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‘Optimal’ pollution abatement—whose benefits matter, and how much?

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Abstract

We examine the determinants of environmental regulatory activity (inspections and enforcement actions) and levels of air and water pollution for 409 US pulp and paper mills, using data for 1985–1997. We focus on the benefits to the surrounding population from pollution abatement. Plants with larger benefits emit less pollution, as do those with more kids and elders nearby. Plants in poor areas emit more pollution, though (surprisingly) we find less pollution in minority areas. Out-of-state neighbors seem to count less than in-state ones, although this effect diminishes if the bordering state’s Congressional delegation is strongly pro-environment. We use ‘spatially lagged’ instrumental variables to control for the potential endogeneity of which individuals choose to locate near the plant. The results for regulatory activity are noticeably less significant than the emissions results.

Keywords: Environmental justice; Regulation; Demographics; Enforcement

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1. Introduction

In this paper we examine the ‘optimal’ allocation of environmental regulation across pulp and paper mills—recognizing that optimality may be defined in many different ways. In this paper, we view the optimal allocation from the point of view of the regulator, who may be concerned about the overall benefits and costs to society of pollution abatement at a given plant, but may also pay

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attention to political pressures from those affected by the pollution. The direct costs of pollution abatement at a particular plant are related to the plant's age, size, and technology, while the benefits are related to the amount of the pollution being generated and the number of people affected. Past studies comparing benefits and costs have focused on fairly simple measures of abatement benefits. In this study, we used more sophisticated measures of the benefits from air and water pollution abatement, based on the SLIM-3 Air Dispersion Model and the Environmental Protection Agency's (EPA) National Water Pollution Control Assessment Model (NWPCAM), respectively.

We would expect regulators to impose stricter regulation on plants located in areas with greater benefits from pollution abatement. However, we also consider political factors that may influence the allocation of regulation across plants. The focus of our paper is on spatial differences across plants in the distribution of benefits from pollution abatement and in the characteristics of the population living nearby. Responding to some of these population measures may be socially optimal if certain population groups are more sensitive to pollution, but might also reflect self-interested behavior by regulators seeking to maximize the political support for their actions.

We perform our analyses using a plant-level panel data set for 409 pulp and paper mills from 1985 to 1997. These plants are spread around the country in 38 states, though 79% are east of the Mississippi. We measure the regulatory stringency being directed towards a particular plant both directly, in terms of the numbers of inspections and enforcement actions directed at that plant, and indirectly, in terms of the amount of air and water pollution emitted by that plant. We find substantial evidence that both benefits and population characteristics affect emissions. Plants with larger benefits to the overall population emit less air and water pollution, and those with more kids and elders nearby emit less air pollution. Plants located in poor neighborhoods emit more pollution. Plants whose pollution affects residents of other states emit more pollution, but these effects are reduced if the nearby states have more pro-environmental Congressional delegations. Not every result fits those predicted by theory: the percentage nonwhite near the plant, expected to reduce regulatory attention (assuming nonwhites have less political clout), is often associated with lower emissions. Also, the overall results for our direct measures of regulatory activity, inspections and enforcement actions, are less often significant than our results for emissions.

One concern with our results could be the potential for reverse causation or sorting: poor people could move into dirty neighborhoods because housing is cheaper there; families with sensitive individuals such as kids and elders might avoid dirty neighborhoods. We cannot use pre-siting demographics to control for such endogeneity (as done in [2,21]) because our sample of paper mills is quite old (most were built before 1960). Instead, we use the demographic characteristics for people living between 50 and 100 miles from the plant as 'spatially lagged' instruments for the demographic characteristics near the plant. As long as the effects of a plant's pollution decline with distance, this procedure should purge most of the endogeneity from the demographic variables.

Some of the differences in results across different variables pose further research questions. For example, we find different effects on air and water pollution of being near the Canadian border: SO_2 emissions are lower, and BOD discharges are higher. This might reflect political pressures caused when acid rain in Canada is attributed to US emissions of SO_2, but by what mechanisms (regulatory or otherwise) are international concerns transmitted to plant level decisions? The weaker results for our direct measures of regulatory activity suggest influences on emissions acting through other channels, some of which might be quantifiable (e.g. the stringency of permitted emission levels or the use of criminal penalties for violations).

The remainder of the paper is organized as follows. Section 2 provides a brief survey of the relevant literature. In Section 3 we provide some background on the pulp and paper industry. Section 4 outlines our model of the regulator's allocation of pollution abatement across plants. In Section 5 we present our empirical methodology and a description of our data. Section 6 contains our results and finally we present some concluding remarks and possible extensions in Section 7.

2. Previous studies

Several studies have addressed the issues raised above, providing empirical estimates of the impact of political boundaries, demographics, and political activism on exposure to pollution. For example, Helland and Whitford [8], using annual county-level data from the Toxic Release Inventory (1987–1996), find that facilities located in counties on state borders (border counties) have systematically higher air and water pollution releases than facilities located in non-border counties: facilities in border counties emit 18% more air pollution and 10% more water pollution than facilities in non-border counties. Kahn [11] finds evidence of a transboundary externality problem with particulates. Sigman [18] finds greater water pollution upstream of international borders, suggesting a 'free-rider' problem. She also finds less of a problem for borders within the European Union, suggesting that close ties between the countries involved may help reduce transboundary pollution.

Hamilton [6,7] examines whether exposure to environmental risk varies by demographics and political activism. Using data at the 'zip-code neighborhood' level, he relates the capacity expansion/contraction decisions of commercial hazardous waste facilities to race, income, education, and level of political activity (voter turnout), finding that capacity expansions are negatively correlated with voter turnout. Jenkins et al. [9] show that minority communities receive lower 'host' fees for the siting of landfills while richer communities receive higher host fees. Kreisel et al. [12] find that minorities are not disproportionately exposed to TRI emissions, but find some evidence that the poor are disproportionately exposed to TRI emissions. Arora and Cason [1] find that race is a significant positive determinant of TRI releases in non-urban areas of the south, but not elsewhere in the country.

Been and Gupta [2] and Wolverton [21] consider the relationship between the siting of 'polluting' plants and neighborhood demographics. Anecdotal evidence suggests that polluting plants tend to be located in disproportionately poor and minority neighborhoods. However, Been and Gupta, who examine the siting decisions of commercial hazardous waste treatment storage and disposal facilities (TSDFs) in 544 communities, find no statistical evidence that TSDFs were sited more often in neighborhoods that were disproportionately African-American at the time of siting. Furthermore, Been and Gupta find that poor neighborhoods are actually less likely to have TSDF sitings. On the other hand, they do find evidence that TSDFs were sited in disproportionately Hispanic areas. Wolverton [21], measuring community characteristics at the time the plant was originally sited, finds that race no longer matters and poor neighborhoods actually attract disproportionately *fewer* polluting plants.

Other studies have examined the determinants of regulatory activity. Deily and Gray [4] find that regulators direct fewer air inspections towards steel mills that are on the verge of closing for economic reasons, suggesting regulators are reluctant to risk being blamed for a plant closing. Viscusi and Hamilton [20] find that Superfund sites in counties with greater voter turnout and in pro-environmental states have stricter environmental clean up targets for cancer risk. Sigman [19] considers the length of time it takes EPA to process Superfund sites, finding that community influence (measured by voter turnout and median income) is an important factor affecting EPA's bureaucratic priorities. Looking at regulations concerning asbestos exposures, Jones [10] finds that OSHA's enforcement activities respond to both the benefits and the costs of the regulations in different industries, suggesting regulator flexibility (despite a regulatory setting where cost was not supposed to be considered).

