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Multimedia Pollution Regulation and Environmental Performance

EPA's Cluster Rule

Wayne B. Gray and Ronald J. Shadbegian

1616 P St. NW
Washington, DC 20036
202-328-5000 www.rff.org



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Abstract

In 1998 the US Environmental Protection Agency (EPA) promulgated its first integrated, multimedia (air and water) regulation, known as the Cluster Rule (CR), which aimed to reduce toxic releases from pulp and paper mills. By integrating the air and water regulations, EPA tried to reduce the overall regulatory burden on the affected plants. In this paper, we compare EPA's ex ante expected reductions to an ex post assessment of those reductions. Using data from 1991 to 2009 for approximately 150 pulp and paper mills for both toxic and conventional pollutants, we find significant reductions in chloroform releases, nearly identical to the ex ante prediction of 99 percent reductions. We see some reductions in air toxics, smaller than the ex ante prediction and not always significant. Reductions in VOC emissions are similar in magnitude to the ex ante predictions for OLS models but smaller for fixed-effect models. No significant impact is found on PM₁₀ emissions. We draw conclusions for regulatory impact analyses and retrospective analyses, including the importance of carefully identifying expected compliance methods and the potential sensitivity of these analyses to the definition of the baseline.

Key Words: air quality, air toxics, water quality, regulatory analysis, pulp and paper, Cluster Rule,

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Wayne B. Gray and Ronald J. Shadbegian*

1. Introduction

The US Environmental Protection Agency (EPA) typically regulates air emissions and water discharges in separate rulemakings. However, in many industries, pollution releases into air and water are highly correlated. A case in point is the pulp and paper industry. The papermaking process is pollution-intensive in terms of both air and water pollution. The production of paper involves two stages. In the first stage, pulp is created by separating some fiber source, ranging from trees and wood chips to recycled cardboard or waste paper, which is combined with water to create a slurry. This generates both conventional and toxic air and water pollution. During the second stage, the slurry (more than 90 percent water at the start) is placed onto a fast-moving wire mesh, which then passes through a series of dryers to remove the water and create a continuous sheet of paper. Conventional and toxic air pollution is caused by power-generating boilers, used to generate steam for the dryers, while conventional water pollution comes from residual fibers remaining in the water as the paper is dried. The conventional pollutants include sulfur dioxide (SO₂), particulate matter (PM₁₀), volatile organic compounds (VOCs), biochemical oxygen demand (BOD), and total suspended solids (TSS), and the toxic pollutants include dioxin, furans, chloroform, chlorinated compounds, formaldehyde, and benzene.

In 1998 EPA promulgated the first integrated, multimedia regulation, known as the Cluster Rule (CR). The goal of the CR was to reduce the pulp and paper industry's toxic releases into the air and water. By promulgating both air and water regulations at the same time, EPA made it possible for pulp and paper mills to select the best combination of pollution prevention and control technologies, with the goal of reducing the regulatory burden. In particular, Morgan

* Gray: Clark University and National Bureau of Economic Research, wgray@clarku.edu. Shadbegian: US Environmental Protection Agency and National Center for Environmental Economics, shadbegian.ron@epa.gov.

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et al. (2014) note that “by promulgating the air and water standards simultaneously, the EPA was able to develop control options that included process change technology that would control both emissions to air and pollutant discharges to water.”

To date, very few papers have examined the impact of multimedia regulations on environmental performance. One such paper by Gray and Shadbegian (2008) examines how the stricter regulations of the CR affected the releases of both air and water toxics. This paper focuses on how the discretion of state government regulators in implementing and enforcing regulations such as the CR (e.g., setting water permit discharge levels, the number of plant inspections) affects environmental outcomes. Gray and Shadbegian find some evidence that plants in states with less political support for stringent regulation had higher toxic releases on average throughout their sample period (1996–2005), but they also had larger declines in toxic releases over time. This suggests that existing differences in regulatory stringency across states may have been reduced by EPA’s adoption of the CR.

Other papers, including Snyder et al. (2003) and Popp and Hafner (2008), examine the effect of the CR’s chlorine regulations on technological innovation. Snyder et al. (2003) conduct an econometric analysis of the effects of the CR on the diffusion of technological change in the chlorine industry. They find that the CR reduced the demand for chlorine, causing chlorine plants to shut down and resulting in an increase in the share of chlorine plants using a cleaner production process. Using information on regulations affecting dioxins and patents from Canada, Finland, Japan, Sweden, and the United States, Popp and Hafner (2008) examine the relationship between regulations and patent activity. They find that pressure from the public to reduce the use of chlorine drove innovation before the promulgation of any environmental regulations. Finally, Bui (2005), using plant-level data, finds that regulation of conventional pollutants (measured by pollution abatement operating costs) also leads to the reduction of toxic releases.

In this paper, we compare EPA’s ex ante expected reductions in air and water releases to an ex post assessment of said releases. The goal of this assessment is to determine whether actual reductions in air and water releases diverged from ex ante estimates, and if so, what factors caused this divergence. Using data from 1991 to 2009 for approximately 150 pulp and paper mills, including information on both toxic and conventional pollutants, we find significant reductions in both air and water releases of chloroform that are nearly identical to the ex ante prediction of 99 percent reductions. There are also some reductions in air toxics, although these are smaller than the ex ante expected amount and not significant for all groups of regulated plants. There is some evidence of reductions in VOC emissions, although the results differ across estimation methods, with ordinary regression estimates similar in magnitude to the ex ante

predictions and fixed-effect estimates somewhat smaller. No significant impact is found on PM₁₀ emissions.

What can we learn from the Cluster Rule about conducting regulatory impact analyses and retrospective analyses? The CR was designed with a multimedia nature to reduce compliance costs, relative to using separate air and water regulations; actual compliance costs seem to have been relatively low, but we cannot observe what costs would have been from using separate regulations. Regulatory impact analyses should carefully describe expected compliance methods and potential heterogeneity in methods across plants to assist retrospective analyses in comparing the actual methods chosen with ex ante expectations. Finally, defining the baseline is crucial for measuring both benefits and costs, since there were considerable emissions reductions and abatement investments in the years before the CR took effect.

Section 2 provides background information on pollution from the pulp and paper industry and a brief history of the Cluster Rule. Section 3 reviews the relevant literature, while Section 4 presents a model of the determinants of environmental performance and discusses the data and empirical methodology. Section 5 presents the results, and Section 6 concludes.

2. Regulating the Pulp and Paper Industry

During the past 35 years, environmental regulation on the US manufacturing sector has become increasingly tougher in terms of both stringency and enforcement and monitoring. Prior to the creation of the federal Environmental Protection Agency (EPA) in the early 1970s, environmental rules were passed primarily at the state level and were not strictly enforced. Since the early 1970s, the federal government has been the primary player in developing more stringent regulations and placing larger emphasis on enforcement, much of which is still carried out by state regulatory agencies under varying levels of federal supervision.

The increasing stringency of environmental regulation has resulted in large compliance costs on traditional “smokestack” industries, like the pulp and paper industry, which is among the most highly regulated industries because of the considerable amounts of both air and water pollution it generates. These stringent regulations are costly to the pulp and paper industry, but they have been very successful in reducing the releases of both conventional and toxic air and water pollutants with the advent of secondary wastewater treatment, electrostatic precipitators, scrubbers, and input changes. Moreover, some pulp and paper mills have not just installed these end-of-pipe control technologies and input changes, but have also redesigned their production process, such as with increased monitoring of material flows to further reduce emissions. By and large these process modifications have been much easier to accomplish at newer plants, which were, at least to some extent, designed with environmental concerns in mind. In fact, some old

pulp mills were purposely built directly over rivers, so that any spills or leaks could flow through holes in the floor for “easy disposal.” These rigidities can be partially or completely counterbalanced for most air regulations by the tendency to include grandfather clauses exempting existing plants from the most stringent requirements—for example, until more recent rules restricted their NO_x emissions, most small, old boilers were exempt from air pollution regulations.

The entire pulp and paper industry faces significant levels of environmental regulation. However, plants within the industry face differential impacts from regulation, depending in part on their technology (pulp and integrated mills versus nonintegrated mills¹), age, geography, and the level of regulatory effort directed at the plant. Previous studies, including Gray and Shadbegian (2003), have shown that the most important determinant of the regulatory impact on a paper mill is whether the mill includes a pulping facility, since the pulping process (separating the fibers needed to make paper from raw wood) is much more pollution-intensive than the papermaking process.² The various pulping processes produce different environmental concerns: mechanical pulping uses more energy, thus producing air pollution from a power boiler, whereas chemical pulping can cause water pollution from spent chemicals, some of them potentially toxic (e.g. dioxin). Moreover, to produce white paper the pulp must be bleached. The kraft chemical pulping process was initially believed to be relatively low-polluting in terms of conventional air and water pollution. However, when the kraft process is combined with elemental chlorine bleaching, it generates chloroform, furan, and trace amounts of dioxin, causing concerns about toxic releases that contributed, at least indirectly, to the development of the Cluster Rule.

