available prior to 1985 on the consumption of various fuels by power plants are unreliable.

¹⁴ The reported temperatures, however, are measured at local airports where peak daily summer temperatures would tend to be significantly lower than those measured in central city locations. Other meteorological conditions such as the occurrence of wintry temperature inversions and stagnant hot air masses would also contribute to higher ambient levels of suspended particulate matter and ozone; however, data on the annual frequency of such episodes are not routinely reported.

¹⁵ Sources: Maryland State Highway Administration; South Western Pennsylvania Regional Planning Committee; North-East Ohio Area-Wide Coordinating Agency.

Year	Baltimore	Allegheny	Cuyahoga	Year	Baltimore	Allegheny	Cuyahoga
1977		16.8		1987	5841		
1980	4734	17.1		1988	5825		
1981	4699			1989	6197		
1982	4665			1990	6451	18.0	26.6
1983	5197			1991	6555		
1984	5141			1992	6594		
1985	5389	18.8		1993	6743		
1986	5698			1994	6939		27.4

State-level VMT data for 1972-94 (millions of annual vehicle miles) were provided by the Department of Transportation, Federal Highway Administration, Office of Highway Information Management (annual *Highway Statistics* reports, Table VM-2). For missing years, VMT was estimated for each county by the following regression equation:

$$VMT_{county} = b_0 + b_1 VMT_{state} (POPULATION_{county} / POPULATION_{state}).^{16}$$

Population Data: County and state population estimates for 1972-92 were compiled from Commerce Department Census Bureau reports.

Regulatory Compliance Costs: State-level capital and operating stationary source air Pollution Abatement and Control Expenditures (PACE) data for 1973-92 were compiled from Commerce Department reports. Because no PACE survey was conducted in 1987, data for that year were estimated by linear interpolation. EPA (1990, Table 3-6) provided estimates of national-level stationary source and particulate matter air pollution control cost data for 1972-92. County-level capital and operating regulatory compliance costs for controlling particulate matter pollution were estimated for each year by the following equation:¹⁷

$$PM-PACE_{co} = (VOS_{co} / VOS_{state}) (Sta-PACE_{state}) (PM-PACE_{nat'l} / Sta-PACE_{nat'l})$$

where:

PM-PACE_{co} = county-level particulate matter air Pollution Abatement and Control Expenditures

VOS_{co} = county-level Value of Shipments

VOS_{state} = state-level VOS

Sta-PACE_{state} = state-level stationary source air PACE

PM-PACE_{nat'l} = national-level particulate matter PACE

Sta-PACE_{nat'l} = national-level stationary source air PACE

¹⁶ Given the paucity of reported VMT data and the uncertainties involved estimating county-level VMT from state-level VMT, the reliability of the VMT estimates are suspect.

¹⁷ If a county represented a disproportionate share of pollution abatement control expenditures in the state, which would seem likely if it was the predominant area of NAAQS non-attainment in the state, then it seems likely that this equation would underestimate county-level PACE expenditures to some extent. While Pennsylvania and Ohio contain multiple, major metropolitan areas, Baltimore is the principal metropolitan area in Maryland. Therefore, the PACE estimates for Baltimore County are probably the least reliable.

To analyze the effects of pollution control investments on ambient air quality trends, cumulative regulatory compliance costs were considered.¹⁸ Cumulative particulate matter regulatory compliance costs for each year were estimated by summing estimated capital expenditures to date and adding the current year's estimated operating costs. Thus, stationary source air pollution controls were assumed to have a non-diminishing 20 year capital life. State and county data were converted to constant 1987 dollars; EPA (1990) reported annual national costs in 1986 dollars.

$$\text{Cumulative PM-PACE}_i = \sum_i \text{Capital PM-PACE}_i + \text{Operating PM-PACE}_i$$
 where $i = 1973, \dots, 1992$.