3. Pulp and paper industry background

During the past 30 years environmental regulation has increased considerably both in terms of stringency and levels of enforcement. In the late 1960s environmental rules were primarily enacted at the state level, and were not vigorously enforced. Since the creation of the EPA in the early 1970s the federal government has been the lead player in proposing and developing stricter regulations, and in encouraging greater emphasis on enforcement, much of which is still performed by state regulatory agencies under some degree of federal supervision. The expansion in environmental regulation has imposed large costs on traditional 'smokestack' industries, like the pulp and paper industry, which is one of the most impacted industries due to its sizable generation of both air and water pollution.

The pulp and paper industry as a whole faces a high degree of environmental regulation. However, plants within the industry can face very different impacts from regulation, depending in part on the technology being used (pulp and integrated mills vs. non-integrated mills[1]), the plant's age, the plant's location, and the level of regulatory effort directed at the plant. The most important determinant of the regulatory impact is whether or not the plant contains a pulping process. Pulp mills begin with raw wood (chips or entire trees) and use a variety of techniques to separate out the wood fibers, which are then used to produce paper. The most common form of pulping in the US is the Kraft technique, which separates the wood into fibers using chemicals. A large number of plants also use mechanical pulping (giant grinders separating out the fibers), while still others use some combination of heat, other chemicals, and mechanical methods. Once the fibers are separated out, they can be bleached and combined with water to produce a slurry. After the pulping stage is complete, residual matter remains which historically was released directly into rivers (hence water pollution), but now must first be treated. The pulping process is energy intensive, so most pulp mills have their own power plant, and thus are significant sources of air pollution. The pulping processes may also involve hazardous chemicals, such as the use of chlorine bleaching in Kraft pulp mills, which can create trace amounts of dioxin, raising concerns over toxic releases.

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[1] Integrated mills produce their own pulp and non-integrated mills purchase pulp or use recycled wastepaper.

The paper-making process is not nearly as pollution intensive as pulping. Non-integrated mills either purchase pulp from other mills or use recycled wastepaper. During the paper-making process, the slurry (more than 90% water at the beginning) is laid on a rapidly moving wire mesh which progresses through a succession of dryers in order to remove the water, thereby creating a continuous sheet of paper. The energy required during this stage is less than during the pulping stage, but it can still cause air pollution concerns if the mill produces its own power. Finally, during the drying process some residual water pollution is created. However, both of these pollution concerns are much smaller than those created during the pulping process.

The past 30 years has seen large reductions in pollution from the paper industry, with the advent of secondary wastewater treatment, electrostatic precipitators, and scrubbers. In addition to these end-of-pipe control technologies, some mills have altered their production process, e.g. more closely monitoring material flows to reduce emissions. Overall these alterations have been much easier to accomplish at newer plants, which were at least partly designed with pollution controls in mind—some old pulp mills were deliberately built on top of the river, so that any spills or leaks could flow through holes in the floor for 'easy disposal'. These rigidities can be partially or completely offset by the tendency for most regulations to include grandfather clauses exempting existing plants from the most stringent requirements—for example, until recent standards limited their NO_x emissions, most small old boilers were exempt from air pollution regulations.

4. Model of pollution abatement regulation

Why do profit-maximizing plants employ resources to abate pollution emissions? If pollution were a pure externality, with all of the burden falling on those who live downwind or downstream, we would not expect to see any profit-maximizing plant spend money on pollution abatement. Some market-based mechanisms like consumer demand for 'green' products or managerial taste for 'good citizenship' could provide incentives for plants to abate pollution. However, we believe that the main motivation for controlling pollution emissions in the US is government regulation of pollution, especially for the air and water pollutants being considered in this paper, so we model pollution abatement as determined by pressure from regulators. Regulatory pressure could be supplemented by pressure from customers and community groups, or polluting firms could be concerned about causing harm to some groups of people but not others. These alternative models would lead to analyses similar to those presented here (pollution levels from paper mills would differ based on the characteristics of the people affected by the pollution).

We believe that states have substantial flexibility to impose different degrees of regulatory pressure, despite the overall supervision of their activities by the federal EPA. Most air and water pollution inspections and enforcement actions are carried out by state regulators, states write the State Implementation Plans identifying permitted air emissions, and most states have direct responsibility for writing water pollution permits. Thus we view the state as the most relevant jurisdiction for determining political support for regulatory stringency, at least for our comparison across US pulp and paper mills.

A socially optimal government regulator maximizes social welfare by increasing the stringency of environmental regulation (requiring greater pollution abatement) up to the point where the marginal benefit from another unit of abatement is equal to the marginal cost of that abatement. In Eq. (1) below, the regulator would choose different optimal abatement values A_i^* for each plant, based on differences in factors affecting the marginal benefits and marginal costs of abatement. The marginal costs of abatement differ across plants based on their production technology, size, and age. The marginal benefits of abatement also differ across plants, driven especially by the number (and characteristics) of the people near the plant who are being exposed to the pollution. Assuming that the marginal cost of pollution abatement increases with stringency (or at least cuts the marginal benefits curve from below), higher marginal benefits (or lower marginal costs) would be associated with more stringent environmental regulation and lower emissions. Therefore, $dA_i^*/d\text{PLANT}_i < 0$ for PLANT characteristics that raise marginal costs, and $dA_i^*/d\text{PEOPLE}_i > 0$ for PEOPLE characteristics that raise marginal benefits

$$\text{MC}(\text{PLANT}_i, A_i^*) = \text{MB}(\text{PEOPLE}_\text{i}, A_i^*). \tag{1}$$

Our analysis focuses on the differences across plants in the marginal benefits of pollution abatement (MB_i), though we also include plant characteristics affecting abatement costs as control variables. We model the regulator as adding up the marginal benefits from pollution reductions for all people living around a plant, as shown in Eq. (2) below. The locations of the people are indexed by x and y. The marginal benefits MB_i for pollution reductions at a given plant will depend heavily on the number of people in the area (measured by ρ_{xy}, the population density at a given point) and the emissions that they are exposed to (E_{xy}). Differences in people's susceptibility to pollution exposure are captured by S_{xy}. Finally, differences in the regulator's valuation of certain people are captured by α_{xy}:

$$MB_i = \int_x \int_y \alpha_{xy} S_{xy} E_{xy} \rho_{xy} \, dx \, dy. \tag{2}$$

Why would α_{xy} differ across people affected by pollution? One strand of the literature raises concerns with "Environmental Justice", suggesting that groups with less political influence (poor or minorities) are discriminated against (assigned a smaller value of α_{xy}) by regulatory agencies aiming at maximizing the overall political support for their actions. Politically, active people who strongly favor environmental issues might put more pressure on regulators, and hence get a larger value of $\alpha_{xy.}$ For plants located near a state (or national) boundary, the benefits from pollution reduction may accrue to people in other jurisdictions for whom α_{xy} might be expected to be zero (or at least less than one). However, some countervailing pressures may arise to offset the latter transboundary effect on regulatory activity.

The creation of a federal EPA in 1972 was at least in part designed to limit cross-state pollution flows, and EPA oversight of state regulatory decisions may be stricter for plants near state boundaries. We measure transboundary effects by a dummy variable for the plant being located near the border with another state, and by the fraction of the population near the plant located in other states. We also include a measure of the pro-environment stance of the neighboring state's Congressional delegation, since presumably the airing of a neighboring state's objections to any transboundary pollution is likely to occur at the federal level.

In the case of Canada two agreements exist which are designed to limit the levels of transboundary pollution: the Canada–United States Great Lakes Water Quality Agreement

(GLWQA) of 1972 and the Canada–United States Air Quality Agreement (AQA) of 1991.[2] The GLWQA establishes that the US and Canada will act to restore and preserve the chemical, physical and biological soundness of the Great Lakes Basin Ecosystem. In particular, it establishes specific objectives to protect beneficial water uses from the combined effects of pollutants like BOD and TSS. The GLWQA also requires the US and Canada to work to ensure that water quality standards and other regulatory requirements set by state and provincial governments be consistent with the achievement of the objectives set forth in the agreement.