The Cluster Rule

An extremely unfortunate incident in Times Beach, Missouri (near St. Louis), helped bolster concerns about toxic pollutants in general and dioxin in particular. On December 5, 1982, the Meramec River flooded Times Beach, contaminating almost everything in the town with dioxin that had been part of a spray treatment meant to reduce dust from dirt roads in the early 1970s. The Centers for Disease Control determined that the town was uninhabitable, and in 1983

¹ Integrated mills produce their own pulp, whereas nonintegrated mills purchase pulp or use recycled wastepaper.

² The two main environmental concerns during the papermaking stage are air pollution, if the mill has its own power plant, and the residual water pollution generated during the drying process.

EPA bought Times Beach and relocated its residents, reinforcing the public's perception of the hazards of dioxin.

As a result of the Times Beach incident, two prominent environmental groups, the Environmental Defense Fund and the National Wildlife Federation, first petitioned and then sued EPA in 1985 for not sufficiently protecting the US public from the risks of dioxin. As part of a 1988 settlement with the environmental groups, EPA agreed to investigate the health risks of dioxin and to promulgate regulations to reduce dioxin emissions, and in 1993 the agency proposed the Cluster Rule. The 1993 proposed rule would have required bleached paper-grade kraft mills to completely eliminate elemental chlorine bleaching starting in mid-1995, expanding their use of oxygen delignification and extended delignification (see EPA 1998, 4–5). O₂ delignification decreases the levels of lignin in the pulp prior to bleaching, thereby minimizing the amount of bleaching chemicals required to brighten the pulp. After a public comment period, the Cluster Rule underwent substantial modification and was finally promulgated in 1998, 10 years after the consent agreement. Not only were fewer mills affected by the final rule than in the 1993 proposal (155 versus 300), but also the final rule did not require the use of O₂ or extended delignification. This led some firms to petition EPA and request rewards for their mills that had already installed O₂ delignification, suggesting that these modifications had been made in anticipation of regulation.

Beyond the benefits of protecting human health by lowering the pulp and paper industry's toxic releases into the air and water, EPA also estimated that the rule would result in cobenefits from reduced emissions of conventional pollutants, including volatile organic compounds and particulate matter. The Maximum Achievable Control Technology (MACT) regulations in the Cluster Rule became effective three years later, on April 15, 2001, while the best available technology economically achievable (BAT) effluent guidelines became effective upon renewal of the plant's National Pollutant Discharge Elimination System (NPDES) permit, which typically occurs on a five-year cycle.³ EPA believed that the combination of the air and water rules could achieve greater pollution prevention and process optimization than either regulation could on its own. For example, some of the requirements of the MACT rule, which was designed to reduce toxic air pollutants, will also reduce toxic pollutants in wastewater, and some of the technologies used to meet BAT provisions will further reduce air emissions. Thus by simultaneously promulgating both air and water regulations, EPA allowed pulp and paper mills

³ Opting into the Voluntary Advanced Technology Incentives Program delayed the compliance date by three years, but this was rarely used—only four plants used this, and they are not identified in our data.

to plan to meet multiple regulatory requirements at one time, with the goal of reducing the overall regulatory burden on the mills.

The MACT air regulations apply to mills that use chemical pulping and call for hazardous air pollutants to be reduced by 59 percent and for VOCs and PM to be reduced by 49 percent and 37 percent, respectively. The BAT water provisions apply to mills that combine chlorine bleaching with kraft chemical pulping and aim to nearly eliminate dioxin, furan, and chloroform discharges, reducing them by 96 percent, 96 percent, and 99 percent, respectively. EPA estimates that approximately 490 pulp and paper mills are subject to the new CR air regulations. Furthermore, any pulp and paper mill that has the potential to emit 10 tons per year of any particular hazardous air pollutant (HAP) or an aggregate of 25 tons per year of all HAPs is subject to the even more stringent maximum achievable control technology (MACT) standards for HAPs, under the National Emission Standards for Hazardous Air Pollutants (NESHAP). EPA estimated that 155 of the 490 affected pulp and paper mills would be subject to the new MACT standards. Ninety-six of the 155 MACT plants are also required to meet the new BAT standards, which, as noted above, become effective when the plant's NPDES permit is renewed, spreading out the effective dates for the plants in our sample over multiple years. Thus we have a set of regulations affecting air and water releases, with different sets of plants facing different levels of stringency on the different media, and with some of the stringency changes occurring at different times for different plants, which complicates any ex ante/ex post comparison.

3. Literature Review

While much of the empirical literature has examined the costs of pollution abatement, a growing literature, including studies by Magat and Viscusi (1990), Laplante and Rilstone (1996), Shadbegian and Gray (2003, 2006), Earnhart (2004a, 2004b), Shimshack and Ward (2005, 2008), and Gray and Shadbegian (2007), examines the environmental performance of polluting plants with respect to conventional air and water pollutants. In terms of the impact of water regulations, Magat and Viscusi (1990) and Laplante and Rilstone (1996) find that greater levels of water pollution enforcement activity result in lower water discharges. Furthermore, Shimshack and Ward (2005) find that one additional fine in a state for violating a water standard leads to roughly a two-thirds reduction in the statewide violation rate the following year, suggesting that the regulator's enhanced reputation has a general deterrence effect. In a second study, Shimshack and Ward (2008) provide evidence that monetary sanctions, even on other facilities, significantly increase overcompliance with regulations. Similarly, Glicksman and Earnhart (2007) examine the environmental performance of chemical facilities and find that monetary sanctions reduce discharges relative to permitted levels.

Earnhart (2004b) analyzes the impact of EPA regulations on the level of environmental performance of municipal wastewater treatment facilities in Kansas, finding that the *threat* of federal inspections and enforcement action and the *threat* of state enforcement action significantly increase environmental performance. In a second study, Earnhart (2004a) finds that both income of a community and its political activism tend to significantly reduce discharge rates of municipal wastewater treatment plants in Kansas. Shadbegian and Gray (2003) perform a more detailed examination of the environmental performance of 68 pulp and paper mills, finding that air emissions are significantly lower at plants that have a larger air pollution abatement capital stock, face more stringent local regulation, and have higher production efficiency. Shadbegian and Gray (2006) examine the impact of regulatory stringency on plants in the pulp and paper, steel, and oil industries and find that plants facing more local regulatory stringency had better (air and water) environmental performance. Finally, Gray and Shadbegian (2007) examine spatial factors affecting environmental performance of polluting plants, measured by air emissions and regulatory compliance. They find that increased regulatory activity has significant effects for compliance but not for emissions.

In addition to the large literature that now exists on the impact of regulation on the environmental performance of polluting plants with respect to conventional pollutants, a growing literature examines the impact of different EPA programs and community characteristics on toxic emissions. For example, Khanna and Damon (1999) find evidence that participation in EPA's voluntary 33/50 Program (a program under which facilities volunteered to decrease a certain specified set of their toxic releases by 33 percent by 1992 and 50 percent by 1995, relative to their 1988 levels) led to a significant decline in these toxic releases over the period 1991–93. Similarly, Innes and Sam (2008) find that EPA's 33/50 Program reduced emissions, but their results showed much bigger effects than Khanna and Damon. On the other hand, Brouhle et al. (2009) did not find robust evidence that participation in EPA's voluntary program for the metal finishing industry, the Strategic Goals Program (SGP), led to significant reductions in emissions. Thus the evaluation of the effectiveness of EPA's voluntary programs has produced mixed results. Finally, Bui (2005) examines whether TRI-induced public disclosure contributed to the decline in reported toxic releases by oil refineries. Bui finds some evidence that the public disclosure provisions of TRI may very well have caused some reductions in reported TRI releases. However, she also finds evidence that reductions in toxic releases are a byproduct of more traditional command-and-control regulation of emissions of *nontoxic* pollutants.

There are existing studies that offer a retrospective look at the impact of the Cluster Rule, focusing on compliance costs. As noted above, EPA anticipated that addressing air and water pollution concerns together would limit the regulatory burden. Morgan et al. (2014) find that

because of the “use of the clean condensate alternative (CCA), flexible compliance options, extended compliance schedules, site-specific rules, use of equivalent-by-permit, and equipment/mill shutdowns and consolidations,” EPA’s ex ante capital cost estimate was 30 percent to 100 percent higher than its ex post cost assessment. However, the authors caution that the dearth of detail in the data available for their study means they could “only speculate on which reason(s) is primarily responsible for the EPA’s overestimate.” Using a methodology similar to that employed in the current paper, Gray et al. (2014) examine the impact of the Cluster Rule on employment, finding evidence of small reductions in employment for some regulated plants and small increases in production worker wages at other regulated plants.

4. Model, Data, and Empirical Methodology

In this paper, we compare EPA’s ex ante expected reductions in air and water releases from the Cluster Rule to an ex post assessment of actual reductions. The goal of this assessment is to determine whether actual air and water releases diverged from ex ante estimates, and if so, what factors caused this divergence. We conduct our analysis using establishment-level data from the Census of Manufactures and Annual Survey of Manufactures at the US Census Bureau from 1991 to 2009. These datasets, included in the Longitudinal Business Database, are described in Jarmin and Miranda (2002). Our Census data include the total value of real shipments, employment, labor productivity (real shipments/production worker hours), and corporate structure (multi- versus single-plant firms). We combine the Census data with data from the *Lockwood-Post Directory* for various years, to identify each plant’s production capacity (PULP CAPACITY and PAPER CAPACITY), as well as plant age (OLD PLANT = already in operation in 1960) and production technology (KRAFT = using kraft pulping). We also identify the plant’s corporate ownership, which allows us to add financial data from Compustat, identifying firm profitability (RETURN ON ASSETS), firm size (FIRM EMPLOYMENT), and whether the firm’s primary industry is paper (SIC26), which has been shown to influence a plant’s environmental performance.

