ENVIRONMENTAL REGULATION AND MANUFACTURING PRODUCTIVITY AT THE PLANT LEVEL*

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Abstract

This paper presents results for an analysis of plant-level data from three manufacturing industries (paper, oil, and steel). We combine productivity data from the Longitudinal Research Database (LRD) with pollution abatement expenditures from the Census Bureau's Pollution Abatement Cost and Expenditures (PACE) survey, as well as regulatory measures taken from datasets maintained by the Environmental Protection Agency. We use data from 1979 to 1985, considering both labor and total factor productivity, both levels and growth rates, and both annual measures and averages over the period.

We find a strong connection between regulation and productivity when regulation is measured by compliance costs. More regulated plants have significantly lower productivity levels and slower productivity growth rates than less regulated plants. The magnitude of the impacts are larger than expected: a $1 increase in compliance costs appears to reduce TFP by the equivalent of $3 to $4. Thus, commonly used methods of calculating the impact of regulation on productivity are substantially underestimated. These results are generally consistent across industries and for different estimation methods. Our other measures of regulation (compliance status, enforcement activity, and emissions) show much less consistent results. Higher enforcement, lower compliance, and higher emissions are generally associated with lower productivity levels and slower productivity growth, but the coefficients are rarely significant.

Keywords: regulation, productivity, pollution, EPA

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I. INTRODUCTION

The late 1960s and early 1970s saw increased federal government regulation in a number of areas through the creation of regulatory agencies such as the Equal Employment Opportunity Commission (EEOC), the Occupational Safety and Health Administration (OSHA), and the Environmental Protection Agency (EPA). Of these, environmental regulation is generally agreed to be the most costly, the EPA's budget representing about one-third of the total federal regulatory budget (Warren and Chilton, 1990) and the manufacturing sector reporting over $17 billion in operating costs and $6 billion in capital expenditures for pollution abatement in 1990. Environmental regulation is also the only regulatory area with a good measure of compliance costs: an annual survey on pollution abatement expenditures by manufacturing plants - U.S. Bureau of the Census (1992).

There have been a number of studies examining the impact of environmental regulation on the economy, particularly in relationship to the U.S. productivity slowdown in the 1970s. One class of 'growth accounting' studies calculates the productivity impact based on measured compliance costs, generally finding a small impact because compliance expenditures are a small share of total costs (see Denison (1979), Portney (1981), Norsworthy, Harper and Hunze (1979), Jorgenson and Wilcoxen (1990), and Conrad and Morrison (1989)). Studies which use regression analysis to estimate the impact of regulation on productivity have often found significant effects (see Christiansen and Haveman (1981), Gray (1986; 1987), Gollop and Roberts (1983), and Barbera and McConnell (1986)). These studies suggest that pollution regulation reduced productivity growth and contributed to the productivity slowdown of the 1970s. Less is known about regulation's impact during the 1980s, and few of the studies are based on plant-level data.

In this paper, we present results for three manufacturing industries, using plant-level productivity data from the Longitudinal Research Database (LRD) maintained at the Center for Economic Studies in the Census Bureau. Our data includes 122 pulp and paper mills (SIC 2611 and 2621), 107 oil refineries (SIC 2911), and 60 steel mills (SIC 3312). Our analysis examines productivity growth and regulation during the 1979-1985 period. We first calculate annual productivity levels and growth rates for each plant, using both labor productivity (LP) and total factor productivity (TFP) measures. We also calculate each plant's average productivity level and average productivity growth rate over the 1979-1985 period. We then relate the plant's productivity level to its pollution abatement expenditures, and its productivity growth rate to changes in its pollution abatement expenditures. This is done using both the annual productivity data and the 1979-1985 averages. We also relate the 1979-1985 average productivity data to other measures of EPA regulation at the plant: compliance status, pollution emissions, and enforcement activity.

We find a strong connection between regulation and productivity when regulation is measured by the plant's pollution abatement expenditures. Plants with higher compliance costs have significantly lower productivity levels and slower productivity growth rates than less regulated plants. The impact of compliance costs is stronger for total factor productivity than for labor productivity, and stronger for productivity growth rates than for levels.

The magnitude of the TFP impacts indicates that compliance costs have a larger than expected effect. A $1 increase in compliance costs appears to reduce TFP by significantly more than the equivalent of $1: the equivalent impacts estimated here average about $3 or $4. Thus the commonly used growth accounting method, which assumes a dollar-for-dollar impact of compliance costs on productivity, appears to substantially underestimate the true impact of regulation on productivity.

The compliance cost results are generally consistent across the different models we estimate. Our other measures of regulation (compliance status, enforcement activity, and emissions) show much less consistent results. Higher enforcement, lower compliance, and higher emissions are generally associated with lower productivity levels and slower productivity growth, but the coefficients are rarely significant.

