Estimating Regulation-Induced Substitution:
The Effect of the Clean Air Act on Water and Ground Pollution

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Recent research has demonstrated that the Clean Air Act Amendments' (CAAAs) regulations are associated with reductions in manufacturing activity and improvements in ambient air quality (Henderson 1996, Becker and Henderson 2000 and 2001, Greenstone 2002 and 2003, and Chay and Greenstone 2003a and 2003b). Some portion of these reductions in emissions is due to lower output and changes in inputs. It is widely believed, however, that much of the reduction is due to air pollution abatement devices such as scrubbers and electrostatic precipitators. These abatement techniques remove the pollutants from the air, but due to the "Law of Conservation of Matter" they are not eliminated and the residuals are released into water bodies, landfills, or injected into the ground. The possibility that the CAAAs have the unintended consequence of increasing releases into other media has not been examined in the economics literature previously. If this cross-media substitution is important, then a complete accounting of the costs and benefits of this legislation requires measures of its extent and the damages associated with releases into each of these media.

This paper examines the effect of the CAAAs on the pollution emissions of the iron and steel industry (SIC codes 331 and 332) into all media from 1987-97. The CAAAs divide U.S. counties into pollutant-specific nonattainment and attainment categories, based on ambient concentrations of the relevant pollutants. Emitters of the controlled pollutants in nonattainment counties are subject to substantially greater regulatory oversight than emitters in attainment counties. The iron and steel industry is chosen for this case study, because it is an important source of industrial emissions of the pollutants regulated by the CAAAs.

I find that the CAAAs' lead, particulate matter (PM), and ground level ozone (O_3) nonattainment designations are associated with reductions in total emissions of these pollutants in the iron and steel industry. This decline in total releases is accomplished through approximately equal reductions in releases into the air and into all other media. Although data on output is unavailable, there is suggestive evidence that emissions per unit of output declined.

I. Brief Background

Clean Air Regulations. The CAAAs direct the Environmental Protection Agency (EPA) to set separate national ambient air quality standards -- a minimum level of air quality that all counties are required to meet -- for six criteria pollutants, including lead, O_3, and PMs. Based on the ambient concentrations, the EPA assigns separate nonattainment or attainment designations annually for each of the criteria pollutants in every U.S. county. The nonattainment designation is reserved for counties with ambient concentrations of the relevant pollutant that exceed the federal standard. Emitters of a pollutant in counties that are nonattainment for that pollutant are subject to stricter restrictions than emitters in attainment counties. Both state environmental agencies and the federal EPA are empowered to enforce the plant-specific regulations in these counties.[1] Previous research has demonstrated that the nonattainment designations are associated with substantial reductions in ambient air concentrations of O_3 and PM, as well as modest reductions in sulfur dioxide.

Emissions in Iron and Steel Production. The two predominant methods of steel and iron manufacturing in the United States are the Basic Oxygen Furnace (BOF) and the Electric Arc Furnace (EAF) processes. There are ample opportunities for the emissions of lead, PM, and volatile organic compounds (VOCs), a key ingredient in O_3, into the air in both the BOF and EAF processes. In the BOF process, including coking but excluding desulfurization, exhaust gas generally contains between 16.5-37.4 kg of PM per ton of steel produced. In the cleaner EAF process, the level of PM in the exhaust gas averages approximately 11 kg per ton of steel. Depending on the lead content of the scrap metal used in production, lead accounts for 0.22-0.77 kg of the PM releases into the air from the EAF process. Approximately 3.3 kg of VOCs are created during the coking process for every ton of steel produced.[2]

Plants can reduce air releases by decreasing output or altering the production process so that unabated emissions per unit of output decline. The possible alterations to production include the burning of "cleaner" coal, use of higher quality scrap metal as an input, and recycling and recovery of materials and/or waste for fuel use. These alternatives reduce emissions into all media.

An alternative approach is to use "end of pipe" abatement devices that reduce air emissions by separating the regulated pollutants from the escaping gas. Scrubbers, baghouses and electrostatic precipitators (ESPs) are the most common air pollution control devices in the iron and steel industries. Dry air or vapor scrubbers may be used to remove lead, PM and VOCs from the exhaust gas stream. Baghouses and electrostatic precipitators are effective for the removal of PM and lead from the exhaust gas. The removal efficiency of these devices ranges from 90%-99%, with scrubbers at the low end of this range (Henry and Heinke 1996). Due to the Law of Conservation of Matter, however, the pollutants are not eliminated but instead converted into wastewater or solids and these residuals are usually treated and then disposed of into landfills (either on- or off-site) or released into a water body. Consequently, these abatement devices reduce air emissions but increase releases into other media.