We merge our pulp and paper mill data with annual plant-level information on quantities of pollution for both air and water pollution and for conventional and toxic pollutants. EPA’s Toxics Release Inventory (TRI) database contains annual information on the amount and type of releases of a wide range of hazardous substances. Given that the Cluster Rule focuses on reducing toxics, we focus on plants that reported TRI data from 1991 to 2009, which provides us with roughly a decade of information before and after the Cluster Rule implementation in 2001. We restrict our analysis to facilities that report TRI data for at least one year before implementation (1991–2000) and at least one year after implementation (2001–9). This

requirement (and a few restrictions for availability of other key variables) results in a sample of approximately 150 plants. We use the TRI data to create four measures of toxic pollution: total on-site releases of chloroform into the air and water, total nonchloroform air releases, and total air toxic releases.⁴

Our measures of conventional air pollutants come from EPA's National Emissions Inventory (NEI) database. This provides annual air pollution emissions data for PM₁₀ and VOCs for 1991–99 and at three-year intervals thereafter (2002, 2005, and 2008). Not all plants have the NEI data available, and fewer years are available after 1999, so only about half the overall dataset is included in the analysis for conventional air pollutants.

As previously mentioned, the stringency of the CR varied across plants. Out of 490 pulp and paper mills, 155 mills had to comply with the air toxics (MACT) regulations, while 96 mills (of the 155 mills) had to comply with the water toxics (BAT) regulations in the CR as well. The remaining 335 mills were not affected by the CR. Because the CR imposed different requirements on different plants within the same industry, we adopt a difference-in-differences approach in order to estimate its effects on air and water releases. In particular, we examine whether changes in air and water releases at plants that had to comply with the CR before and after it became effective are similar to changes in air and water releases at plants that did not have to comply with the CR. Because of the importance of pulping in determining the pollution generated at plants in this industry, we restrict our control group to those plants that included some sort of pulping process.⁵

By using plants in the same industry that did not have to comply with the CR as the control group, we will be able to control for other confounding effects. For example, the demand conditions in the pulp and paper industry may fluctuate over time and would have affected plants' pollution levels even in the absence of the CR. Similarly, the prices of inputs, supply of materials, and production technology may change over time and could lead to changes in pollution levels as well. To control for these changes in air and water releases that would have

⁴ Of the different chemicals targeted by the Cluster Rule, only chloroform has been recorded in the TRI for a sufficiently long time to be included in our analysis. (Dioxin and related compounds were not added to the TRI until 2000, by which time many plants had already achieved their reductions.)

⁵ Using difference-in-differences estimation is most appropriate when the treatment—in our case, being designated a MACT and BAT plant—is random or an observable characteristic can be used to control for treatment. However, as is clear from the description of the CR, mills were not randomly assigned to the MACT and BAT groups. Therefore, we also examined the use of propensity score matching to develop an alternative control group, as discussed in our results below.

occurred in the absence of the CR, a valid control group should be chosen that satisfies two conditions. First, the control group should not be influenced by the CR. Second, the control group should otherwise be as similar as possible to the treatment group. Because plants in the control group were in the same industry as the treatment group (and both groups included only plants with a pulping process), we expect the two groups will be reasonably similar in the factors affecting their air and water releases other than the CR, satisfying the second condition. By definition, plants in the control group were not covered by the CR, satisfying the first condition. As a result, the difference-in-differences approach should allow us to control for any time-invariant unobserved heterogeneity as well as changes over time that affect both groups similarly without having to explicitly measure them.

We also control for differences in regulatory stringency at the state level, given the considerable discretion afforded to state agencies within the federal regulatory framework. For this we rely on an index of the political support for environmental regulation within a state, based on the proenvironment voting of its congressional delegation (LCV VOTE). These data are collected and reported by the League of Conservation Voters. They provide considerable explanatory variation both across states and over time, and we have used this variable extensively in earlier research.

Baseline

To accurately assess the reduction in pollution releases associated with the Cluster Rule, it is important to accurately determine the baseline—the reference point that indicates the state of the world without the regulation. The baseline serves as the main point of comparison for the analysis of a policy action. Because the economic analysis considers the impact of a policy or regulation in relation to this baseline, its specification can have a large impact on the outcome of any economic analysis.⁶ In its regulatory impact analysis for the final Cluster Rule, EPA established 1995 as the baseline year for which all comparisons would be made and revised earlier estimates to reflect pre-1995 changes. We therefore treat the pollution releases occurring in 1995 as the baseline against which we will compare pollution releases after the Cluster Rule became effective. However, simply adopting 1995 pollution releases as baseline releases could lead to an underestimate of the true impact the Cluster Rule had on releases. As mentioned above, the Cluster Rule took a long time to be developed, and representatives of the pulp and

⁶ For additional information on baselines, see EPA (2010).

paper industry have argued that some pulp mills undertook pollution abatement actions to reduce dioxin discharges in anticipation of the Cluster Rule.⁷

Not all of the pre–Cluster Rule pollution abatement actions were necessarily voluntary. Houck (1991) notes that pressure from environmental groups and a series of lawsuits led EPA in 1988 to require states to develop water quality standards for dioxin, which in turn could lead to discharge limits for individual pulp and paper mills. Houck notes that by 1991, 36 states had adopted dioxin standards and a majority of plants examined (88 of 98) faced discharge limits for dioxin. EPA reported continuing reductions in dioxin discharges (possibly driven by these state standards) throughout the pre–Cluster Rule period, falling from 70 grams per year (g/yr) in 1992 to 15 g/yr in 1995—much larger than the projected decline of 11 g/yr following the Cluster Rule. Thus most plants may already have been pressured by state regulation or adverse publicity to make the dioxin-reducing changes in their production process by 1995, with the Cluster Rule playing a role that focused more on cleaning up the laggards.

Not everyone agrees, with some sources pointing to reasons for delaying abatement spending as long as possible. Ferguson (1995) argues that the pulp and paper industry refrained from the most aggressive abatement efforts until the Cluster Rule was promulgated. Maynard and Shortle (2001) use a “double-hurdle” model of the abatement decision and find the uncertainty accompanying the irreversible investment made it worthwhile for mills to adopt a “wait and see” stance before investing in cleaner technology. Moreover, Maynard and Shortle find that “public pressure” variables, including TRI data and membership in environmental groups, have a statistically significant positive effect on the adoption of cleaner technologies.

Model Specification

The difference-in-differences technique then estimates the average treatment effect of the CR on air and water releases. Our standard model specification is as follows:

$$\ln Z_{pkt} = \beta_0 + \beta_1 MACT_p + \beta_2 BAT_p + \beta_3 MACTEFF_{pt} + \beta_4 BATEFF_{pt} + \gamma X_{pt} + \delta_t + u_{pt} \quad (1)$$

⁷ See public comments from the National Council for Air and Stream Improvement and American Forest and Paper Association during EPA’s Science Advisory Board’s review of EPA (2012). These comments provided evidence of voluntary, preemptive spending before the Cluster Rule’s promulgation in 1998. <http://yosemite.epa.gov/sab/sabproduct.nsf/MeetingCal/E8CE4F3AB391B61485257AD80049F231?OpenDocument>

where p indexes plants and t indexes years. Here Z_{pkt} measures the environmental performance of plant p at time t along dimension k , including emissions of air and water pollutants, conventional as well as toxic (note that in this context, higher values of Z would represent poorer performance, so we would expect negative coefficients on terms that improve performance). $MACT$ equals one for a plant that must comply with the MACT regulations of the CR and zero otherwise; BAT equals one for a plant that must comply with the BAT regulations of the CR and zero otherwise; and $MACTEFF$ and $BATEFF$ are terms reflecting the dates on which the plant was required to comply with those regulations. We define $BATEFF$ based on the date when a plant renewed its water permit, while MACT regulations came into effect for everyone on April 2001, so we define $MACTEFF$ as starting in 2001. Their coefficients β_3 and β_4 thus measure the difference-in-differences effect of the CR on air and water releases, with β_4 reflecting the difference between the BAT plants and the MACT-only plants. The model also includes various control variables (X) and year dummies (δ_t).

We also estimate models that include plant fixed-effect terms (α_p). When we include these terms in the model, the $MACT$ and BAT variables disappear (as do those X variables that are fixed for the plant), and our model can be rewritten as follows:

$$\ln Z_{pkt} = \alpha_p + \beta_3 MACTEFF_{pt} + \beta_4 BATEFF_{pt} + \gamma * X_{pt} + \delta_t + u_{pt} \quad (2)$$

We are also interested in any correlations between the unexplained variation in the different environmental performance measures, which include both air and water pollutants and toxic and conventional pollutants. Because we have different samples for the toxic and conventional pollutant measures, we are not able to run a seemingly unrelated regression model, but we do examine the correlations between the residuals from each of the pollutants in all our analyses. We would generally expect to find positive correlations across pollutants, as unobserved factors (such as management ability or local regulatory pressures) could lead a plant to do better (or worse) than expected on a wide range of pollutants, but it is possible that some plants wind up substituting one type of pollution abatement for another when redesigning their production process.