Section II contains a brief description of the structure of EPA regulation, and an explanation of why regulation might be expected to affect productivity growth. The data and econometric issues are described in Section III. The results are presented in Section IV, and Section V concludes the paper.

II. WHY SHOULD ENVIRONMENTAL REGULATION AFFECT PRODUCTIVITY?

Productivity in a manufacturing plant is measured by the ratio between the plant's output and its inputs: a more productive plant can produce more output with fewer inputs. The most commonly used productivity measure is labor productivity (LP), which calculates the amount of output produced per unit of labor. This measure is simple to calculate, but ignores the contribution of other inputs such as capital and materials. Total factor productivity (TFP) measures calculate the amount of output produced per unit of 'aggregate input', where all inputs (labor, capital, and materials) are aggregated together. TFP measures require more complicated calculations and some assumptions about the form of the aggregate input, but are less sensitive than LP measures to changes in non-labor inputs.

Pollution regulation could affect productivity in a number of ways. The first arises because measures of productivity do not distinguish between inputs used for production and inputs used for regulatory compliance. If a plant is required to spend $1 million to purchase a scrubber for its smokestack, that expenditure is treated as increasing the plant's capital stock, just as if it had been spent on new production machinery. Since installing the scrubber expands the plant's inputs without increasing its output, measured TFP would decrease by the fraction of total expenditures that are used for regulatory compliance. We would expect to observe a similar effect on LP measures, but a smaller one, since labor is a relatively small part of compliance expenditures.

Even if compliance costs are subtracted from measured inputs to correct the productivity calculation for the 'mismeasurement' effect, there may still be some impact of regulation on 'true' productivity. Changes made to promote compliance may reduce the productive efficiency of inputs used in production. For example, putting a baghouse on a smokestack may limit the flow of air out of a boiler, reducing its efficiency and hence reducing 'true' productivity. When a new production technique is adopted to reduce pollution, it may be less productive (in its use of non-compliance inputs) than the original technique, or at least require some time before the plant moves down its 'learning curve', during which productivity may be lower than it was initially.

Regulation may also increase the uncertainty faced by firms, affecting their decisions in a variety of ways. Viscusi (1983) discusses the role of uncertainty about future regulations (and hence about the future profitability of the firm) in reducing a firm's investment, or at least in postponing the investment until the uncertainty is resolved. Hoerger, Beamer, and Hanson (1983) point out that new product development could be affected by uncertainty about future regulation of new products. Development of new production processes could also be hindered by uncertainty about future regulations, as current regulatory requirements are generally designed with existing production processes in mind.

In some cases, regulation may increase productivity. In response to pressures to reduce wastewater discharges, some plants adopted 'closed-loop' production processes and discovered after doing so that the cost savings from recycling raw materials reduced total costs. Firms may increase pressure on workers and managers to be more productive in an attempt to recoup some of the increased costs imposed by regulation (see Clark (1980) for a similar effect following the unionization of cement plants). New equipment, installed to reduce pollution, may also be more productive than the old equipment it replaces (although this would only increase true productivity if one assumes that the plant would not have installed new equipment without the regulatory pressures).

The measured cost of complying with pollution regulation is itself prone to measurement error, in part because of difficulties of definition. In principle, compliance costs could include all possible influences on productivity, in which case the effect of regulation on productivity would be equal to compliance costs by definition. In practice, some types of compliance costs are more likely to be identified by survey respondents than other types. Pollution control equipment that is 'end-of-line' is relatively easy to identify (scrubbers on smokestacks, emissions controls on cars, wastewater treatment plants). Compliance costs associated with completely redesigning the production process are more difficult to identify, since there are typically other objectives besides pollution reduction: lower energy costs, reduced labor requirements, or higher quality output. Other compliance costs are unlikely to be identified: distraction of upper management attention away from production towards compliance; clerical time spent filling out EPA-required reports; managers' time spent accompanying regulatory personnel during inspections of the plant.

The pattern of pollution abatement expenditures for all of manufacturing and for our three industries is shown in Figures 1 and 2. Pollution abatement capital expenditures is around 9 percent of total capital expenditures in manufacturing during the mid-1970s, declines to around 3-4 percent in the mid-1980s, and rises again in the late 1980s. Pollution abatement operating costs rise steadily through the period, doubling as a share of total manufacturing shipments from 0.3 percent to 0.6 percent. The pattern for our industries is similar, but much more variable and at a much higher level. Operating costs are between 0.8 and 2.5 percent of the value of shipments (lowest for oil, higher for paper and steel). As much as 20-30 percent of capital expenditures went to pollution abatement in the early 1970s, with lower amounts in the 1980s.

III. DATA AND ESTIMATION ISSUES

Our data used for estimating productivity come from the Longitudinal Research Database (LRD) maintained by the Center for Economic Studies at the Census Bureau. The LRD includes annual data from 1972 through 1989 on nearly all large U.S. manufacturing plants. The data originally come from the Annual Survey of Manufactures (ASM) and the Census of Manufactures (CM), and are linked together over time to create a panel dataset. Industry-level price indices for shipments, materials, and new investment are used to transform the nominal LRD data into real terms for calculating productivity measures.