The subsequent analysis will test whether the nonattainment designation was associated with reductions in emissions into all media or only into the air. The results will lend insight into whether plants primarily relied on "end of pipe" devices to comply with the CAAAs.

II. Data Sources and Descriptive Statistics

Pollution Emissions Data. The *Toxics Release Inventory* (*TRI*) is one of the two primary data files used in this paper. The *TRI* is a plant level data file that contains identifying information about the facility (e.g., name, county of location, industry) and releases into the air, water, land, underground, and transfers off site of approximately 600 toxic chemicals. In the examined period (1987-97), facilities were required to report to the EPA if they: (1) had 10 or more full-time employees or the equivalent; (2) were in a covered SIC code (the entire manufacturing sector is covered); and (3) "manufactured" or "processed" more than 25,000 pounds or "otherwise used" more than 10,000 of any listed chemical during a calendar year.[3] Plants that meet (1) and (2) must file separate reports for each toxic chemical that exceeds the threshold. The average iron and steel plant files reports for four *TRI* chemicals per year. Notably, the only penalties associated with the TRI are for false reports, not for high levels of emissions.[4]

It is evident that the *TRI* is not a random sample of iron and steel plants. The number of iron and steel plants reporting per year ranges from between 600 to 850. In a given year, the number of plants in the *TRI* is approximately 1/3 of the number of iron and steel plants reported to be operating in the *County*

Business Patterns and roughly 1/2 of the plants with more than 10 employees in that data file. Beyond noting that it is likely that the *TRI* includes the plants that are the largest producers of pollution (and steel), there is little that can be done to account for the non-random sampling without information from another data set.[5]

The basis of the analysis is plant-level release data on the 270 toxic chemicals that are on the *TRI* list in each of the years from 1987-97. Importantly, many of these toxic chemicals can be classified as either lead, PMs, or VOCs, which are 3 of the 6 pollutants regulated by the CAAAs. This makes it possible to use the *TRI* for the first examination of the impacts of the CAAAs on plant emissions. "Lead" is one of the 270 listed chemicals. I contacted the EPA to determine which of the remaining chemicals are considered PM and/or VOCs, but these conversations did not lead to definitive classifications for many of the chemicals. Consequently, I also hired a PhD chemist to assign the chemicals to these two categories. Ultimately, I assigned 75 chemicals to the PM category and 175 to the VOCs category. Since 30 chemicals are included in both categories, I classify the remaining 50 chemicals as unregulated by the CAAAs.[6] These 50 chemicals are henceforth referred to as the "Unregulated" toxics. They may provide a valid counterfactual for the time path of media-specific releases of the regulated pollutants in the absence of the CAAAs.

The iron and steel industry was chosen for this case study, because it is one of the most important industrial sources of lead, PM, and VOCs. For instance, this industry accounts for 5.8% (18.9%) of emissions into the air (all media) of PM from the manufacturing sector according to calculations from the *TRI* data file. The comparable figures for VOCs and lead are 2.3% (2.3%) and 19.8% (13.5%), respectively.

Figure 1 reports trends in tons of raw steel produced by the entire iron and steel industry and emissions into the air of lead, PM, and VOCs from the plants in the *TRI*.[7] Each series is normalized by its 1987 value. In 1987 total raw steel production was 89 million tons and by 1997 it had increased more than 20% to almost 109 million tons. In this period of increased steel production, all three types of air emissions declined dramatically. In particular, lead emissions were 37% lower in 1997 than in 1987 and PMs and VOCs declined by 72% and 46%, respectively. These data suggest that air emissions of these pollutants per unit of output declined substantially during this period.

Nonattainment Data. The second primary data file contains the annual, attainment/nonattainment designations for each of the 6 regulated pollutants for the more than 3,000 U.S. counties. The *Code of Federal Regulations* (*CFRs*) publishes the identity of these counties each year. This data was hand-entered from the *CFRs* twice and discordant entries were checked to ensure accuracy. Importantly, the *TRI* contains a county identifier, which allows the two files to be merged.