The AQA aims at controlling transboundary air pollution caused by sulfur dioxide and nitrogen oxide emissions. Among other things, it requires the US to reduce annual sulfur dioxide emissions by approximately 10 million tons from 1980 levels (in accordance with Title IV of the Clean Air Act), to achieve a permanent national emission cap of 8.95 million tons of sulfur dioxide per year for electric utilities by 2010 (also required by Title IV of the Clean Air Act), and to reduce total annual emissions of nitrogen oxides by approximately 2 million tons from the 1980 emission levels by 2000. Given these agreements it is plausible that plants along the Canadian border could face more stringent (or at least no less stringent) environmental regulation, though the mechanisms whereby this increased stringency would be imposed are not clear.[3]

5. Data and empirical methodology

Our study measures the relationship between regulatory activity and emissions, and the characteristics of the surrounding population, using data on the intensity of environmental regulation faced by US pulp and paper mills. The 409 plants in our data set were selected based on having EPA regulatory data available for either air or water pollution regulation (or both). Since the EPA data sets are more likely to include data for large plants, the plants in our sample are probably somewhat larger than average for the industry. To get an indication of coverage, nearly all of our plants would probably be classified in the pulp, paper, or paperboard industries (SICs 2611, 2621, and 2631), which in the 1992 Census of Manufacturing consisted of 529 plants. This suggests fairly complete coverage (77%), and hence reasonably representative results.

We use data on both air and water pollution inspections and enforcement actions to measure the stringency of environmental regulation directed towards each mill. To measure actual outcomes from regulation at the mill we use data on both air and water pollution emissions from the mill. Our analysis controls for a variety of plant- and firm-specific characteristics. We also include a number of other control variables designed to capture characteristics of the location of the mill that could influence the level of regulatory activity it faces.

We use models of the spread of pollution to estimate the relative impacts of the pollution on people living near the plant. On the air pollution side, the model utilizes an air dispersion model, SLIM-3. This model incorporates information from the pollution source (stack height and characteristics of the pollutants being emitted) and meteorological data (mixing height, wind directions and speeds). The model calculates the average ambient particulate exposure across all

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[2] A memorandum of intent on air quality has been in place since 1981.

[3] For more information on both of these agreements see the web site (http://www.ijc.org/ijcweb-e.html) of the International Joint Commission which was created by the International Boundary Waters Treaty Act of 1909.

points within a wide circle around the plant, per unit of pollution emissions (calculated separately for particulate and sulfur dioxide emissions). This average exposure is multiplied by the number of people living within the circle and a (linear) dose–response function to calculate the expected number of fatalities from the increased exposure to particulates. This is multiplied by the value of a statistical life to yield the overall dollar benefits from reducing air pollution at each plant (see [17] for more details). Note that, despite the formula's complexity, it generates a linear relationship between emissions and dollar benefits, yielding a constant marginal benefit per ton of emissions reduction; also note that we get separate benefits measures for particulate and sulfur dioxide emissions.

On the water pollution side we use data from the EPA's National Water Pollution Control Assessment Model (NWPCAM). This model includes discharge data for over 50,000 industrial and 13,000 municipal water polluters, combined with stream and river flow data to calculate the transport of pollutants downstream and the resulting water quality on a mile-by-mile basis for every stream in the model. We use an experimental version of the NWPCAM model being developed for EPA at Research Triangle Institute, with a continuous water quality index (0–100) rather than the traditional four-valued outcomes (unusuable, boatable, fishable, swimmable), allowing for a more precise valuation of water quality changes. Carson and Mitchell [3] develop a formula for the dollar benefits of improved water quality (TOTWTP), based on a survey of consumers' willingness to pay for an average improvement in all rivers in a state.[4]

Of the paper mills in our data set, 231 have data present in the NWPCAM model. For each of these mills, we first calculate a baseline model assuming current discharges from all other water polluters but zero discharges from this plant. We then estimate 5 scenario models, increasing the pollution discharged from the mill by a wide range of amounts, and measuring how each scenario affects water quality downstream of the plant in dollar terms (TOTWTP). These dollar values are added up across all affected stream miles and divided by the amount of pollution discharged in that scenario, yielding a value per unit of pollution in each scenario. We used the largest value from the 5 scenarios to measure the benefits of water pollution abatement (WATERBEN)—for most plants only large increases in their pollution discharges generate measurable water quality impacts downstream.

Detailed data on the characteristics of the population within a 50-mile[5] radius of each plant, including age distribution, racial composition, and within-jurisdiction residency, are based on the 1990 US Census of Population, as compiled in the Census-CD data sets prepared by Geolytics, Inc. This provides information based on detailed geographic areas (Census block groups). Distances are calculated between the paper mill and the centroid of each block group to determine

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[4] $\text{TOTWTP} = \exp(5.0385 + 0.819 * \log(\text{WQI}/10))$, where WQI is the 0–100 water quality index. The formula in the article includes other individual-specific terms, but we replace these with the reported sample averages, since we do not have comparable data here. Since this is the per-capita benefit from improving average water quality in all rivers in the state, we multiply the change in TOTWTP by the number of people in the state and divide by the number of river miles in the state. Finally, we do a similar calculation for national willingness to pay and calculated a weighted average, one-third national benefits and two-thirds in-state benefits (since respondents to the survey indicated two-thirds of their willingness to pay came from within-state benefits).

[5] Alternative circles of 10 and 25 miles were also tested and we found qualitatively similar results to those presented here (when using the spatially lagged instrumental variables).

which block groups fall within 50 miles of the mill, and the block group values for each population characteristic are aggregated to get the overall value for each mill.

In past studies we developed a comprehensive database of US pulp and paper mills to study the impact of environmental regulation on plant-level productivity and investment. This database includes published plant-level data from the *Lockwood Directory* and other industry sources to identify each plant's production capacity, age, production technology, and corporate ownership. We add financial data taken from Compustat, identifying firm profitability. One explanatory variable used in past research on the steel industry by Deily and Gray [4] is the predicted probability of the plant closing. Though there have been some plant closings in the paper industry, there are relatively few among the plants in our data set—only 8 of the 409 plants are not operating in 1997—ruling out that type of analysis here (and precluding any analysis of the possible endogeneity of plant closings).

Our pulp and paper mill data is merged with annual plant-level information on regulatory enforcement and quantities of pollution for both air and water pollution, taken from EPA regulatory databases. Regulatory enforcement data for 1985–1997 come from the EPA's Envirofacts and Integrated Data for Enforcement Analysis databases, as do the water pollution discharges data for biochemical oxygen demand (BOD) and total suspended solids (TSS). These data sets allow us to differentiate between two different types of regulatory actions—enforcement actions (e.g. notice of violation) and inspections. Based on conversations with regulators, the number of enforcement actions is more likely to be connected with problems at the plant, while the number of inspections is more connected with the plant's size. Air pollution emissions data for particulates (PM10) and sulfur dioxide (SO_2) comes from the Aerometric Information Retrieval System database for 1985–1990 and from the National Emissions Inventory for 1990–1997.[6]

Our analyses consider two different measures of the environmental regulatory pressures faced by each plant. The number of inspections and the number of enforcement actions received by the plant provide direct measures of regulatory attention. The level of air pollution emissions and water pollution discharges from the plant provide a measure of the environmental performance by the plant, which we would expect to be related to regulatory pressures, all else equal (i.e. assuming that other variables included in the analyses control for differences in the amount of pollution that would be emitted by the plant in the absence of regulation).

Each dependent variable Y_{it} is a function of PLANT and PEOPLE characteristics, as well as STATE variables and year dummies:

$$Y_{it} = f(\mathrm{PLANT}_{it}, \mathrm{PEOPLE}_{it}, \mathrm{STATE}_{it}, \mathrm{YEAR}_{t}), \tag{3}$$

where Y_{it} is one of the eight dependent variables in our analysis: Air and Water Pollution Inspections and Enforcement, Water Discharges of BOD and TSS, and Air Emissions of PM10 and SO_2. Since increased regulatory activity will be seen (directly) in more inspections and enforcement actions, and (indirectly) in less air and water pollution, we expect to find opposite signs for the coefficients in the regulatory activity and pollution quantity equations.