5. Results

Table 1 presents descriptive statistics for our data. The average plant in our sample reports nearly a million pounds of toxic releases annually, of which the majority are air toxics. As noted earlier, most of the dioxin-related substances were not included in the TRI until 2000, so we focus on releases of chloroform as an indicator of activity that might generate dioxin. We include separate measures of air and water releases of chloroform. These chloroform releases

represent only about 3 percent of total TRI releases. Releases of chloroform are relatively rare, with only about half of the sample reporting any chloroform releases; this number shrank rapidly during the years between 1991 and 2009. Most plants in our sample are pre-1960, use kraft pulping, and belong to multiestablishment firms. Most of the sample was covered by the MACT air regulations. About half the sample was also covered by the BAT water regulations, and these show some variability in their start date, on average taking effect slightly before the MACT rules (in 2000 rather than 2001).

Figure 1 shows the trends over time in average emissions for our six pollutant measures. Chloroform releases fell dramatically throughout the sample period, with much of the reduction happening in the 1990s, before the effective date of the Cluster Rule. Air and total toxic releases increased in the first half of the sample and declined in the second half. PM₁₀ emissions show some reductions over the sample period, while VOC emissions show some increases.

Our initial ordinary least squares (OLS) analysis of the toxic release data is presented in columns 1–4 of Table 2. Most of the variables in the model show significant effects and generally have the expected signs. Our model explains about one-quarter to one-half of the variation in the emissions measures. Plant characteristics are significant, as expected, with larger pulping plants and kraft mills having more toxic releases than smaller, nonkraft mills, while the results for older plants are mixed (less releases overall but more releases for chloroform). Not surprisingly, plants with more shipments had more releases, while more productive plants had fewer releases. Firm characteristics show somewhat less consistent effects. More profitable firms tend to have less releases, though not significant, and multiunit firms have more releases overall. Firms specializing in the paper industry had less air releases but more chloroform releases. Larger firms have significantly less chloroform releases (possibly due to large firms being more sensitive to the bad publicity surrounding dioxin). Our measure of state-level political support for regulatory stringency, LCV VOTE, is associated with significantly lower releases for all measures, while being in a nonattainment county is positively associated with chloroform releases. The results for the conventional air pollutants PM₁₀ and VOCs, shown in columns 5 and 6, are broadly similar for most of the plant characteristics, with greater emissions at larger pulping plants, plants using kraft pulping, plants with higher shipments and lower productivity, and plants in less stringent states (as measured by LCV VOTE). A few of the firm characteristics show differing impacts on PM₁₀ and VOCs, including firm size, multiestablishment firm, and firms specializing in the paper industry.

Table 2 also includes year dummies, from which we can see whether toxic releases in the years after the Cluster Rule was implemented appear significantly different (and lower) than toxic releases in the years before implementation. Note that these year dummies reflect the

average experience of all plants in our sample, not just those plants that faced especially strict MACT or BAT requirements. Air and total releases fell in 2001 relative to the values in 2000 but remained higher than they were in 1991. Statistical tests for coefficient equality across the year dummies (at the bottom of Table 2) show essentially no difference within the coefficients in the later period, but they show significant differences within the earlier period and a significant difference across all the years in the sample. Chloroform releases show a substantial downward trend, but the trend begins at the start of the pre-CR period, with a leveling out (at much lower levels) in the later period. We find significant differences within the pre-CR period and between the pre- and post-CR periods, but not within the post-CR period. This is consistent with paper manufacturers taking steps during the 1990s, including the installation of equipment for extended cooking techniques and oxygen delignification, to reduce their use of chlorine bleaching, even before the Cluster Rule took effect, with little additional reductions in later years. As noted in Figure 1, PM₁₀ emissions tended to fall over the period, while VOC emissions increased.

The residual correlations presented at the bottom of Table 2 show a very strong connection between unexplained air and water releases of chloroform. There are also positive correlations between unexplained releases of chloroform and other air toxics. Unexplained emissions of the conventional air pollutants are positively related to each other and to nonchloroform air toxics but show little relationship to unexplained chloroform releases.

Table 3 presents the results of an analysis that includes plant-specific fixed effects. Most of the plant-specific characteristics from Table 2 are omitted, as they have no within-plant variation. Those observations with higher shipments and lower productivity still show greater air and total releases, and county nonattainment is still associated with greater chloroform releases. The coefficients on year dummies are also similar to those in Table 2, with the F-tests again showing significant variation overall and within the pre-CR period, but not within the post-CR period. However, many of the other coefficients show differences, most notably LCV VOTE, which shows a surprisingly positive relationship to chloroform releases. Most of the residual correlations show similar signs to those in Table 2, although the correlations between the air toxics residual and the conventional air pollutants are not as strong.

Table 4 contains results from OLS models that include measures of the Cluster Rule requirements that different plants face. We omit a discussion of the coefficients on the control variables, which are similar to those seen in Table 2. Although we anticipate a general increase in regulatory stringency around the implementation date, different plants faced different requirements, and as discussed earlier, there was also some variation in the timing of the BAT requirements. Some plants faced stricter MACT air requirements, others faced stricter requirements for both air and water (MACT and BAT), and still others faced neither MACT nor

BAT requirements. We include dummy variables indicating whether the plant is covered by the MACT or BAT rules, along with dummy variables (EFFECTIVE-MACT and EFFECTIVE-BAT) formed by interacting the MACT and BAT dummies with a time period dummy indicating when that part of the Cluster Rule requirements took effect for that plant. Since all MACT plants are also covered by BAT, the MACT coefficients reflect the differences between the MACT-only plants and the control group of plants unaffected by the CR, while the BAT coefficients reflect the differences between MACT-only and MACT-plus-BAT plants.

As expected, the MACT coefficients are significantly positive with respect to air and total toxic releases, reflecting the greater size of those plants relative to the control group, but those plants do not show substantially larger chloroform releases. On the other hand, the BAT coefficients show that the BAT plants have similar total and air releases to the MACT-only plants, while their chloroform releases are much larger. The EFFECTIVE-MACT coefficients show similar changes over time in air and total toxics in MACT-only and the control plants, with somewhat greater reductions in chloroform releases. The EFFECTIVE-BAT coefficients are all significantly negative, and especially large for the chloroform releases, reflecting greater reductions at BAT plants (compared with MACT-only plants) for all measures of toxic releases. For both of the conventional air pollutants, the MACT-only plants have higher emissions than control plants, with somewhat lower emissions at BAT plants (though their emissions are still higher than those for the control plants). The EFFECTIVE-MACT and EFFECTIVE-BAT coefficients show little impact on PM₁₀ emissions and some reductions on VOC emissions at both MACT-only and BAT plants relative to the control plants.

Table 5 shows the impact of including plant-specific fixed effects in the analysis. As with Table 3, the control variables that do not have any within-plant variation drop out of the analysis. In this case, that includes the MACT and BAT dummies reflecting the type of CR regulations faced by the plant. The remaining regulatory variables, EFFECTIVE-MACT and EFFECTIVE-BAT, show similar results to those found in Table 4. MACT-only plants again show changes in toxic releases similar to those of the control plants, except for the significant positive coefficient for total releases. BAT plants again show significantly greater reductions than MACT-only plants for all toxic releases. For the conventional air pollutants, we see little impacts on PM₁₀ emissions and some reductions (relative to control plants) in VOC emissions, although these reductions are now larger in BAT plants than in MACT-only plants.

How do the reductions observed for toxic and conventional emissions at MACT and BAT plants (relative to the control group) compare with the ex ante predictions from EPA? As noted above, the predictions are that chloroform would be reduced by 99 percent, while air toxics would fall by 59 percent, VOCs by 49 percent, and PM by 37 percent. The ex post estimated

reductions seen in Tables 4 and 5 are fairly similar to these numbers. Summing the EFFECTIVE-MACT and EFFECTIVE-BAT coefficients and adjusting them for the semilog nature of the regression,⁸ we find that BAT plants had reductions in chloroform releases in air by 99 percent and in water by 96 percent, with essentially the same estimated effects for the OLS and FE models. The reductions in air toxic releases were not as large as expected, with small and insignificant effects seen for the MACT-only plants, while BAT plants saw marginally significant reductions on the order of 17 percent (FE) to 30 percent (OLS). For VOC emissions, we see sizable reductions in both OLS and FE models, although the models differ on the estimated impacts. For MACT plants, we see VOC reductions of 52 percent (OLS) and 15 percent (FE); for BAT plants, we see reductions of 58 percent (OLS) and 36 percent (FE). The changes in PM₁₀ are small and insignificant for both MACT and BAT plants in both OLS and FE models.