There are 490 counties with iron or steel plants in operation in the 1987-97 period. All of these counties were attainment for lead from 1987 through 1991 but in the years from 1992-96 between 5 and 6 counties were nonattainment. The number of O_3 nonattainment counties rises from 178 in 1987 to 197 in 1992-93 and then declines to 146 in 1996.[8] Finally, the number of PM nonattainment counties varied little in this period, ranging from 58 to 71.[9]

III. Econometric Framework and Results

In order to explore the effects of the nonattainment designations on the growth of emissions of iron and steel plants, the plant-level data is fit to the following equation:

$$(1) \qquad \%\Delta E_{ipt} = (E_{ipt} - E_{ipt-1})/((E_{ipt} + E_{ipt-1})/2)$$

$$= \sum_{88}^{97} \delta_t + \beta\, 1(\text{Nonattain}_{ipt-1}) + \Delta\varepsilon_{ipt},$$

where $\Delta\varepsilon_{pt} = \alpha_p + \Delta u_{ipt}$. Here i indexes pollutant type (i.e., Lead, PM, VOCs, or "Unregulated"), p references a plant, t and t-1 index the current and previous year, respectively. $\%\Delta E_{ipt}$ is the dependent variable and is measured as the percentage change between t and t-1.[10] The specification includes a full set of year indicators, δ_t. The sample size is 8,626 in all specifications.

$\Delta\varepsilon_{pt}$ is the stochastic error term and it includes a plant-specific component, α_p. The estimated variance-covariance matrix allows for dependence of observations within the same plant over time but assumes independence across plants.[11] Since there is little variation in nonattainment status over time, it is not feasible to estimate models with plant or county fixed effects without a dramatic loss in precision.

The parameter β captures the growth in emissions in nonattainment counties relative to attainment ones. Recall, nonattainment status is assigned at the county level. Henceforth, β is referred to as the "regulation effect." Notably, the subsequent results are based on specifications that include the single "own-pollutant" nonattainment variable. For example, I make the restriction that lead nonattainment status has no effect on emissions of VOCs. These restrictions are discussed further below.

Table 1 reports the results from fitting equation (1) when total plant releases across all media is the dependent variables. The entries in the intersection of a row and panel report the parameter estimate, standard error, and R-squared from a separate regression. Columns refer to a pollutant-specific nonattainment parameter and panels are reserved for the pollutant-specific dependent variables. The low R-squared statistics reflect the difficulty in explaining the percentage change in plant-level emissions.

The first entry in the table suggests that on average total lead emissions by iron and steel plants declined by roughly 7.1% more in lead nonattainment counties than in attainment counties. The PM and O_3 parameters imply relative declines of 3.5% and 5.6% of PM and VOCs releases in nonattainment counties, respectively, and both of these estimates would be judged different from zero by conventional criteria. Overall, these three parameters indicate that total releases of lead, PM, and VOCs declined by 21,000 lbs, 24.2 million lbs, and 12.2 million lbs, respectively, in the relevant nonattainment counties over the entire period.[12]

The last panel presents the parameter estimates from separate regressions of total releases of the "Unregulated" toxics on the lead, PM, and VOCs nonattainment variables. A comparison of these entries with those in the first three panels reveals that the regulation effects on lead, PMs, and VOCs releases are of a larger magnitude. Under the assumption that the change in emissions of "Unregulated" toxics is proportional to the change in output, these findings imply that nonattainment status is associated with reductions in emissions of the regulated pollutants per unit of output.[13]

Tables 2A and 2B repeat this analysis for air releases and releases into all other media (i.e., the sum of water releases, underground releases and transfers to landfills), respectively. The air regulation effects reveal a negative association between each of the nonattainment designations and the relevant pollutant, although only the VOC regulation effect is statistically significant. If plants obtained these reductions in air pollution by installing "end of pipe" devices, then it is possible that releases to other media increased or at least decreased by less than air releases. However, the point estimates in Table 2B are at least as large in magnitude as those in 2A. This suggests that the regulations do not simply cause plants to substitute air releases for releases into other media, rather emissions into all media decline. This finding was foreshadowed by the results in Table 1. The regulation effects on the "Unregulated" toxics are again smaller, in some cases substantially so, than the regulation effects on the pollutants regulated by the CAAAs.

Equation (1) is a parsimonious specification, which raises the possibility that the results in Tables 1 and 2 are not robust. I probed these results in a number of ways. For example, I experimented with specifications that separately add 3-digit SIC by year indicators and state by year indicators. I also estimated equations that are weighted by the square root of the denominator of the dependent variable to account for differences in plant size. In all these cases, the qualitative results are unchanged.