First, let us review the plant-, firm-, state-, and county-level control variables included in each model. These controls include plant capacity, plant age, firm financial condition, county

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[6] When a plant has data from both sources for 1990, the values are identical about half the time (46% for particulates and 48% for SO_2) and highly correlated (0.927 for particulates and 0.925 for SO_2).

attainment status (air only), major source and public health effects (water only), and state environmental attitudes.[7] All the results presented here include state dummies, but models without state dummies yield similar conclusions.[8] To avoid having the state dummies absorb too much of the cross-plant variation, we only include state dummies for states with 5 or more plants in the given regression (e.g. the air pollution inspection model includes 22 state dummies, with the base group being all other non-specified states).

We include pulp and paper capacity (PULP/PAPER CAPACITY) to control for plant size, a dummy variable to indicate if the plant was established after 1960 (NEW PLANT), and a dummy variable to indicate if the plant is the only paper or pulp mill owned by the firm (SINGLE). We also include information about the plant's Occupational Safety and Health Agency's violations (OSHA VIOL), since previous research [5] has shown that OSHA violations are positively correlated with EPA violations. To indicate the financial health of the firm which owns the plant, we include a measure from Compustat of the owning-firm's rate of return on its assets (RETURN ON ASSETS). We also include firm dummies for the 7 firms which own more than 10 paper mills, to allow for persistent differences across firms in their environmental behavior.

We include three additional variables to control for exogenous factors affecting the level of regulatory stringency faced by the plant. In the air equations we include a dummy variable to indicate if the plant is located in a county that is in non-attainment status with respect to particulate standards (NONTSP; in our data non-attainment for sulfur dioxide is much less common, and nearly always overlaps with particulate non-attainment, so we use particulate attainment status in all air pollution equations). In the water equations we include a numeric rating from EPA's Majors Rating Database indicating the extent to which the plant is an important source of water pollution (MAJORS) and a dummy variable to indicate if the plant discharges into a stream that is a source of drinking water, giving water pollution from that plant the potential for health effects (PUBLIC HEALTH).

We control for the state-level regulatory climate using GREEN VOTE, a measure of support for environmental legislation by that state's Congressional delegation. The League of Conservation Voters calculates a scorecard for each member of Congress on environmental issues, with data available back to the early 1970s. We use the average score for the state's House of Representative members in our analysis. We also calculate the average inspection rate for all other plants in the state (in all industries), separately for air and water (AVG AIR INSPECTIONS and AVG WATER INSPECTIONS).[9] The unemployment rate in the state for that year (UNEMP) and percent of the county designated as urbanized (URBAN) round out our control variables.

Now consider the variables which are at the heart of our analyses, those influencing the marginal benefits from pollution abatement at a particular mill (MB_i in Eq. (2)). As described above, we have information on the expected benefits per unit of pollution reduction (AIRBEN and WATERBEN). On the air pollution side, we also have the percentage of the nearby

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[7] Previous research [4,5,13,14] showed a strong relationship between compliance and enforcement. When we included lagged compliance in our model, plants in compliance had significantly lower pollution and faced less regulatory activity. Concerns about the endogeneity of compliance led us to exclude compliance from our final model, but this exclusion does not greatly affect the coefficients on the key variables in our analyses.

[8] Results available as supplementary material archived in http://www.aere.org/journal/index.html.

[9] These inspection rates are calculated separately for each plant, excluding the inspections directed at that plant.

population under the age of 6 (KIDS) and those 65 and over (ELDERS), representing groups with greater sensitivity to air pollution (S_{xy} in Eq. (2)). We would expect each of them to be positively related to regulatory activity (inspections and enforcement actions), and negatively associated with pollution quantities.

Differences in α_{xy} across people are measured with several variables. We test for Environmental Justice factors by including two measures of potentially "less valued" populations: poor and minorities. POOR is the percentage of the nearby population living below the poverty line. The minority variable is the percentage of the population that is nonwhite (NONWHITE). We would expect both to be negatively associated with regulatory activity and positively associated with pollution levels.

A positive influence on α_{xy} is expected to come from voter activity, measured using county voter turnout in the previous presidential election (TURNOUT). The use of voter activity to overcome externalities is discussed in Olson [15]. However, it is possible that in some cases a majority of the electorate could oppose environmental regulation, so that higher turnout need not always increase regulation. Thus we include an interaction between turnout and membership in conservation organizations (TURNOUT $*$ CONVMEMB), which would be expected to have a positive association with regulatory activity (CONVMEMB is measured at the state level).

We test for the effects of political boundaries by including two dummy variables indicating whether the plant is within 50 miles of another jurisdiction (STATE BORDER and CANADIAN BORDER). For these plants, some of their pollution may "spill over" to the other jurisdiction. All else equal, state regulators should care less about such pollution, so regulatory activity should be diminished for those plants. However, the other jurisdiction(s) might respond to any transboundary pollution. Depending on the institutional arrangements in place, the political costs associated with transboundary pollution could be larger than the costs of intrastate pollution. For cross-state pollution, the sensitivity of the other state to transboundary pollution (and hence the pressure it would apply to reduce such pollution) is presumed to be associated with that state's GREEN VOTE measure of pro-environmental Congressional support.

An alternative approach to these benefit-related variables is to disaggregate the total benefits received by the surrounding population into those received by different groups, in an effort to see whether the coefficient on benefits differs across groups. In some regressions we add an interaction between the total benefits and the share of the surrounding population in each group, so that the coefficients on the interaction terms show the differences across groups. To measure transboundary effects on the air pollution side we assume that the benefits are distributed proportionately to the fraction of the population within 50 miles of the plant that is out of state. On the water pollution side we measure the benefits for each out-of-state river segment directly (where a river forms the border between states, half of the benefit is allocated to each state).

We estimate the eight different equations for the dependent variables measuring regulatory stringency using two statistical techniques. For both air and water pollution we measure stringency as the number of inspections (INSP) and enforcement actions (ENF) a plant receives in a given year. Since both INSP and ENF are often zero and are otherwise relatively small integers, we estimate the equations using a Poisson model (actually, we use a Negative Binomial model, to allow for the observed over-dispersion of the data, relative to the simpler Poisson model). For the four pollution quantity equations, we use ordinary least squares on the logarithm of emissions quantities because of the wide dispersion in emissions across plants.

Our focus in the analysis will be on the impact of the demographic characteristics of the area near the plant on the regulatory activity directed towards the plant, and on the emissions performance of the plant. One concern with interpreting the results from this analysis is the potential for reverse causality due to sorting of housing. Poor people could move into dirty neighborhoods because housing is cheaper there. Families with sensitive individuals such as kids and elders might avoid dirty neighborhoods. The most common procedure to deal with potential endogeneity is to find an instrumental variable, correlated with the demographic variables but not with the unexplained residual for this particular plant. We cannot use lagged values of the Census demographic variables as instruments, since our sample of paper mills is quite old. Most of our plants were built before 1960, so the 'problem' of this plant's pollution affecting the housing decisions of people nearby would remain, even in 1970 or 1980 data. In addition, the 1990 Census of Population data used here is the first to give such spatially detailed demographic data for non-urban areas, so there are no earlier demographic values available to generate lagged values for many of our plants.