To estimate ozone pollution control costs, the costs associated with the control of volatile organic compounds (VOCs) from stationary sources were combined with the costs of mobile source controls.¹⁹ County-level capital and operating regulatory compliance costs for controlling stationary VOCs were estimated for each year by the following equation:

$$\text{VOC-PACE}_{\text{co}} = (\text{VOS}_{\text{co}}/\text{VOS}_{\text{state}})(\text{Sta-PACE}_{\text{state}})(\text{VOC-PACE}_{\text{nat'l}}/\text{Sta-PACE}_{\text{nat'l}})$$

where:

VOC-PACE_{co} = county-level Volatile Organic Compounds stationary air Pollution Abatement and Control Expenditures

VOS_{co} = county-level Value of Shipments

VOS_{state} = state-level VOS

Sta-PACE_{state} = state-level stationary source air PACE

VOC-PACE_{nat'l} = national-level VOC PACE

Sta-PACE_{nat'l} = national-level stationary source air PACE

Because state-level PACE data were not available for mobile sources, county mobile source ozone control costs were estimated from national mobile source control cost data.²⁰ Total

¹⁸ It should be noted that there may be a time lag between when pollution control investments are made and when they come on-line. Because cumulative compliance costs were considered, however, lag effects were not expected to have a substantial impact on the results of the statistical analysis.

¹⁹ Although control of VOCs from stationary sources would commonly be motivated by controlling emissions of Hazardous Air Pollutants, control of VOCs from any source would reduce emissions of ozone precursors.

²⁰ Unlike the case of stationary source air pollution control costs for which EPA (1990) disaggregated costs by pollutant, EPA (1990) did not break-down national mobile source air pollution control costs by pollutant (i.e., ozone, carbon monoxide, lead, etc.). Therefore, total mobile source control costs were used. Although some of the mobile source controls would have no impact on ozone formation (e.g., lead), mobile source controls based on improved combustion efficiency--whether specifically targeting ozone or not--would presumably contribute to reduced ozone formation. Assuming that mobile source ozone control costs represent a constant proportion of total mobile source control costs (at least over the period of analysis), total mobile source control costs would overestimate ozone control costs in a consistent fashion.

county-level ozone control costs, therefore, were estimated for each year by the following equation:²¹

$$\text{Ozone-PACEco} = (\text{MOBILEnat'l})(\text{POPco}/\text{POPnat'l}) + \text{VOC-PACEco}$$

where:

Ozone-PACEco = total county-level ozone pollution control costs

MOBILEnat'l = national mobile source pollution control costs

POPco = county population

POPnat'l = national population

VOC-PACEco = county-level Volatile Organic Compounds stationary air Pollution Abatement and Control Expenditures

Cumulative stationary source VOC control costs for each year were estimated by summing estimated capital expenditures to date and adding the current year's estimated operating costs. Thus, stationary source air pollution controls were assumed to have a non-diminishing 20 year capital life. Mobile source controls, on the other hand, were assumed to have a non-diminishing 10 year capital life (i.e., cumulative mobile source control costs were estimated by summing over the preceding 10 years.)

3. STATISTICAL ANALYSIS

Some would argue that air quality data before the mid-1970s, or in some cases later, are of such dubious quality that they should not be included in trend analyses. However, if, as conventional wisdom suggests, early regulatory actions pick most of the "low hanging fruit," then excluding early data runs the risk of restricting the analysis to the flat part of the curve. Therefore, there is some practical justification for evaluating the trends over the entire period of available data. In addition, measurement error in the ambient air quality data would tend to increase the unexplained variability in reported trends but would not bias the statistical estimates of the effects of the presumed determinants of air quality trends. Nevertheless, in addition to analyzing the data over the longest complete time series available, the TSP and ozone data were broken into two time series for analysis. For TSP, these periods are 1973-82 and 1982-92. For ozone, they are 1972-78 and 1979-1992 (presumably after the calibration adjustment was made). (The PM-10 data were not similarly broken up into sub-series because the standard was only established in 1987.)