Another specification issue is whether the estimating equation should include the "cross-pollutant" regulation effects. The estimates of the "own-pollutant" regulation effects (e.g., the effect of PM nonattainment status on PM releases) are qualitatively similar to the ones described above when the "cross-pollutant" parameters are included. It is reasonable to suspect, however, that the regulation of one pollutant causes releases of another pollutant to decline. In this case, it might be appropriate to treat the "cross-pollutant" parameters as genuine effects of regulation. Across the dependent variables, the "cross-pollutant" regulation effects are generally negative, small in magnitude, and statistically indistinguishable from zero. The notable exception is that VOCs nonattainment status is associated with a statistically significant decline in lead and PM emissions into all media.

IV. Discussion and Future Work

This case study of the iron and steel industries has demonstrated that the CAAAs' lead, particulate matter, and ozone nonattainment designations are associated with reductions in total emissions of these pollutants in this industry. These declines in total releases are achieved through reductions in releases into the air and other media. Although data on output is unavailable in the *TRI*, there is suggestive evidence that emissions per unit of output declined.

There are at least two directions for future research. First, it is important to understand whether these results hold in other industries. A crucial policy parameter that is poorly understood is the monetary value of pollution emissions in the production process. This parameter is important, because it provides a direct measure of the costs to firms of mandated reductions in emissions and easily can be compared to the benefits of these reductions (Chay and Greenstone 2003a, 2003b, and 2003c). This paper's results suggest that nonattainment status may be a valid instrumental variable for total releases in plant-level production functions. Thus, the second direction for future research is to use the nonattainment variables as instruments to obtain estimates of the economic value of emissions to plants.

REFERENCES

Ackermann, Richard, Gordon Hughes, David Hanrahan, Anil Somani, Sanjeev Aggarwal and Arthur FitzGerald. Pollution Prevention and Abatement Handbook 1998. Washington, D.C.: The World Bank, 1999.

Becker, Randy and Vernon Henderson. "Effects of Air Quality Regulations on Polluting Industries." Journal of Political Economy, April 2000, 108(2), pp. 379-421.

______. "Costs of Air Quality Regulation," in Carlo Carraro and Gilbert E. Metcalf, eds., Behavioral and Distributional Effects of Environmental Policy. Chicago: The University of Chicago Press, 2001, pp. 159-82.

Chay, Kenneth and Michael Greenstone. "Does Air Quality Matter? Evidence from the Housing Market." Mimeo, University of Chicago, 2003a.

______. "Air Quality, Infant Mortality, and the Clean Air Act of 1970." Mimeo, University of Chicago, 2003b.

______. "The Impact of Air Pollution on Infant Mortality: Evidence from Geographic Variation in Pollution Shocks Induced by a Recession." Mimeo, University of Chicago, 2003c.

Greenstone, Michael. "The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufacturers." Journal of Political Economy, December 2002, 110(6), pp. 1175-1219.

______. "The Impact of the Clean Air Act Amendments on Sulfur Dioxide Concentrations." Mimeo, University of Chicago, 2003.

Henderson, J. Vernon. "Effects of Air Quality Regulation." American Economic Review, September 1996, 86(4): pp. 789-813.

Henry, J. Glynn and Gary W. Heinke. Environmental Science and Engineering. Upper Saddle River, N.J.: Prentice Hall, 1996.

Liroff, Richard A. Reforming Air Pollution Regulations: The Toil and Trouble of EPA's Bubble. Washington, D.C.: The Conservation Foundation, 1986.

Table 1: Estimated Regression Models for the Effect of Nonattainment Status on Total Release of Toxics

Dependent Variable	Nonattainment Parameter		
% Change in Total Releases of:	Lead (1)	PM (2)	O_3 (3)
Lead	-.071	-----	-----
	(.040)	-----	-----
R-squared	.003	-----	-----
Particulate Matter	-----	-.035	-----
	-----	(.018)	-----
R-squared	-----	.006	-----
VOCs	-----	-----	-.056
	-----	-----	(.014)
R-squared	-----	-----	.014
"Unregulated" Toxics	-.033	-.022	-.023
	(.032)	(.008)	(.006)
R-Squared	.003	.004	.004

Notes: Each set of entries is from a separate regression. The entries report the R-squared statistic and the parameter and standard error from the nonattainment variable indicated at the top of the columns. The dependent variables are the change in plant total (i.e., into all media) releases of Lead (1^{st} panel), Particulate Matter (2^{nd} panel), VOCs (3rd panel), and "Other" (4^{th} panel) toxics between a year and the previous year (i.e., year t and t-1), divided by the mean of the t and t-1 levels. The data comes from the 1987-97 TRI sample of iron and steel firms and the sample size is 8,626. All specifications include year fixed effects. The estimated variance-covariance matrix allows for dependence of observations within the same plant over time but assumes independence across plants.