A potential concern with our results is that the MACT and BAT regulations are not randomly assigned to pulp and paper mills. Rubin (2008) notes that one can approximate a randomized experiment by selecting a suitably matched control group to eliminate or at least reduce this bias. We used a version of the propensity score matching (PSM) estimator developed by Rosenbaum and Rubin (1983) to match each treatment plant (MACT-only or BAT) to a plant in our control group (with replacement),⁹ giving us matched pairs of treatment and control plants. We tested a variety of specifications before achieving the desired “balance” of matching variables between our treatment and control groups. The final matching model included the plant’s real output, age, county attainment status, an index of the state’s proenvironmental congressional voting, and state-year mean wage and employment. Unfortunately, while this approach provides us with a theoretically more appropriate control group, it also changes our sample, since a few treatment plants and some control plants from our primary dataset are not included in the matched sample. Census Bureau rules designed to protect data confidentiality raise complications for obtaining those results. However, the estimated reductions in toxic and conventional emissions at MACT and BAT plants (relative to the control group) for the matched sample are quite similar to the results presented above, in both magnitude and significance. This provides us with some assurance that our results are not being driven by observable differences between our treatment and control groups.

⁸ Percentage impact = $\exp(\text{coefficient}) - 1$.

⁹ To estimate the propensity score and produce our matched control group, we employed the psmatch2 algorithm in Stata, developed by Leuven and Sianesi (2003).

We also compared the actual reductions in emissions with those predicted by our models, to see whether any plant characteristics were associated with more or less accurate predictions. We found that prediction accuracy was not related to plant age, but that non-kraft-pulping mills and smaller-capacity mills tended to have their emissions reductions predicted less accurately than larger, kraft-pulping mills. The prediction accuracy for reductions in most pollutants were similar across BAT, MACT-only, and control plants, but the reductions in chloroform emissions were better predicted for BAT plants, once we eliminated cases of zero emissions (which were more common for non-BAT plants).

6. Conclusion

In this paper, we have examined the impact of the Cluster Rule on the toxic and conventional pollution emissions of plants in the pulp and paper industry. This was EPA's first integrated, multimedia regulation, combining MACT air regulations and BAT water regulations, promulgated in 1997 and effective in 2001 (with some variations in effective date across plants, as described above). We compared EPA's ex ante estimates of the reductions in different pollutants to ex post measurements, using a dataset of approximately 150 plants that combines information from Census, EPA, and industry databases.

In this analysis, our ex post measurements come from regression models implementing a difference-in-differences strategy, comparing the changes in pollution emissions at regulated plants around the time the Cluster Rule took effect with changes at plants not covered by the Cluster Rule, controlling for a variety of plant and firm characteristics. The estimated reductions in chloroform releases at BAT plants are nearly identical to the ex ante predictions, on the order of 99 percent. Reductions in air toxics were smaller than expected, especially at the MACT-only plants. There is some evidence of reductions in VOC emissions, with OLS estimates similar in magnitude to the ex ante predictions and the FE estimates somewhat smaller; no significant impact is found on PM₁₀ emissions.

What can we learn from the Cluster Rule about conducting regulatory impact analyses and retrospective analyses? One justification for the multimedia nature of the Cluster Rule was that it would reduce compliance costs, relative to using separate air and water regulations. This seems logical, and research cited here finds compliance costs even lower than EPA's estimates, but since the counterfactual of separate air and water regulations is unobserved, retrospective analyses cannot really judge how much (if anything) was saved by the multimedia approach.

Regulatory flexibility also affects compliance costs, but it can be difficult to identify ex ante which areas of flexibility will be important. Regulatory impact analyses should carefully describe the expected compliance methods and potential heterogeneity in methods across plants;

retrospective analyses should start by comparing actual compliance methods with those expected *ex ante*. This could be especially important in measuring the impact of technological advances in compliance methods that substantially reduce compliance costs.

Finally, deciding on the appropriate baseline is a necessary step in measuring the benefits and costs from a regulation. This decision was especially important for the Cluster Rule. Paper mills faced pressures from state regulators and public opinion to modify their production processes to reduce dioxin many years before the Cluster Rule took effect. The emissions reductions and abatement investments that happened before the official baseline were quite large—possibly even larger than the benefits and costs that happened afterward—and given the long process of developing the Cluster Rule, EPA had to modify its calculations of benefits and costs to reflect the changing baseline. It is conceptually as well as practically difficult to categorize whether the preregulation benefits and costs were done in anticipation of the Cluster Rule or in response to pressures from state regulation and public opinion. The direct impact of the Cluster Rule may have been mostly about cleaning up the laggards, but failing to pressure those laggards might have had adverse consequences for compliance with future regulations.

Future research could extend this analysis in several ways. More detailed data on the production process used by each plant and the timing of process changes could provide a clearer picture of how the emissions reductions are achieved. Abatement methods could be connected to production costs with census microdata and engineering calculations. Heterogeneity in how different abatement methods affect different types of plants could be examined. The timing of benefits and costs could also be explored to see how sensitive those calculations are to the choice of baseline date, likely to be especially important here. Finally, other regulations could be analyzed to see how broadly applicable our conclusions are.

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Tables and Figures

Table 1. Descriptive Statistics (N = 2251 unless otherwise noted)

Variable	Mean (std. dev.)	{log m,sd}
Dependent Variables		
AIR CHLOROFORM EMISSIONS ^a Total chloroform air releases (in pounds)	30687.2 (83073.41)	{3.12,5.02}
WATER CHLOROFORM EMISSIONS ^a Total chloroform water releases (in pounds)	981.5 (6083.27)	{1.72,3.12}
TOTAL AIR EMISSIONS ^a Total toxic air releases (in pounds)	785065.0 (834442.8)	{2.69,4.75}
TOTAL TRI EMISSIONS ^a Total toxic releases (in pounds)	969205.0 (998839.4)	{11.51,3.75}
PM ₁₀ (N = 1122) ^a Tons of particulate emissions per year	576.6 (647.9)	{5.11,1.86}
VOCs (N = 1122) ^a Tons of volatile organic compound emissions per year	631.6 (766.8)	{5.59,1.72}
Explanatory Variables		
<i>Regulatory-related characteristics</i>		
MACT Dummy variable = 1 for plants that must install maximum available control technology to abate toxic air emissions	0.79 (0.41)	
EFFECTIVE-MACT Dummy variable = 1 for MACT plants after 2000	0.34 (0.47)	
BAT Dummy variable = 1 for plants that must install best available technology to abate toxic water releases	0.53 (0.50)	
EFFECTIVE-BAT Dummy variable = 1 for BAT plants with timing based on date of plant's water permit	0.25 (0.43)	

Table 1, cont.

LCV VOTE	44.64 (20.83)	
State proenvironment congressional voting (League of Conservation Voters)		
NON-ATTAIN	0.040 (0.20)	
Dummy variable = 1 for plants located in nonattainment area for TSP		
<i>Plant characteristics</i>		
KRAFT	0.73 (0.44)	
Dummy variable = 1 for plants that use the kraft pulping process		
PULP CAPACITY ^a	927.6 (609.5)	(6.42,1.36)
Plant capacity (tons of pulp per day)		
PAPER CAPACITY ^a	871.0 (639.65)	(5.79,2.42)
Plant capacity (tons of paper per day)		
OLD PLANT	0.63	(0.48)
Dummy variable = 1 for plants opened before 1960		
PLANT SHIPMENTS ^a	273,339 (208,059)	(12.33,0.64)
Plant value of shipments		
LABOR PRODUCTIVITY ^a	248.6 (118.6)	(5.42,0.43)
Labor productivity (output per production worker hour)		
<i>Firm characteristics</i>		
RETURN ON ASSETS	1.15 (4.01)	
Firm's rate of return on assets (Compustat)		
FIRM EMPLOYMENT ^a	38.22 (29.83)	(2.13,1.76)
Firm's number of employees in 1,000s (Compustat)		
SIC26	0.50 (0.50)	
Dummy variable = 1 for plants owned by firms primarily operating in paper industry		
MULTI-UNIT FIRM	>0.8	
Plant owned by firm with multiple manufacturing plants		

^a measured in logs in the regressions

Table 2. Basic OLS Models

Dep. var.	Chloroform air	Chloroform water	Total air emissions	Total TRI emissions	PM ₁₀	VOCs
<i>Plant characteristics</i>						
KRAFT	0.445** (0.222)	0.400*** (0.142)	2.524*** (0.131)	1.913*** (0.114)	0.978*** (0.092)	0.215* (0.113)
PULP CAPACITY	0.450*** (0.077)	0.276*** (0.049)	0.682*** (0.045)	0.682*** (0.040)	0.311*** (0.032)	0.272*** (0.040)
PAPER CAPACITY	-0.560*** (0.041)	-0.298*** (0.026)	-0.010 (0.024)	-0.061*** (0.021)	-0.088*** (0.017)	-0.023 (0.021)
OLD PLANT	0.917*** (0.206)	0.457*** (0.131)	-0.399*** (0.122)	-0.314*** (0.106)	-0.362*** (0.088)	-0.017 (0.108)
PLANT SHIPMENTS	1.541*** (0.164)	0.834*** (0.104)	0.764*** (0.097)	0.766*** (0.084)	0.853*** (0.068)	0.838*** (0.084)
LABOR PRODUCTIVITY	-1.255*** (0.287)	-0.891*** (0.183)	-0.695*** (0.170)	-0.628*** (0.148)	-0.742*** (0.128)	-0.556*** (0.157)
<i>Firm characteristics</i>						
RETURN ON ASSETS	-2.648 (2.456)	0.002 (1.564)	-1.084 (1.452)	-2.065 (1.263)	-1.089 (0.870)	-1.378 (1.066)
FIRM EMPLOYMENT	-0.476*** (0.102)	-0.184*** (0.065)	0.038 (0.060)	0.074 (0.052)	0.069 (0.044)	-0.157*** (0.054)
SIC26	0.219 (0.256)	-0.234 (0.163)	-0.315** (0.151)	-0.152 (0.131)	-0.284*** (0.104)	0.050 (0.127)
MULTI-UNIT FIRM	-	-	+***	+***	-***	+
<i>Plant regulation</i>						
LCV VOTE	-0.013*** (0.005)	-0.008** (0.003)	-0.015*** (0.003)	-0.014*** (0.003)	-0.014*** (0.002)	-0.016*** (0.003)
NON-ATTAIN	1.091** (0.452)	0.887*** (0.288)	0.109 (0.267)	0.019 (0.233)	0.297* (0.178)	0.543** (0.218)

Table 2, cont.