Because multiple observations from the same ambient monitoring site in the same year are influenced by essentially the same dynamics (apart from day-to-day variation), it would be inappropriate to treat them as independent measurements and is necessary to summarize the site-year data for the purposes of statistical analysis. Each data point, therefore, represents the median of the four maximum values reported for each site-year (for particulates, the four maximum 24-hour values ($\mu\text{g}/\text{m}^3$); for ozone, the four maximum valid daily 1-hour values (ppm)). Generally, this sort of data aggregation results in an improved fit of the regression

²¹ Stationary VOC control costs were not included in the estimates of total ozone control costs for the two observations in 1972 when state-level air PACE data were unavailable. However, stationary VOC control costs were a minor contributor to estimated total control costs for other years.

(i.e., a higher R^2) and less efficient parameter estimates (meaning that the statistical significance tests of the parameters are less sensitive) (Greene 1993). Because the medians are all based on four observations, however, it is expected that their variances are equal and that the resulting parameter estimates remain unbiased. The practical consequence of the information loss associated with this data aggregation is that the error band around the estimated regression equations may not always contain *the* highest ambient air pollutant concentrations recorded.

It should be re-emphasized that the high-end data used in this analysis come from a restricted part of the underlying annual distribution of observations from the ambient air quality monitoring sites. This study makes no attempt to draw from this truncated sample inferences about the entire distribution of observations. This investigation is limited to analyzing the effects of various regulatory and non-regulatory factors on the high-end part of the distribution--i.e., where exceedances of NAAQS are expected to occur--and should not be misinterpreted as explaining changes in more typical values (e.g., the median) of ambient air pollution concentrations.

The data analysis was performed using weighted least squares (WLS) regression to relax the ordinary least squares (OLS) assumptions of no heteroscedacity and no autocorrelation of the residuals. (The variances were expected to vary among counties due to differences in underlying economic trends across counties and because the time series from different counties were not strictly concurrent in all cases. The assumption of no autocorrelation is frequently violated with time series data).²²

Autocorrelation was estimated to be statistically significant ($p \leq 0.05$) only in the case of the PM-10 data; therefore the WLS analyses of the TSP and ozone data were conducted relaxing only the assumption of no cross-sectional heteroscedacity. For each county and model specification combination, the data were tested for autocorrelation by: 1) collapsing the data (which could have one or more observations per county-year) into a single time series of mean values of the model parameters for each county-year; 2) conducting a WLS analysis of the collapsed data (with analytical weights equal to the number of observations in the county per year); and 3) testing the serial correlation of the resultant residuals.²³

The PM-10 data were corrected for autocorrelation prior to performing WLS by adapting the Prais-Winsten transformation (Greene 1993, p. 456). The transformation applied the estimated autocorrelation for each county to each site observation in the county and used

²² The parameter estimates could be biased when the data were pooled if the intercepts differ among counties, but dummy variables for the counties were not used in analyzing the pooled data in order to conserve the power of statistical tests. The unpooled data were separately analyzed to evaluate effects of factors within individual counties, but in some cases there were relatively few observations from which to draw inferences.

²³ Applying this method of testing for autocorrelation presumes that the monitoring sites can be treated as a random sample of the county, though, as indicated above, the sites are supposed to be located in areas where NAAQS exceedances are most likely to occur.

the mean value of observations from all j sites in year $t-1$ to transform each observation in year t :

$$\mathbf{x}_{*t} = \begin{bmatrix} (1-r_i^2)^{1/2} x_{ij1} \\ x_{ij2} - r_i \bar{x}_{i1} \\ x_{ij3} - r_i \bar{x}_{i2} \\ \dots \\ x_{ijT} - r_i \bar{x}_{iT-1} \end{bmatrix}$$

where: \bar{x}_{it} = the mean value over j monitoring sites for county i in year t
 r_i = the estimated autocorrelation for county i for year $1 \dots T$.

4. RESULTS

a. TSP

Figure 1 shows the marked decline in TSP concentrations (maxima) in Baltimore and Cuyahoga over the period 1972-92. (The flat line in the figures indicates the 24-hr. NAAQS for TSP ($260 \mu\text{g}/\text{m}^3$), while the curved line (formed using a Lowess smoother) roughly sketches the trend in the data over time. Recall that the Quick Look Report provided no TSP data at all for Allegheny County.) [Figures are available from the author.]