Table 2: Estimated Regression Models for the Effect of Nonattainment Status on Release of Toxics by Media

A. Air Releases

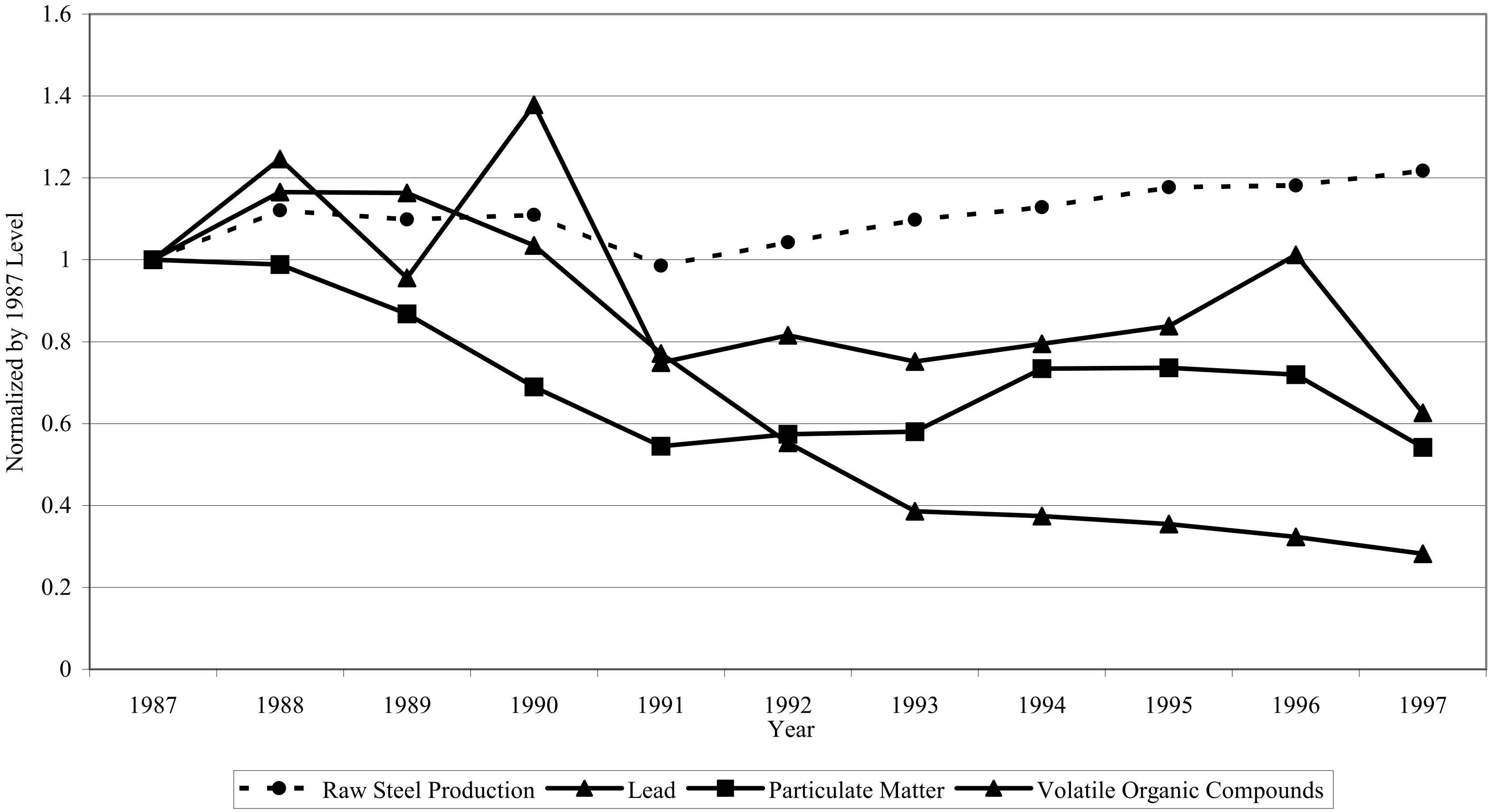
Dependent Variable % Change in Air Releases of	Nonattainment Parameter Lead (1)	 PM (2)	 O_3 (3)
Lead	-.077	-----	-----
	(.048)	-----	-----
R-squared	.002	-----	-----
Particulate Matter	-----	-.024	-----
	-----	(.015)	-----
R-squared	-----	.011	-----
VOCs	-----	-----	-.034
	-----	-----	(.014)
R-squared	-----	-----	.015
"Unregulated" Toxics	-.038	-.015	-.017
	(.032)	(.007)	(.006)
R-Squared	.006	.006	.006