Instead of using 'temporally lagged' instruments, we use 'spatially lagged' instruments. We calculate each of the demographic variables for the set of people living between 50 and 100 miles from the plant, and use these as instruments for the demographic values nearer the plant. As long as the impact of pollution emissions declines reasonably quickly with distance, the location decisions for people living 50 or 100 miles away (the 'outer ring') will have little to do with any unexplained residual pollution from this particular plant located in the center of the 'inner ring'. These outer ring demographics values will reflect the tendencies of different types of people to live in this general area, and should therefore be correlated with the demographic characteristics of the area near the plant. We run a first-stage regression of the local demographic values on the outer ring demographic values, along with state dummies. The predicted demographic values from this first stage are then entered into the second stage estimation, in place of the actual demographic values near the plant.[10] Note that the strong positive coefficients on the demographic variables in the first stage suggest no serious difficulties from reverse sorting: if wealthier people chose to live in the outer ring while the poor lived in the inner ring, we should see negative coefficients in Table 2. Presumably broader spatial trends (e.g. certain areas having more or less poverty overall) drive the Table 2 results.

6. Results

Table 1 contains the means and standard deviations (along with variable descriptions) of all variables used in this study. Note that the number of observations varies across the models being estimated, depending on the availability of data for the dependent variable and some specific explanatory variables. We have more data for regulatory activity (inspections and enforcement actions) than we do for pollution quantities. To avoid having too many different sample sizes, we restrict the pollution quantity estimation to plants which have both pollutants reported. To

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[10] The non-instrumented results are similar—see http://www.aere.org/journal/index.html.

Table 1
Descriptive statistics ($N = 4032$, air enforcement data set, unless otherwise noted)

Variable (N)	Mean	(Std dev)	{log mean, std}
Dependent variables			
AIR INSP	2.396	(4.214)	
Number of air pollution inspections			
AIR ENF	0.356	(1.143)	
Number of air pollution enforcement actions			
PM10 ($N = 3107$)	369.2	(608.7)	{4.32, 2.18}
Tons of particulate emissions per year			
SO_2 ($N = 3107$)	1722.7	(3232.7)	{5.83, 2.42}
Tons of sulfur dioxide emissions per year			
WATER INSP ($N = 3431$)	1.650	(1.560)	
Number of water pollution inspections			
WATER ENF ($N = 3431$)	0.183	(0.710)	
Number of water pollution enforcement actions			
BOD ($N = 2113$)	4061	(8258)	{7.20, 1.75}
Biological oxygen demand discharged			
TSS ($N = 2113$)	7611	(31,442)	{7.48, 1.93}
Total suspended solids discharged			
Key explanatory variables			
AIRBEN	2997	(4092)	{7.27, 1.30}
Marginal benefit of air pollution abatement (particulate + SO_2) ($1990/ton)			
PMBEN	3528	(4834)	{7.44, 1.29}
Marginal benefit of particulate air pollution abatement ($1990/ton)			
SO_2BEN	1431	(1907)	{6.56, 1.27}
Marginal benefit of SO_2 air pollution abatement ($1990/ton)			
WATERBEN ($N = 3431$)	327.2	(834.1)	{3.37, 1.86}
Marginal benefit of water pollution abatement (BOD + TSS) ($1990/unit)			
KIDS	0.087	(0.006)	
Percentage of the population under 6 years old			
ELDERS	0.131	(0.019)	
Percentage of the population 65 years old and over			
POOR	0.135	(0.051)	
Percentage of the population living below the poverty line			
NONWHITE	0.137	(0.132)	
Percentage of the population who are nonwhite			
TURNOUT	41.673	(6.859)	
Percentage of the population over 18 voting in previous presidential election			
STATE BORDER	0.655	(0.476)	
Dummy indicating a plant located within 50 miles of a state border			
CANADIAN BORDER	0.126	(0.332)	
Dummy indicating a plant located within 50 miles of the Canadian border			
Control variables			
PULP CAPACITY	404.1	(630.4)	(2.893, 3.284)
Plant capacity—tons of pulp per day			
PAPER CAPACITY	497.7	(582.5)	(4.999, 2.266)
Plant capacity—tons of paper per day			

Table 1 (*continued*)

Variable (*N*)	Mean	(Std dev)	{log mean, std}
NEW PLANT	0.249	(0.433)	
Dummy variable indicating the plant was opened after 1960			
SINGLE	0.247	(0.431)	
Dummy variable indicating that this is the only paper plant owned by the firm			
MAJORS ($N = 3431$)	114.627	(37.388)	
Numeric majors rating from the EPA's majors rating database			
PUBLIC HEALTH ($N = 3431$)	0.430	(0.495)	
Dummy variable indicating stream used as drinking water source			
RETURN ON ASSETS	0.023	(0.056)	
Firm's rate of return on assets (Compustat)			
OSHA VIOL	0.293	(0.408)	
Fraction of OSHA inspections with violations (3-year moving average, last-this-next years)			
AVG AIR INSPECTIONS	0.294	(0.160)	
Average air pollution inspection rate in state (all other plants in state)			
AVG WATER INSPECTIONS	0.527	(0.289)	
Average water pollution inspection rate in state (all other plants in state)			
NONTSP	0.342	(0.474)	
Dummy indicating plant is located in non-attainment area for TSP			
URBAN	39.140	(39.22)	
Percent of county designated as urbanized			
GREEN VOTE	54.309	(17.768)	
State pro-environment Congressional voting (League of Conservation Voters)			
UNEMP	6.000	(1.584)	
State unemployment rate			
CONVMEMB	8.957	(3.386)	
State membership in 3 conservation groups, late 1980s, per 1000 population			

simplify Table 1, all of the control variables have their values reported only for the largest data set, corresponding to air pollution regulatory activity.

In our data the average plant-year observation receives nearly ten times as many inspections as enforcement actions: approximately two air or water pollution inspections per year and one air or water enforcement action every 5 or more years. The distribution of enforcement actions is skewed in our data, with many plants receiving none and others receiving several. There is also substantial variation across plants in their air emissions and water discharges.

Considering the explanatory variables, the marginal benefits from pollution abatement vary substantially for both air and water pollution. There is much less variation in the age-related demographics variables (KIDS and ELDERS) compared to the 'Environmental Justice' variables (POOR and NONWHITE). Most plants (66%) are within 50 miles of a state border, while just 13% are located near the Canadian border. Most plants were in existence by 1960 (75%) and are owned by a firm with more than one paper mill (75%). Approximately half of the plants (43%) are discharging water pollution into streams used for drinking water and 34% of the plants are located in counties that are not in attainment with particulate emission standards. About half of the plants (55%) have no pulping activity: these tend to be smaller than the pulp mills (with an

Table 2
First-stage estimates of demographic values using spatially lagged demographics as instruments

Dependent variable	ELDERS	KIDS	POOR	NONWHITE
Spatially lagged demographics	0.566	0.576	0.762	0.745
	(6.35)	(10.03)	(17.75)	(17.31)
R^2	0.315	0.431	0.727	0.778

T-statistics in parentheses. All regressions also include state dummies.
'Spatially lagged' demographic variables are the corresponding demographic variables, but calculated for all the people living 50–100 miles from the plant.

average paper-making capacity of 194 tons per day vs. 876 for pulp mills) and emit correspondingly less pollution (e.g. SO_2 emissions of 529 tons per year vs. 2647 for pulp mills).

Table 2 presents the first-stage results, regressing the demographic variables measured near each plant on the comparable 'spatially lagged' values calculated for people living between 50 and 100 miles from that plant—the regressions also include state dummies. Note that the regressions are explaining a large part of the variation in the demographic variables, on the order of 30–80 percent, and the outer ring demographic values are highly significant.

Tables 3 and 4 present the results of the basic model for air pollution and water pollution regulation respectively. Consider first the control variables in each equation. The effects of plant capacity seem to come primarily in terms of pulping capacity, rather than paper capacity (larger coefficients and more frequently significant). Larger plants generate more pollution and face more regulatory activity (except water inspections). Plants in urban areas generate less pollution, but also (surprisingly) face somewhat less regulatory activity. Plants in areas with high unemployment rates generate more air pollution and less water pollution, and face more air enforcement actions. OSHA violations are surprisingly associated with lower pollution quantities (though significant only for SO_2), and more enforcement actions. The time trends are mostly unremarkable. The base year is 1985 (during the Reagan administration) except for the water pollution quantity equations, which use a base year of 1989 (during the Bush administration). We see significantly higher regulatory activity and lower pollution quantities during the Clinton administration (except for water inspections, which are significantly lower).