The value of manufacturing shipments (VOS), aggregate electric utility power output, and cumulative particulate matter control costs (CC) were hypothesized to be local determinants of TSP concentrations. Aggregate electric power output, however, did not significantly contribute to predicting TSP maxima. (It was dropped in forward and backward stepwise regression with VOS and CC, therefore, it was not retained in the final model specification.) This result is probably due to differences in the quality of fuels consumed over time and across counties. Table 1 displays the results of the analysis of the final model specification, which included only value of shipments and cumulative control costs. (Unless otherwise indicated in the tables below, factors are significant at $p \leq .05$.)

Note that over the period 1973-92, both VOS and CC account for 41% of the variation in TSP maxima in Baltimore and Cuyahoga. After controlling for VOS (i.e., holding VOS "constant"), CC accounts for 16% of the variation in both counties over the same period. The effect of pollution control investments in reducing TSP concentrations (maxima) also appears considerably stronger in Baltimore county than in Cuyahoga county. (It should be noted that VOS and CC are highly correlated, making it difficult to tease apart their "independent" effects with much confidence. Because many of the factors in the models analyzed in this study are correlated, coefficients for individual factors should be interpreted with extreme caution. Also, although the tables below display the squared partial correlations for non-regulatory factors in the tables, the reader should focus attention on those for CC since, while pollution controls are considered to be "caused" by non-regulatory factors, the reverse does not hold.)

It is difficult to draw a simple conclusion from the differing results of the two time series (1973-82 & 1982-92). Both manufacturing activity and pollution controls (i.e., the

model) account for less of the variation in TSP concentrations (maxima) in the later period, and it appears that TSP controls may have had less of an effect, if any, in the later period, after controlling for the level of manufacturing activity. On the other hand, the lack of significance of the individual coefficients in spite of the moderately high R^2 is symptomatic of highly correlated regressors. In this case, the collinearity apparently prevents any effort to tease their individual effects apart.

Note also the statistically significant *negative* association between manufacturing activity and TSP maxima in Baltimore during 1982-92. This result probably reflects the changing composition of the manufacturing sector in Baltimore county. In contrast to Allegheny and Cuyahoga counties where the level of manufacturing activity declined and bottomed out over the period 1972-92, in Baltimore county, there were cyclical downturns in manufacturing activity and specific sectors (e.g., steel) declined. Across all manufacturing sectors, however, the level of activity rose overall in Baltimore county during 1972-92.

Table 1. TSP Results

Model: $TSP = b_0 + b_1VOS + b_2CC$

1973-92

Parameter estimates

County(ies)	b0	b1	b2	Root MSE
Baltimore	342.2929	-.0194091 (n.s.)	-2.30434	38.833
Cuyahoga	-20.90685	.0140037	-.3432456	71.71
BC	118.3224	.0101387	-.746018	56.738

Partitioned Variance

County(ies)	MODEL (Adjusted R^2)	VOS (Squared Partial Correlation)	CC (Squared Partial Correlation)
Baltimore	.32	n.s.	.22(-)
Cuyahoga	.33	.23	.03(-)
BC	.41	.37	.16(-)

1973-82

Partitioned Variance

County(ies)	MODEL	VOS	CC
Baltimore	.13	n.s.	.16(-)
Cuyahoga	.26	.14	.03(-)(+)
BC	.36	.33	.13(-)

Table 1. TSP Results (cont'd)

1982-92

Partitioned Variance

County(ies)	MODEL	VOS	CC
Baltimore	.03	.06(-)	n.s.
Cuyahoga	.02	n.s.	n.s.
BC	.28	n.s.	n.s.