Pre-Cluster Rule

y1992	-0.280 (0.516)	-0.298 (0.329)	0.159 (0.305)	0.052 (0.265)	-0.087 (0.172)	0.060 (0.211)
y1993	-0.242 (0.517)	-0.214 (0.329)	0.165 (0.306)	0.065 (0.266)	0.212 (0.172)	0.339 (0.211)
y1994	-0.879* (0.519)	-0.648* (0.331)	0.966*** (0.307)	0.761*** (0.267)	0.237 (0.172)	0.448** (0.211)
y1995	-1.627*** (0.532)	-1.269*** (0.339)	0.854*** (0.314)	0.554** (0.273)	-0.051 (0.177)	0.291 (0.217)
y1996	-2.082*** (0.520)	-1.605*** (0.331)	0.901*** (0.307)	0.656** (0.267)	-0.335** (0.171)	0.418** (0.209)
y1997	-2.664*** (0.519)	-1.859*** (0.331)	1.002*** (0.307)	0.750*** (0.267)	-0.335* (0.171)	0.415** (0.209)
y1998	-3.003*** (0.535)	-2.110*** (0.341)	1.180*** (0.316)	0.943*** (0.275)	-0.311* (0.178)	0.420* (0.218)
y1999	-3.323*** (0.543)	-2.215*** (0.346)	1.174*** (0.321)	0.851*** (0.279)	-0.342* (0.181)	0.445** (0.222)
y2000	-4.385*** (0.539)	-2.850*** (0.343)	1.156*** (0.319)	0.879*** (0.277)	.	.
<i>Post-Cluster Rule</i>						
Y2001	-5.358*** (0.538)	-3.340*** (0.342)	0.609* (0.318)	0.358 (0.276)	.	.
y2002	-5.570*** (0.547)	-3.515*** (0.348)	0.812** (0.323)	0.637** (0.281)	-0.325* (0.189)	0.949*** (0.231)
y2003	-5.736*** (0.563)	-3.650*** (0.358)	0.900*** (0.333)	0.651** (0.289)	.	.
y2004	-5.816*** (0.564)	-3.663*** (0.359)	1.115*** (0.333)	0.877*** (0.290)	.	.
y2005	-5.913*** (0.571)	-3.655*** (0.364)	1.048*** (0.337)	0.826*** (0.294)	+	+
y2006	-5.762*** (0.576)	-3.585*** (0.367)	1.053*** (0.341)	0.858*** (0.296)	.	.
y2007	-5.764*** (0.584)	-3.580*** (0.372)	1.011*** (0.345)	0.802*** (0.300)	.	.
y2008	-5.796*** (0.590)	-3.532*** (0.376)	1.172*** (0.349)	0.927*** (0.304)	-0.455** (0.209)	0.875*** (0.256)
y2009	-5.488*** (0.588)	-3.438*** (0.374)	0.931*** (0.347)	0.695** (0.302)	.	.

N	2251	2251	2251	2251	1122	1122
R ²	0.335	0.299	0.425	0.443	.401	.242

Table 2, cont.

F-TEST I	0.0000	0.0000	0.0000	0.0002	0.0005	0.2762
F-TEST II	0.9885	0.9916	0.7975	0.6112	0.6021	0.9209
F-TEST III	0.0000	0.0000	0.0013	0.0043	0.0011	0.0158

Residual correlations

	Chloroform air	Chloroform water	Total air emissions	PM ₁₀	VOCs
Chloroform air	1.0000				
Chloroform water	0.8449*	1.0000			
Total air emissions	0.0779*	0.1428*	1.0000		
PM ₁₀	-0.0174	-0.0008	0.2103*	1.0000	
VOCs	0.0047	0.0267	0.2754*	0.2096*	1.0000

Notes: t-statistics are in parentheses (* = $p < 0.10$, ** = $p < 0.05$, *** = $p < 0.01$). F-TEST I tests for the equality of y1991–y2000 (p-value), F-TEST II tests for the equality of y2001–y2009 (p-value), and F-TEST III tests for the equality of y1991–y2009 (p-value). All models include a dummy variable MISSFIRM=1 for firms with missing Compustat data. Residual correlations for total TRI inadvertently omitted in results released from Census. PM₁₀ and VOC emissions data not available for 2000, 2001, 2003, 2004, 2006, 2007, and 2009. Coefficients for MULTI-UNIT firms and y2005 not shown due to Census restrictions; only sign and significance are given.

Table 3. Basic FE Models

Dep. var.	Chloroform air	Chloroform water	Total air emissions	Total TRI emissions	PM ₁₀	VOCs
<i>Plant characteristics</i>						
PLANT	0.246	0.146	0.582***	0.258**	0.680***	0.489***
	(0.271)	(0.171)	(0.140)	(0.123)	(0.094)	(0.125)
LABOR	0.069	0.075	-0.474**	-0.321*	-0.527***	-0.971***
	(0.408)	(0.257)	(0.211)	(0.185)	(0.164)	(0.217)
<i>Firm characteristics</i>						
RETURN ON	1.246	2.017	2.138**	0.264	-1.418**	-0.056
	(2.050)	(1.292)	(1.061)	(0.928)	(0.594)	(0.785)
FIRM	-0.146	-0.106	0.139**	0.053	-0.009	-0.222***
	(0.129)	(0.082)	(0.067)	(0.059)	(0.053)	(0.070)
EMPLOYMENT	1.791***	1.019***	0.357	0.223	-0.288*	0.222
	(0.498)	(0.314)	(0.258)	(0.225)	(0.161)	(0.214)
MULTI-UNIT FIRM	-***	-***	-	-	-***	+
<i>Plant regulation</i>						
LCV VOTE	0.019**	0.013**	-0.004	-0.005	-0.005	0.012***
	(0.009)	(0.005)	(0.004)	(0.004)	(0.003)	(0.004)
NON-ATTAIN	1.387**	1.188***	-0.131	-0.193	0.454**	0.246
	(0.573)	(0.361)	(0.297)	(0.259)	(0.181)	(0.239)
<i>Pre-Cluster Rule</i>						
y1992	0.058	-0.074	0.167	0.056	0.008	0.207
	(0.406)	(0.256)	(0.210)	(0.184)	(0.105)	(0.139)
y1993	-0.522	-0.396	0.000	-0.075	0.154	0.022
	(0.406)	(0.256)	(0.210)	(0.184)	(0.105)	(0.139)
y1994	-1.157***	-0.826***	0.654***	0.460**	0.203*	0.217
	(0.405)	(0.255)	(0.210)	(0.183)	(0.104)	(0.137)
y1995	-1.554***	-1.230***	0.614***	0.352*	0.106	0.360**
	(0.422)	(0.266)	(0.219)	(0.191)	(0.109)	(0.144)
y1996	-1.951***	-1.559***	0.777***	0.530***	-0.146	0.457***
	(0.410)	(0.258)	(0.212)	(0.186)	(0.104)	(0.138)
y1997	-2.478***	-1.753***	0.903***	0.700***	-0.205**	0.458***
	(0.408)	(0.257)	(0.211)	(0.185)	(0.104)	(0.138)
y1998	-2.943***	-2.120***	0.966***	0.795***	-0.197*	0.581***
	(0.431)	(0.272)	(0.223)	(0.195)	(0.115)	(0.153)
y1999	-3.293***	-2.240***	1.051***	0.806***	-0.179	0.649***
	(0.443)	(0.279)	(0.229)	(0.201)	(0.120)	(0.159)
y2000	-4.432***	-2.921***	1.000***	0.725***	.	.
	(0.441)	(0.278)	(0.228)	(0.200)		

Table 3, cont.