Now consider the benefits-related variables that are the focus of our analysis. The marginal benefits per unit of pollution abatement for the overall population are associated with significantly lower pollution levels for all four pollutants, but are also associated with significantly less air regulatory activity. Plants surrounded by more people from sensitive population groups (KIDS and ELDERS) emit significantly less air pollution—the only exception being SO_2 for elders. Since the dependent variables are measured in log form, the coefficients reflect percentage impacts on pollution. For example, a one standard deviation increase in ELDERS (0.019) is associated with 59% lower particulate emissions; a comparable increase (0.006) for KIDS is associated with 27% lower PM10 and 39% lower SO_2 emissions. A one standard deviation increase in air pollution abatement benefits (1.3 in logs) is associated with 13% lower PM10 and 11% lower SO_2 emissions. A comparable (1.9) increase in water pollution benefits is associated with 16% lower BOD and 23% lower TSS discharges.

Table 3
Basic air model

DEPVAR	AIR INSP	AIR ENF	PM10	SO_2
OBS	4032	4032	3107	3107
AIRBEN	−0.045	−0.204	−0.099	−0.088
	(−1.790)	(−2.940)	(−2.840)	(−1.970)
ELDERS	−8.753	8.470	−31.024	−6.366
	(−1.400)	(0.480)	(−3.920)	(−0.540)
KIDS	2.992	40.515	−44.198	−65.236
	(0.240)	(1.200)	(−2.490)	(−2.800)
POOR	3.409	−9.815	12.765	1.101
	(2.260)	(−2.220)	(6.410)	(0.390)
NONWHITE	−0.102	0.568	−3.035	−4.783
	(−0.200)	(0.360)	(−3.920)	(−4.340)
STATE BORDER	−0.140	−0.580	−0.459	−0.104
	(−1.350)	(−1.930)	(−3.040)	(−0.500)
STATEBORDER * GREENVOTE	0.004	0.012	0.008	0.003
	(1.960)	(2.240)	(2.850)	(0.970)
CANADIAN BORDER	0.028	0.647	0.078	−0.640
	(0.420)	(3.580)	(0.720)	(−4.690)
TURNOUT	−0.391	−1.105	−0.302	1.723
	(−1.010)	(−1.010)	(−0.520)	(2.130)
TURNOUT * CONVMEMB	0.031	0.233	−0.080	−0.249
	(1.000)	(3.090)	(−2.130)	(−4.420)
Control variables				
PULP CAPACITY	0.123	0.202	0.355	0.328
	(15.990)	(9.720)	(26.610)	(19.510)
PAPER CAPACITY	−0.006	−0.034	−0.022	0.062
	(−0.710)	(−1.460)	(−1.680)	(3.880)
NEW PLANT	−0.037	0.182	0.221	0.023
	(−0.880)	(1.580)	(3.520)	(0.260)
SINGLE	−0.090	−0.164	−0.199	−0.174
	(−2.020)	(−1.260)	(−2.900)	(−1.910)
RETURN ON ASSETS	0.675	0.464	1.284	0.445
	(2.370)	(0.530)	(1.320)	(0.370)
OSHA VIOL	−0.009	0.495	−0.022	−0.299
	(−0.170)	(3.040)	(−0.270)	(−2.720)
AVG AIR INSPECTIONS	2.214	0.778	−0.171	0.399
	(19.480)	(2.400)	(−1.130)	(1.810)
NONTSP	0.049	−0.102	0.006	−0.143
	(0.990)	(−0.780)	(0.070)	(−1.480)
URBAN	−0.002	0.001	−0.004	−0.005
	(−2.960)	(0.920)	(−4.340)	(−4.790)
GREEN VOTE	0.001	−0.016	−0.003	0.003
	(0.360)	(−2.760)	(−1.130)	(0.750)
UNEMP	0.006	0.183	0.043	0.126
	(0.370)	(3.380)	(1.900)	(4.180)
YR86	0.168	1.168	−0.012	0.018
	(2.130)	(2.970)	(−0.090)	(0.110)

Table 3 (*continued*)

DEPVAR	AIR INSP	AIR ENF	PM10	SO_2
YR87	0.116	1.614	−0.062	0.052
	(1.460)	(4.510)	(−0.430)	(0.300)
YR88	0.161	1.919	−0.095	0.161
	(1.790)	(5.210)	(−0.660)	(0.920)
YR89	0.051	2.247	−0.072	0.141
	(0.580)	(5.930)	(−0.500)	(0.800)
YR90	0.135	1.995	−0.278	−0.067
	(1.580)	(5.450)	(−2.030)	(−0.400)
YR91	0.063	1.563	−0.435	−0.261
	(0.780)	(4.400)	(−3.410)	(−1.630)
YR92	0.256	1.586	−0.404	−0.378
	(3.030)	(4.490)	(−3.040)	(−2.250)
YR93	0.229	2.194	−0.367	−0.465
	(2.800)	(6.170)	(−2.870)	(−2.820)
YR94	0.220	2.519	−0.314	−0.337
	(2.560)	(7.230)	(−2.460)	(−2.030)
YR95	0.186	2.244	−0.330	−0.300
	(2.060)	(6.160)	(−2.420)	(−1.690)
YR96	0.096	2.494	−0.601	−0.438
	(1.050)	(6.700)	(−4.290)	(−2.480)
YR97	0.108	2.926	−0.578	−0.478
	(1.050)	(7.870)	(−4.110)	(−2.650)
R^2	0.193	0.119	0.655	0.482

T-statistics in parentheses. All regressions include state dummies.
AIRBEN row is PMBEN and SO_2 BEN for PM10 and SO_2 models.
Regulatory activity models (INSP and ENF) use Negative Binomial model.
Pollution quantity models use Log(pollution) in OLS model.

The results for the "Environmental Justice" variables are mixed. POOR has the expected effects in most cases: significantly more air (insignificant for SO_2) and water pollution, and fewer enforcement actions (although unexpectedly more inspections). However, the NONWHITE coefficient is always opposite in sign from POOR (less, rather than more, pollution), and usually significant. It appears that nonwhites do not face disproportionately more pollution, but the poor do.[11]

Plants located in areas of high political activity and high support for environmental regulation, as measured by TURNOUT $*$ CONVMEMB, are expected to face more regulatory activity and have less pollution. Pollution levels are significantly lower as expected, although the greater relative magnitude of the TURNOUT coefficient for the models in Table 4 means that the net effect of greater TURNOUT is to increase discharges of water pollution for plants in all but relatively high CONVMEMB states. The regulatory activity results are mixed, as areas with high

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[11] These results are not due to multicollinearity between minority and poor populations, even though the correlation between NONWHITE and POOR is 0.66. The NONWHITE coefficients tend to remain significantly negative when POOR is omitted from the regression—see results in http://www.aere.org/journal/index.html.