TSP	Total Suspended Particulates	n.s.	not statistically significant
VOS	Value of Shipments	+	significant at 0.1 level
CC	Pollution Control Costs	-	sign of the coefficient is <i>negative</i>
BC	Baltimore and Cuyahoga Counties	Root MSE	Square Root of the Mean Square Error

b. PM-10

Figure 2 shows the decline in PM-10 concentrations (maxima) in Allegheny, Baltimore, and Cuyahoga counties during 1984-92. (The flat line in the figures indicates the 24-hr. NAAQS for PM-10 ($150 \mu\text{g}/\text{m}^3$), while the curved line (formed using a Lowess smoother) roughly sketches the trend in the data over time.) [Figures are available from the author.]

The value of manufacturing shipments (VOS), electric utility coal consumption (COAL), and cumulative particulate matter control costs (CC) were hypothesized to be local determinants of PM-10 concentrations.²⁴ Table 2 displays the results of the analysis of the final model specification, which included value of shipments, electric utility coal consumption, and cumulative control costs. (The county-level parameter estimates are not reported due to their marginal or lack of statistical significance.)

Note that over the period 1985-92, the model (VOS, COAL, and CC) account for 55% of the variation in PM-10 maxima in Allegheny, Baltimore, and Cuyahoga. However, only COAL is a statistically significant factor across the three counties. (A joint test of VOS and CC was non-significant.) The separate county-level results of the full model (VOS, COAL, and CC) should be interpreted cautiously. For each county, there were only approximately 20 PM-10 observations, making it difficult to draw any inferences about a model with four parameters (three factors plus the intercept). (The collinearity between COAL and CC ($r=0.51$) may be responsible for the lack of significance. VOS and CC are highly correlated ($r=0.96$), but a test of their joint significance was non-significant.)

²⁴ Recall that reliable data on the consumption of various fuels by power plants was available only for the period 1985-92; therefore, reliable coal consumption data were available for the entire length of the PM-10 time series but not so for TSP.

Table 2. PM-10 Results

Model: PM-10 = b0 + b1VOS + b2COAL + b3CC
1985-92

Parameter Estimates

Counties	b0	b1	b2	b3	Root MSE
ABC	63.20932	.0005845(n.s.)	.0105335	.0156439(n.s.)	37.891

Partitioned Variance

County(ies)	MODEL (Adjusted R ²)	VOS (Squared Partial Correlation)	COAL (Squared Partial Correlation)	CC (Squared Partial Correlation)
Allegheny	.50	.16(+)	n.s.	.13(-)(+)
Baltimore	.73	.13(+)	n.s.	n.s.
Cuyahoga	.86	.32	.21(+)	.16(-)(+)
ABC	.55	n.s.	.26	n.s.

Particulate Matter smaller than 10 microns in diameter

Allegheny, Baltimore, and Cuyahoga Counties

VOS Value of Shipments

n.s. not statistically significant

COAL Electric Utility Coal Consumption

+ significant at 0.1 level

CC Pollution Control Costs

- sign of the coefficient is *negative*

Root MSE Square Root of the Mean Square Error

c. Ozone

Figure 3 shows that ozone concentrations (maxima) converged toward the NAAQS over the period 1972-92. In other words, the variance in the ozone data reduced over time. A plausible explanation for the observed pattern is that while regulatory controls dampened the peak ozone concentrations, growth in ozone precursor emissions (e.g., due to increased vehicular traffic) elevated peak ozone concentrations, and the two opposing trends tightened the band of annual variation in the data. (The flat lines in the figures indicate the 1-hour NAAQS for ozone--0.08 ppm prior to 1979 and 0.12 ppm after 1979. The curved line (formed using a Lowess smoother) roughly sketches the trend in the data over time.) [Figures are available from the author.]

Over the period 1972-92, the full model (including the number of days in each year with temperatures exceeding 90° F (DD90), vehicle miles travelled (VMT), and ozone control costs (CC)) accounts for only 20% of the variation in ozone maxima in Allegheny, Baltimore, and Cuyahoga counties. After controlling for DD90 and VMT, CC accounts for 5% of the variation in the data. The effect of ozone controls appears to have been strongest in Allegheny county. Significant correlations between VMT and DD90 and CC may be responsible for the marginal significance and counterintuitive sign of the coefficient of VMT. It may also signify that the VMT estimates are particularly poor. Eliminating VMT from the model, however, does not appreciably alter the results of the analysis over the period 1972-92.