Post-Cluster Rule

Y2001	-5.536*** (0.443)	-3.450*** (0.279)	0.514** (0.229)	0.352* (0.200)	.	.
y2002	-5.946*** (0.459)	-3.736*** (0.289)	0.438* (0.238)	0.266 (0.208)	-0.216 (0.135)	1.102*** (0.178)
y2003	-6.106*** (0.467)	-3.849*** (0.294)	0.544** (0.242)	0.354* (0.211)	.	.
y2004	-6.197*** (0.472)	-3.863*** (0.297)	0.615** (0.244)	0.448** (0.214)	.	.
y2005	-6.225*** (0.480)	-3.814*** (0.303)	0.598** (0.249)	0.424* (0.218)	-	+*
y2006	-6.167*** (0.489)	-3.819*** (0.308)	0.544** (0.253)	0.389* (0.222)	.	.
y2007	-6.358*** (0.493)	-3.937*** (0.311)	0.536** (0.255)	0.384* (0.223)	.	.
y2008	-6.355*** (0.497)	-3.891*** (0.313)	0.779*** (0.257)	0.546** (0.225)	-0.538*** (0.151)	0.812*** (0.199)
y2009	-6.318*** (0.491)	-3.925*** (0.309)	0.457* (0.254)	0.216 (0.222)	.	.
N	2251	2251	2251	2251	1122	1122
R ²	0.615	0.603	0.745	0.750	0.795	0.698
F-TEST I	0.0000	0.0000	0.0000	0.0000	0.0001	0.0003
F-TEST II	0.6659	0.7664	0.9220	0.8676	0.0219	0.1414
F-TEST III	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000
<i>Residual correlations</i>						
	Chloroform air	Chloroform water	Total air emissions	PM ₁₀	VOCs	
Chloroform air	1.0000					
Chloroform water	0.8423*	1.0000				
Total air emissions	0.0263	0.0565*	1.0000			
PM ₁₀	0.0416	0.0524	-0.0012	1.0000		
VOCs	0.0276	0.0550	0.0724*	0.2649*	1.0000	

Note: See Table 2.

Table 4. Extended OLS Models

Dep. var.	Chloroform air	Chloroform water	Total air emissions	Total TRI emissions	PM ₁₀	VOCs
MACT	-0.260 (0.321)	0.050 (0.210)	2.498*** (0.200)	1.901*** (0.175)	0.794*** (0.131)	1.223*** (0.159)
EFFECTIVE- MACT	-0.648 (0.432)	-0.502* (0.282)	-0.006 (0.269)	0.253 (0.235)	0.009 (0.277)	-0.739** (0.336)
BAT	5.381*** (0.259)	3.007*** (0.170)	0.085 (0.162)	0.226 (0.141)	-0.272*** (0.103)	-0.224* (0.125)
EFFECTIVE- BAT	-5.085*** (0.323)	-2.780*** (0.211)	-0.345* (0.201)	-0.392** (0.176)	-0.021 (0.187)	-0.138 (0.226)
<i>Plant characteristics</i>						
KRAFT	0.261 (0.208)	0.258* (0.136)	1.840*** (0.129)	1.345*** (0.113)	0.836*** (0.094)	0.028 (0.114)
PULP	0.427*** (0.071)	0.252*** (0.047)	0.493*** (0.044)	0.531*** (0.039)	0.243*** (0.034)	0.168*** (0.041)
CAPACITY PAPER	-0.462*** (0.037)	-0.238*** (0.024)	0.062*** (0.023)	0.001 (0.020)	-0.072*** (0.017)	0.002 (0.021)
OLD PLANT	1.062*** (0.183)	0.545*** (0.120)	-0.291** (0.114)	-0.217** (0.100)	-0.332*** (0.087)	0.040 (0.106)
PLANT SHIPMENTS	0.538*** (0.160)	0.249** (0.105)	0.532*** (0.100)	0.541*** (0.087)	0.897*** (0.075)	0.845*** (0.091)
LABOR PRODUCTIVITY	-0.012 (0.272)	-0.165 (0.178)	-0.372** (0.169)	-0.311** (0.148)	-0.773*** (0.132)	-0.539*** (0.160)
<i>Firm characteristics</i>						
RETURN ON ASSETS	-1.072 (2.197)	0.973 (1.436)	-0.860 (1.369)	-1.829 (1.197)	-1.367 (0.865)	-1.805* (1.048)
FIRM EMPLOYMENT	-0.518*** (0.090)	-0.206*** (0.059)	0.055 (0.056)	0.087* (0.049)	0.070 (0.043)	-0.161*** (0.052)
SIC26	0.580** (0.230)	-0.011 (0.151)	-0.010 (0.143)	0.117 (0.126)	-0.265** (0.103)	0.086 (0.125)
MULTI-UNIT FIRM	+	+	+***	+***	-***	+

Table 4, cont.

Plant regulation

LCV VOTE	-0.016*** (0.004)	-0.010*** (0.003)	-0.013*** (0.003)	-0.012*** (0.002)	-0.013*** (0.002)	-0.014*** (0.003)
NON-ATTAIN	0.458 (0.404)	0.529** (0.264)	0.035 (0.251)	-0.069 (0.22)	0.282 (0.176)	0.490** (0.214)

Pre-Cluster Rule

y1992	-0.334 (0.458)	-0.326 (0.300)	0.185 (0.286)	0.067 (0.250)	-0.081 (0.169)	0.069 (0.205)
y1993	-0.336 (0.459)	-0.267 (0.300)	0.145 (0.286)	0.042 (0.250)	0.207 (0.169)	0.331 (0.206)
y1994	-1.049** (0.461)	-0.748** (0.302)	0.907*** (0.288)	0.707*** (0.252)	0.224 (0.169)	0.423** (0.205)
y1995	-1.900*** (0.473)	-1.428*** (0.309)	0.822*** (0.295)	0.519** (0.258)	-0.042 (0.174)	0.295 (0.211)
y1996	-2.278*** (0.462)	-1.717*** (0.302)	0.885*** (0.288)	0.636** (0.252)	-0.329** (0.168)	0.420** (0.203)
y1997	-2.781*** (0.461)	-1.926*** (0.302)	0.986*** (0.288)	0.733*** (0.252)	-0.340** (0.168)	0.402** (0.204)
y1998	-2.808*** (0.476)	-2.012*** (0.311)	1.172*** (0.297)	0.937*** (0.260)	-0.313* (0.176)	0.415* (0.213)
y1999	-2.932*** (0.485)	-2.010*** (0.317)	1.181*** (0.302)	0.858*** (0.264)	-0.336* (0.180)	0.457** (0.218)
y2000	-3.525*** (0.485)	-2.391*** (0.317)	1.162*** (0.302)	0.896*** (0.265)	.	.

Post-Cluster Rule

Y2001	-2.768*** (0.568)	-1.819*** (0.372)	0.696** (0.354)	0.264 (0.310)	.	.
y2002	-2.650*** (0.580)	-1.817*** (0.379)	0.831** (0.362)	0.489 (0.316)	-0.352 (0.280)	1.580*** (0.339)
y2003	-2.809*** (0.592)	-1.947*** (0.387)	0.937** (0.369)	0.516 (0.323)	.	.
y2004	-2.970*** (0.593)	-2.008*** (0.387)	1.126*** (0.369)	0.720** (0.323)	.	.
y2005	-3.092*** (0.597)	-2.013*** (0.390)	1.070*** (0.372)	0.679** (0.325)	+	+
y2006	-3.018*** (0.602)	-1.990*** (0.393)	1.046*** (0.375)	0.685** (0.328)	.	.
y2007	-3.020*** (0.605)	-1.983*** (0.396)	1.024*** (0.377)	0.647* (0.330)	.	.
y2008	-2.976*** (0.611)	-1.889*** (0.399)	1.188*** (0.381)	0.777** (0.333)	-0.479* (0.284)	1.462*** (0.345)

Table 4, cont.

y2009	-2.786*** (0.609)	-1.865*** (0.398)	0.921** (0.380)	0.519 (0.332)	.	.
N	2251	2251	2251	2251	1122	1122
R ²	0.475	0.417	0.495	0.506	0.421	0.282
F-TEST I	0.0000	0.000	0.000	0.0001	0.0006	0.2814
F-TEST II	0.9931	0.9984	0.8477	0.6781	0.6448	0.8705
F-TEST III	0.0000	0.0000	0.0006	0.0026	0.0015	0.0036
Residual correlations						
	Chloroform air	Chloroform water	Total air emissions	PM ₁₀	VOCs	
Chloroform air	1.0000					
Chloroform water	0.8104*	1.0000				
Total air emissions	0.0298	0.1044*	1.0000			
PM ₁₀	-0.0094	0.0047	0.1532*	1.0000		
VOCs	-0.0133	0.0103	0.1998*	0.1754*	1.0000	

Note: See Table 2.