B. Releases into All Other Media

Dependent Variable % Change in Other Media Releases of:	Nonattainment Parameter Lead (1)	 PM (2)	 O_3 (3)
Lead	-.083	-----	-----
	(.042)	-----	-----
R-squared	.006	-----	-----
Particulate Matter	-----	-.037	-----
	-----	(.016)	-----
R-squared	-----	.004	-----
VOCs	-----	-----	-.040
	-----	-----	(.011)
R-squared	-----	-----	.005
"Unregulated" Toxics	.013	-.014	-.017
	(.005)	(.006)	(.004)
R-Squared	.001	.002	.002

Notes: See the Notes to Table 1. In 2A the dependent variables are the change in plant air releases of Lead (1^{st} panel), Particulate Matter (2^{nd} panel), VOCs (3rd panel), and "Other" (4^{th} panel) toxics between a year and the previous year (i.e., year t and t-1), divided by the mean of the t and t-1 levels. In 2B the dependent variables are the percentage changes in the pollutant-specific releases into all media besides air.

Figure 1: Trends in Raw Steel Production and Air Emissions of Lead, Particulate Matter, and Volatile Organic Compounds in the Iron and Steel Industry, 1987-97



Notes: The Raw Steel Production data are taken from various issues of the American Iron and Steel Institute's *Annual Statistical Report*. The emissions data is calculated from the *Toxics Releases Inventory* (*TRI*) datafile. The steel production data reflects the output of all steel plants while the emissions data are based on the nonrandom sample of plants in the *TRI*. See the text for more details

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[1] See Liroff (1986) for a more detailed description of the CAAAs and the regulations they imposed on polluters.

[2] The estimates of emissions per ton of steel are from Ackermann et al. (1999).

[3] A number of EPA documents provide more information on the precise definitions of "manufacture", "process", or "otherwise use" and on other important elements of the *TRI*. See, for example, the *1996 Toxics Release Inventory: Public Data Release Report*, which is available at http://www.epa.gov/tri/tridata/tri96/pdr/.

[4] The data on releases are generally estimated from engineering pollution production functions that take account of the inputs and the installed abatement devices. In a minority of the cases, the release data is due to monitoring.

[5] Although the TRI is a nonrandom sample, the selection rule that determined whether a plant was required to report was constant throughout the 1987-97 period.

[6] The categorization of the 270 toxics into the lead, PMs, VOCs, and "Other" category is available upon request from the author.

[7] The raw steel production data are taken from various issues of the American Iron and Steel Institute's *Annual Statistical Report*. From this publication, it is not evident whether these production data cover all or part of SIC codes 331 and 332.

[8] There are separate nonattainment designations for O_3 and nitrogen dioxide, and, in principle, a county could be nonattainment for one but not the other. Since O_3 is the result of a complicated chemical process that involves nitrogen dioxide and VOCs, I consider a county to be O_3 nonattainment if it is listed as nonattainment for either O_3 or nitrogen dioxide. All future references to O_3 nonattainment status refer to this combined measure.

[9] During the 1987-97 period, a county could be designated for either or both PM_{10} (particles less than 10 μm in diameter) and total suspended particulates (particles less than 40 μm). In the analysis, a county is designated PM nonattainment if it is designated nonattainment for at least one of them.

[10] This measure of percentage change is an alternative to the difference of the natural logarithms of the year t and t-1 levels. It is a second-order approximation to the ln difference measure, ranges from -2.0 to +2.0, and portrays expansion and contraction symmetrically. Importantly, it allows the sample to contain observations on "births" and "deaths," that is plants that do not operate in either t-1 or t.

[11] An alternative is to allow for dependence of observations within a county by year. The standard errors on the regulation effects are essentially unchanged when this assumption is implemented.

[12] The point estimates are smaller in magnitude but the qualitative story is similar when entrants or entrants and exiters are dropped from the sample.

[13] These results can also be interpreted as providing a test of internal validity. From this perspective, it is reassuring that the regulation effects on the "Unregulated" toxics are smaller than the regulation effects on the regulated pollutants.