Due to the limited number of observations available prior to 1979 (30 between Baltimore and Cuyahoga counties; recall that the Quick Look Report provided no ozone data for Allegheny County prior to 1978), only DD90 and CC were evaluated for this period. As

indicated, the analysis was unable to detect any effect of pollution control investments on ozone maxima during the period 1972-78. In comparison to the period preceding the revision of the NAAQS for ozone in 1979, the model with and without VMT accounted for more of the variance in ozone maxima during the period 1979-92. After controlling for DD90 and VMT, pollution control investments accounted for 9% of the variation in ozone maxima in Allegheny, Baltimore, and Cuyahoga counties during this period.

Table 3. Ozone Results

Model: OZONE = b0 + b1DD90 + b2VMT + b3CC

1972-92

Parameter Estimates

Counties	b0	b1	b2	b3	Root MSE
Allegheny(a)	.4209072	.0009737	-.015926(+)	-.0001036	.01616
Baltimore	.1440769	.0008246	-4.93e-6(n.s.)	-.0001213(n.s.)	.03328
Cuyahoga	.2871685	.0008531(n.s.)	-.0084771(n.s.)	.0000685(n.s.)	.02365
ABC	.1214517	.009372	-2.53e-06(+)	-.0000569	.02505

Partitioned Variance

County(ies)	MODEL (Adjusted R ²)	DD90 (Squared Partial Correlation)	VMT (Squared Partial Correlation)	CC (Squared Partial Correlation)
Allegheny(a)	.41	.28	.10(+)(-)	.18(-)
Baltimore	.13	.09	n.s.	n.s.
Cuyahoga	.03	n.s.	n.s.	n.s.
ABC	.20	.14	.02(+)(-)	.05(-)

Model: OZONE = b0 + b1DD90 + b2CC

1972-92

Partitioned Variance

County(ies)	MODEL	DD90	CC
Allegheny(a)	.37	.33	.29(-)
Baltimore	.15	.09	.12(-)
Cuyahoga	.02	n.s.	n.s.
ABC	.19	.14	.02(+)(-)

1972-78

Partitioned Variance

County(ies)	MODEL	DD90	CC
Baltimore	0	n.s.	n.s.
Cuyahoga	0	n.s.	n.s.
BC	.15	.15	n.s.

Table 3. Ozone Results (cont'd)**Model: OZONE = b₀ + b₁DD90 + b₂VMT + b₃CC**

1979-92

Partitioned Variance

County(ies)	MODEL	DD90	VMT	CC
Allegheny(a)	.42	.29	.17(-)	n.s.
Baltimore	.53	.54	.20(-)	.17(-)
Cuyahoga	.12	.32(+)	n.s.	n.s.
ABC	.43	.38	.12(-)	.09(-)

Model: OZONE = b₀ + b₁DD90 + b₂CC

1979-92

Partitioned Variance

County(ies)	MODEL	DD90	CC
Allegheny(a)	.33	.34	.18
Baltimore	.43	.46	n.s.
Cuyahoga	.18	.31	n.s.
ABC	.37	.31	n.s.

DD90 Number of 90 degree days

VMT Vehicle Miles Traveled

CC Pollution Control Costs

a Allegheny ozone data began in 1978

Allegheny, Baltimore, and Cuyahoga Counties

n.s. not statistically significant

+ significant at 0.1 level

- sign of the coefficient is *negative*

Root MSE Square Root of the Mean Square Error

5. CONCLUSIONS

Overall, the results of this analysis suggest that mandated pollution control investments have often had a significant effect in reducing maximum air pollutant concentrations. The effects of regulatory controls, however, generally have been overshadowed by the effects of economic changes, weather, and other factors. Also, the failure of local factors (e.g., the level of local manufacturing activity and local pollution control investments) to account for a majority of the variation in local air quality underscores the importance of regional or national factors (both regulatory and non-regulatory) in determining local air quality.

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