Table 5. Extended FE Models

Dep. var.	Chloroform air	Chloroform water	Total air emissions	Total TRI emissions	PM ₁₀	VOCs
EFFECTIVE- MACT	-0.151 (0.341)	-0.128 (0.222)	0.139 (0.200)	0.363** (0.175)	0.115 (0.182)	-0.163 (0.241)
EFFECTIVE- BAT	-5.499*** (0.253)	-3.031*** (0.165)	-0.330** (0.149)	-0.395*** (0.130)	-0.108 (0.119)	-0.283* (0.157)
<i>Plant characteristics</i>						
PLANT	-0.008 (0.239)	0.006 (0.156)	0.567*** (0.141)	0.240* (0.123)	0.672*** (0.095)	0.469*** (0.125)
SHIPMENTS						
LABOR	-0.034 (0.360)	0.016 (0.234)	-0.473** (0.211)	-0.312* (0.185)	-0.516*** (0.165)	-0.920*** (0.217)
PRODUCTIVITY						
<i>Firm characteristics</i>						
RETURN ON ASSETS	-0.565 (1.811)	1.025 (1.178)	2.009* (1.062)	0.084 (0.928)	-1.486** (0.599)	-0.278 (0.791)
FIRM	-0.189* (0.114)	-0.129* (0.074)	0.136** (0.067)	0.049 (0.059)	-0.011 (0.053)	-0.231*** (0.070)
EMPLOYMENT						
SIC26	0.990** (0.440)	0.573** (0.287)	0.323 (0.258)	0.202 (0.226)	-0.285* (0.162)	0.195 (0.214)
MULTI-UNIT FIRM	-*	-	-	-	-***	+
<i>Plant regulation</i>						
LCV VOTE	0.026*** (0.008)	0.017*** (0.005)	-0.004 (0.004)	-0.004 (0.004)	-0.004 (0.003)	0.012*** (0.004)
NON-ATTAIN	0.725 (0.506)	0.822** (0.329)	-0.167 (0.297)	-0.231 (0.259)	0.451** (0.181)	0.242 (0.239)
<i>Pre-Cluster Rule</i>						
y1992	-0.005 (0.358)	-0.109 (0.233)	0.163 (0.210)	0.052 (0.183)	0.008 (0.105)	0.206 (0.138)
y1993	-0.703** (0.358)	-0.496** (0.233)	-0.011 (0.210)	-0.091 (0.184)	0.152 (0.105)	0.021 (0.139)
y1994	-1.265*** (0.357)	-0.886*** (0.232)	0.649*** (0.210)	0.455** (0.183)	0.202* (0.104)	0.215 (0.137)
y1995	-1.527*** (0.372)	-1.216*** (0.242)	0.617*** (0.218)	0.359* (0.191)	0.109 (0.109)	0.365** (0.144)
y1996	-2.004*** (0.361)	-1.588*** (0.235)	0.775*** (0.212)	0.530*** (0.185)	-0.146 (0.105)	0.456*** (0.138)
y1997	-2.559*** (0.359)	-1.798*** (0.234)	0.899*** (0.211)	0.695*** (0.184)	-0.205** (0.104)	0.452*** (0.137)
y1998	-2.444*** (0.381)	-1.845*** (0.248)	0.996*** (0.223)	0.831*** (0.195)	-0.190 (0.116)	0.589*** (0.153)

Table 5, cont.

y1999	-2.537*** (0.392)	-1.824*** (0.255)	1.096*** (0.230)	0.858*** (0.201)	-0.166 (0.121)	0.669*** (0.160)
y2000	-3.074*** (0.394)	-2.172*** (0.256)	1.081*** (0.231)	0.820*** (0.202)	.	.
<i>Post-Cluster Rule</i>						
Y2001	-2.807*** (0.460)	-1.910*** (0.299)	0.560** (0.270)	0.250 (0.236)	.	.
y2002	-2.767*** (0.477)	-1.946*** (0.310)	0.507* (0.280)	0.187 (0.245)	-0.257 (0.191)	1.372*** (0.252)
y2003	-2.978*** (0.482)	-2.089*** (0.314)	0.610** (0.283)	0.271 (0.247)	.	.
y2004	-3.047*** (0.485)	-2.091*** (0.316)	0.682** (0.285)	0.369 (0.249)	.	.
y2005	-3.116*** (0.491)	-2.064*** (0.319)	0.664** (0.288)	0.344 (0.252)	-	+**
y2006	-3.077*** (0.498)	-2.080*** (0.324)	0.609** (0.292)	0.308 (0.255)	.	.
y2007	-3.311*** (0.500)	-2.221*** (0.325)	0.600** (0.293)	0.302 (0.256)	.	.
y2008	-3.416*** (0.504)	-2.235*** (0.328)	0.834*** (0.296)	0.452* (0.259)	-0.579*** (0.197)	1.056*** (0.261)
y2009	-3.362*** (0.499)	-2.260*** (0.324)	0.515* (0.293)	0.125 (0.256)	.	.
N	2251	2251	2251	2251	1122	1122
R ²	0.701	0.671	0.745	0.751	0.795	0.699
F-TEST I	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002
F-TEST II	0.7194	0.8904	0.9234	0.8647	0.0215	0.1164
F-TEST III	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000

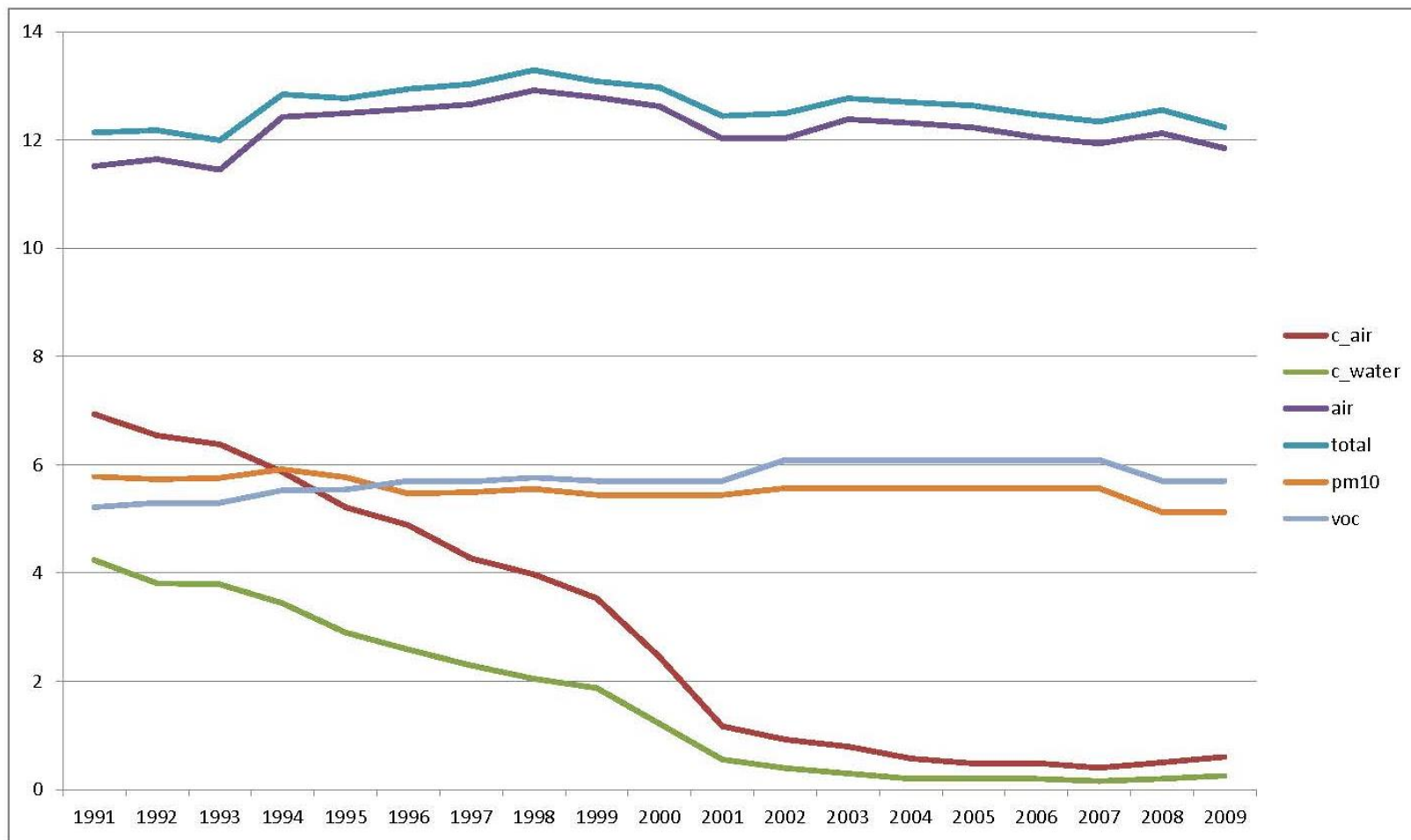
Table 5, cont.

Residual correlations

	Chloroform air	Chloroform water	Total air emissions	PM ₁₀	VOCs
Chloroform air	1.0000				
Chloroform water	0.8057*	1.0000			
Total air emissions	0.0049	0.0410	1.0000		
PM ₁₀	0.0395	0.0510	-0.0024	1.0000	
VOCs	0.0064	0.0389	0.0667*	0.2645*	1.0000

Note: See Table 2.

Figure 1. Average Emissions, 1991–2009



Note: TRI toxic releases were available annually for all years, 1991–2009; PM₁₀ and VOCs were available annually for 1991–99, then for only 2002, 2005, and 2008 (and 2005 numbers were not released based on Census review, so the only real data points post-1999 are those for 2002 and 2008, which explains the “flat” stretches on those two lines).