Table 4
Basic water model

DEPVAR	WATER INSP	WATER ENF	TSS	BOD
OBS	3431	3431	2113	2113
WATERBEN	−0.002	0.052	−0.085	−0.126
	(−0.250)	(1.460)	(−5.450)	(−8.410)
POOR	1.963	−5.840	4.279	3.903
	(2.270)	(−1.630)	(2.160)	(1.980)
NONWHITE	−0.427	5.101	−3.882	−2.659
	(−1.200)	(3.430)	(−5.290)	(−3.820)
STATE BORDER	−0.028	−0.079	0.250	0.188
	(−0.350)	(−0.250)	(1.690)	(1.280)
STATEBORDER * GREENVOTE	−0.000	0.003	−0.001	−0.001
	(−0.260)	(0.460)	(−0.440)	(−0.310)
CANADIAN BORDER	−0.095	−0.013	0.037	0.407
	(−1.800)	(−0.070)	(0.330)	(4.080)
TURNOUT	1.178	1.868	2.918	4.316
	(3.590)	(1.070)	(4.060)	(6.040)
TURNOUT * CONVMEMB	−0.050	−0.252	−0.265	−0.300
	(−1.940)	(−1.450)	(−4.300)	(−4.840)
Control variables				
MAJORS	0.005	0.004	0.014	0.012
	(9.950)	(1.910)	(9.170)	(8.410)
PUBLIC HEALTH	0.087	0.179	0.020	0.129
	(2.550)	(1.310)	(0.270)	(1.720)
PULP CAPACITY	−0.011	0.050	0.204	0.177
	(−1.740)	(1.900)	(15.210)	(12.760)
PAPER CAPACITY	−0.001	0.012	−0.061	−0.058
	(−0.230)	(0.370)	(−4.750)	(−4.810)
NEW PLANT	−0.015	−0.322	0.058	0.009
	(−0.480)	(−2.120)	(0.880)	(0.140)
SINGLE	0.029	0.479	−0.213	0.023
	(0.750)	(2.970)	(−2.640)	(0.300)
RETURN ON ASSETS	−0.041	2.051	−0.018	−0.120
	(−0.270)	(1.200)	(−0.070)	(−0.720)
OSHA VIOL	−0.015	0.326	−0.039	0.005
	(−0.340)	(1.710)	(−0.450)	(0.060)
AVG WATER INSPECTIONS	1.748	0.289	−0.263	−0.246
	(14.590)	(0.530)	(−1.240)	(−1.140)
URBAN	−0.001	−0.003	−0.004	−0.004
	(−2.730)	(−1.560)	(−3.700)	(−4.110)
GREEN VOTE	0.000	0.004	−0.005	−0.002
	(0.240)	(0.540)	(−1.160)	(−0.600)
UNEMP	−0.012	0.021	−0.136	−0.163
	(−0.890)	(0.400)	(−3.250)	(−3.950)
YR86	−0.020	0.438		
	(−0.300)	(0.940)		
YR87	−0.195	0.840		
	(−2.870)	(2.040)		

Table 4 (*continued*)

DEPVAR	WATER INSP	WATER ENF	TSS	BOD
YR88	−0.044	1.088		
	(−0.640)	(2.490)		
YR89	−0.076	1.139		
	(−1.080)	(2.740)		
YR90	−0.141	1.132	0.062	0.067
	(−2.090)	(2.770)	(0.540)	(0.620)
YR91	−0.162	1.437	0.145	0.167
	(−2.470)	(3.590)	(1.070)	(1.230)
YR92	−0.303	1.433	0.016	0.077
	(−4.440)	(3.440)	(0.110)	(0.540)
YR93	−0.384	0.762	0.022	−0.015
	(−5.680)	(1.920)	(0.170)	(−0.120)
YR94	−0.320	1.160	−0.117	−0.191
	(−4.770)	(2.910)	(−0.920)	(−1.570)
YR95	−0.348	0.909	−0.260	−0.325
	(−4.710)	(2.150)	(−1.990)	(−2.520)
YR96	−0.411	0.684	−0.306	−0.355
	(−5.380)	(1.600)	(−2.380)	(−2.790)
YR97	−0.485	0.586	−0.383	−0.437
	(−6.390)	(1.290)	(−2.980)	(−3.360)
R^2	0.123	0.171	0.628	0.582

T-statistics in parentheses. All regressions include state dummies.
Regulatory activity models (INSP and ENF) use Negative Binomial model.
Pollution quantity models use Log(pollution) in OLS model.

turnout and above-average CONVMEMB values are associated with less, rather than more, regulatory activity for water pollution actions and inspections.

The border effects in Tables 3 and 4 do not follow the expected pattern. Plants which are located near state borders show no significant differences in SO_2 or BOD emissions and unexpectedly lower particulate emissions. Furthermore, there is more air pollution where the bordering states are stronger environmentally.[12] The results for plants near the Canadian border suggest different impacts for different pollutants. On the water pollution side we observe more BOD pollution and fewer inspections. On the air pollution side we observe less SO_2 pollution and more enforcement actions. This focus on SO_2 emissions is consistent with the substantial political attention paid to acid rain caused by SO_2 emissions from US plants in the AQA treaty.

We are surprised that some variables get the same sign in both the regulatory activity and emissions models (e.g. AIRBEN in Table 3), because we attribute the lower emissions at high-benefit plants to greater regulatory attention aimed at those plants. In contrast, these plants seem to get less regulatory activity as measured by inspections or enforcement actions. An alternative

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[12] This is due at least in part to the use of 50 mile circles to define being near a state border—two-thirds of our plants are near a state border by this definition. Earlier analyses using a 5 mile circle to define state borders find significantly greater SO_2 and BOD emissions at border plants, and lower pollution (though not significant) when those border states are stronger environmentally—see results in http://www.aere.org/journal/index.html.

Table 5
Extended air benefits model

DEPVAR	AIR INSP	AIR ENF	PM10	SO_2
OBS	4032	4032	3107	3107
AIRBEN	−0.185	−0.601	0.456	1.229
	(−0.870)	(−0.990)	(1.580)	(2.700)
AIRBEN * OUT-STATE	0.016	−0.046	0.096	0.317
	(0.560)	(−0.550)	(2.120)	(4.380)
AIRBEN * OUT-STATE * GREENVOTE	0.000	0.002	−0.001	−0.004
	(0.880)	(1.540)	(−1.590)	(−3.170)
AIRBEN * ELDERS	−0.824	0.492	−3.375	−2.391
	(−0.970)	(0.200)	(−3.020)	(−1.250)
AIRBEN * KIDS	1.912	5.317	−3.738	−11.622
	(1.150)	(1.110)	(−1.600)	(−3.270)
AIRBEN * POOR	0.539	−1.386	1.917	0.203
	(2.570)	(−2.210)	(7.210)	(0.460)
AIRBEN * NONWHITE	0.021	0.084	−0.429	−0.657
	(0.310)	(0.400)	(−4.330)	(−4.110)
CANADIAN BORDER	0.012	0.686	0.077	−0.552
	(0.180)	(3.880)	(0.740)	(−4.220)
TURNOUT	−0.189	−1.011	−0.413	1.681
	(−0.500)	(−0.910)	(−0.710)	(2.140)
TURNOUT * GREENVOTE	0.036	0.235	−0.019	−0.202
	(1.160)	(3.030)	(−0.520)	(−3.580)
R^2	0.194	0.119	0.656	0.487

T-statistics in parentheses. All regressions include state dummies.
Models include all control variables from Table 3.
AIRBEN refers to PMBEN and SO_2 BEN for PM10 and SO_2 models.
Regulatory activity models (INSP and ENF) use Negative Binomial model.
Pollution quantity models use Log(pollution) in OLS model.

interpretation (suggested by an anonymous reviewer) is that the lower emissions at high-benefit plants are due to other pressures (community action, permit stringency, etc.). Regulators, knowing that a plant is facing these other pressures, might use fewer inspections and enforcement actions there.

Tables 5 and 6 present the results when the various population characteristics are interacted with the benefits from pollution abatement, testing for differences across groups in the ‘weight’ given their benefits when determining regulatory stringency. These results are similar to those in Tables 3 and 4 for the different population characteristics. We see greater benefits associated with lower pollution levels at plants with low values of POOR and high values of KIDS, ELDERS and (surprisingly) NONWHITE.[13] Because of the large negative effects of the interactions with KIDS and ELDERS the non-interacted AIRBEN coefficient becomes positive, but when we evaluate the overall AIRBEN effect at the mean values of the various interactions we still get a negative impact

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[13] Unlike the results in Tables 3 and 4, these NONWHITE coefficients become noticeably less negative when POOR is omitted from the regressions, as seen in http://www.aere.org/journal/index.html.

Table 6
Extended water benefits model

DEPVAR	WATER INSP	WATER ENF	TSS	BOD
OBS	3431	3431	2113	2113
WATERBEN	−0.000	0.115	−0.263	−0.288
	(−0.010)	(1.200)	(−5.620)	(−6.620)
WATERBEN ∗ OUT-STATE	−0.035	−0.138	0.010	0.073
	(−1.500)	(−1.480)	(0.210)	(1.530)
WATERBEN ∗ OUT-STATE ∗ GREENVOTE	0.000	0.001	−0.000	−0.001
	(0.570)	(0.400)	(−0.180)	(−1.560)
WATERBEN ∗ POOR	0.098	−0.967	1.519	1.616
	(0.480)	(−1.190)	(3.660)	(3.820)
WATERBEN ∗ NONWHITE	−0.060	0.665	−0.265	−0.441
	(−0.740)	(2.050)	(−1.510)	(−2.440)
CANADIAN BORDER	−0.065	−0.194	0.019	0.359
	(−1.430)	(−1.030)	(0.190)	(3.890)
TURNOUT	1.264	2.065	2.515	4.134
	(3.840)	(1.220)	(3.480)	(5.780)
TURNOUT ∗ CONVMEMB	−0.065	−0.294	−0.194	−0.257
	(−2.770)	(−1.810)	(−3.650)	(−4.780)
R^2	0.123	0.170	0.625	0.583

T-statistics in parentheses. All regressions include state dummies.
Models include all control variables from Table 4.
Regulatory activity models (INSP and ENF) use Negative Binomial model.
Pollution quantity models use Log(pollution) in OLS model.

of 11% on particulates and 16% on SO_2. The comparable numbers for WATERBEN are 9% for TSS and 13% for BOD.

More importantly, we now get the expected results for the state border variables. Plants near other states have more pollution, but this effect is reduced when the neighboring state is stronger environmentally (though these effects are not significant for water pollution). How large are these effects? Recall that the overall impact of AIRBEN on SO_2 was −16%. The coefficient of 0.317 on AIRBEN ∗ OUT-STATE, combined with the AIRBEN ∗ OUT-STATE ∗ GREENVOTE coefficient of −0.004 evaluated at the mean GREENVOTE of 54, reduces this effect to −6%, indicating that benefits outside the state have only one-third the impact of in-state benefits. The calculations for particulates also indicate that out-of-state benefits have a smaller impact, −7% rather than −11%. Changing the neighboring state's GREENVOTE from one standard deviation below average to one standard deviation above average (from 36 to 72) cause the SO_2 impact for out-of-state benefits to range from +2% to −13%, a variation nearly as large as the difference between in-state and out-of-state benefits. The impacts for other pollutants are quite a bit smaller, though the signs go in the same direction. The regulatory activity equations are generally consistent with our expectations in terms of their signs: less regulatory activity is faced by plants with benefits outside the state and with more activity when the surrounding states are stronger environmentally. The Canadian border effects are similar to those in the earlier models.

We can quantify the impact of changes in demographics around a plant using the coefficients in Tables 5 and 6. For SO_2, a one standard deviation increase in ELDERS increases the impact of benefits by about one-quarter, from -16% to -20% (for KIDS it increases the impact to -23%); for BOD a comparable increase in POOR reduces the impact of benefits from -13% to -5%. There is some variation in impact across pollutants, but overall the results show substantial impacts of the demographics around a plant on the responsiveness of our environmental measures to the marginal benefits of abatement.

We can also try to test for the importance of unmeasured plant characteristics across the different equations. Plants may differ in terms of management ability and production technology in ways which we can not directly measure. To test for the importance of these omitted variables, we calculated the residuals for each of the 8 equations in Tables 5 and 6, and checked the correlations among these equations.[14] The only large correlations come for pollutants, where plants with high emissions of one pollutant also tend to emit large amounts of the other pollutant in that same media. These values are quite high, with correlations of 0.87 between BOD and TSS discharges and 0.5 between particulates and sulfur dioxide emissions. Correlations between air and water pollutants are on the order of 0.1–0.2, and correlations among the different measures of regulatory activity tend to be 0.1 or less.

Seemingly unrelated regression (SUR) models provide a more formal way to examine correlations across regulatory measures. We have four different samples, depending on whether a plant has each type of regulatory data. We tested an (easily calculated) SUR model requiring a balanced panel of data, which resulted in a much smaller sample size than those used in these models: 1143 observations in the balanced sample, rather than sample sizes of 2113–4032 for the individual sets of regulatory data.[15] These SUR results are also based on OLS models for inspections and enforcement actions, rather than negative binomials. Because of these shortcomings we do not report the SUR results here,[16] but the residual correlations across the equations in the SUR model are very similar to the residual correlations described above, with very high positive correlations between the pollution levels in the same medium, and much smaller correlations among the rest of the variables.

7. Conclusions and possible extensions

In this paper we use a plant-level panel data set consisting of 409 pulp and paper mills from 1985–1997 to examine the allocation of environmental regulation across plants. We focus on the benefit side of the $MB = MC$ equation, and find that plants in areas with higher marginal benefits of pollution abatement have lower pollution levels. Demographics also matter, as plants with more kids, more elders, and fewer poor people nearby emit less pollution. Plants whose pollution affects residents of other states emit more pollution, with these boundary effects reduced if the

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[14] Results available in http://www.aere.org/journal/index.html.

[15] Schmidt [16] shows that it is possible to do SUR analyses with unbalanced panels, but finds that balanced panel estimators which ignore the information in the 'extra' unbalanced observations do not perform badly relative to estimators that use the extra information, unless the correlation between the disturbances is on the order of 0.9 (much higher than we observe here).

[16] Results available in http://www.aere.org/journal/index.html.

bordering states have more pro-environment Congressional delegations. Plants in areas with politically active populations that are also environmentally conscious emit less pollution.

Not every result fits the predictions of our model. The percentage nonwhite near the plant, expected to reduce regulatory attention in the Environmental Justice model, is often associated with more regulatory activity and lower emissions. The results for the regulatory activity equations are generally less consistent with our hypotheses than those for the emissions equations. Perhaps regulators use other, unmeasured, mechanisms to control emissions levels, such as the details of the air and water permit requirements for each plant. Still, the significant results for the air pollution emissions and water pollution discharges suggest a role for these benefit-side factors in determining the environmental performance of different plants.

One concern with our results could be the potential for reverse causation or sorting: poor people could move into dirty neighborhoods because housing is cheaper there; families with sensitive individuals such as kids and elders might avoid dirty neighborhoods. We cannot use pre-siting demographics to control for such endogeneity because our sample of paper mills is quite old (most were built before 1960). Instead, we use the demographic characteristics for people living between 50 and 100 miles from the plant as 'spatially lagged' instruments for the demographic characteristics near the plant. As long as the effects of a plant's pollution decline with distance, this procedure should purge most of the endogeneity from the demographic variables.

Some of the differences in results across different variables pose further research questions. For example, we find different effects on air and water pollution of being near the Canadian border: SO_2 emissions are lower, and BOD discharges are higher. This might reflect political pressures caused when acid rain in Canada is attributed to US emissions of SO_2, but by what mechanisms (regulatory or otherwise) are international concerns transmitted to plant level decisions? We get weaker results when we try to explain direct measures of regulatory activity such as inspections and enforcement actions. This suggests the presence of other factors influencing emissions, some of which might be quantifiable (e.g. the stringency of permitted emission levels or the use of criminal penalties for violations).

Potential extensions of this project include a more detailed examination of these border effects and the differences between air and water pollution regulation. We plan to distinguish between state and federal enforcement and to explore other ways to more accurately measure the political activism of a community. We will test whether a plant's pollution abatement spending is also affected by the benefits of pollution abatement. Finally, we will examine data from other industries, to see whether our results for the paper industry hold up in other settings.

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