One source of information on regulation is the Census Bureau's Pollution Abatement Costs and Expenditures (PACE) survey, done annually from 1973 to 1985, as the original plant-level data from 1973-1978 are not available, and there have been problems linking the post-1985 PACE data with the LRD data. The PACE survey samples about 20,000 plants each year, asking them about both capital expenditures and operating costs for pollution abatement. We concentrate on operating costs, which are more stable over time than capital expenditures for a plant.[1] We impute pollution abatement operating costs for years in which the plant was missing from the PACE sample, based on the plant's data in other years.[2] We measure compliance costs as the plant's average annual operating cost for pollution abatement between 1979 and 1985, divided by the plant's average value of shipments over the same period.

Another source of information about regulation comes from EPA's regulatory datasets, tracking enforcement activity by both federal and state regulators. We have linked in data from EPA's Compliance Data System (CDS) to count the air pollution inspections (both federal and state) for each plant in our LRD sample during the 1979-1985 period.[3] This serves as a proxy for the intensity of regulatory enforcement faced by the plant, and is expected to be negatively related to productivity.[4] If a plant did not appear in the CDS, we assume that it did not

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[1] The analysis of pollution abatement capital expenditures is also complicated by the absence of pre-1979 data. As Figure 1 indicates, much of the pollution abatement capital expenditures in these industries was done prior to 1979.

[2] Some plants are missing from the sample in each year, so requiring plants to be present every year from 1979 to 1985 would reduce our sample sizes by about one-third.

[3] We also tried using the total number of enforcement actions faced by the plant ('actions' is a broader and more heterogeneous category than 'inspections', including notifications of violation, conferences held, and letters sent). This measure is highly correlated across plants with the number of inspections, and gives similar results.

[4] Gray and Deily (1991) find that steel mills facing more enforcement were more likely to be closed, and Gray (1987) finds that industries facing more enforcement had a greater productivity slowdown.

receive any inspections.[5] We have multiple years of CDS data (1981, 1984, 1986, 1987, and 1989), and use them to provide a measure of a plant's compliance with air pollution regulations: the fraction of times a plant is in compliance (for example, a plant observed twice in violation and three times in compliance would have a 60% compliance rate). The multiple years of CDS data also provide multiple observations on a plant's air pollution emissions for major air polluters, and we calculate the median of the observed emissions values for particulates, sulfur dioxide, and nitrogen dioxide. For those plants which did not have emissions data for a particular pollutant, we include a dummy variable in the regression (rather than reducing our sample size still further).

Our information on water pollution regulation is taken from the EPA's Permit Compliance System (PCS). As with air pollution, we measure enforcement by the number of state and federal inspections during the 1979-1985 period. The PCS also includes monthly data on water pollution discharges from major polluters for the 1986-1991 period. We use the median value of these discharges for two major water pollutants: BOD (Biological Oxygen Demand) and TSS (Total Suspended Solids). The PCS also indicates for each month's data whether the discharge is in compliance with the water pollution regulations. This compliance

[5] Only a few plants in our final samples did not appear in the CDS data.

measure cannot be calculated for plants without discharge data, and we include a dummy for missing compliance data in the regression (we also use dummies for missing data in the regressions using emissions data).

These measures of air and water pollution regulation are combined in our analysis[6] We add together the number of air and water pollution inspections for each plant to get our enforcement measure. For the compliance measure we average together the plant's compliance status on air and water pollution. Each emissions variable is examined separately in the analysis, as we have no information that would provide weights for the different pollutants to calculate an aggregate emissions measure.

We also include one control variable, measuring differences across plants in the newness of their capital stock. We add up the plant's investment spending from 1979 to 1985, and divide this by the plant's capital stock in 1982. This gives us a measure of the vintage of the plant's capital stock (presumably newer is better, both for LP and TFP). Other controls (including R&D intensity at the plant, plant location, or plant size) might be related to productivity, but have not yet been explored and in many cases will involve merging more data with the LRD.[7]

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[6] We did some early analyses using separate measures for air and water pollution regulation. These showed the same pattern of signs presented here, but with some differences in magnitude and significance between the air and water coefficients (with no particular pattern across industries).

[7] We tried using the plant's capital-labor ratio in some early analyses for the paper industry, but it did not perform as well as 'new investment'.

Our sample of plants is initially based on a previous research project, done outside the Census Bureau, which merged together regulatory datasets for an analysis of OSHA and EPA enforcement and compliance activity in the same three industries. We required the plants to be in the LRD throughout the time period, with adequate data to construct a capital stock measure.[8] Our initial regulatory sample includes the larger plants in each industry, so our sample includes most of the plants in these industries with complete LRD data. Our sample includes 60 percent of total industry shipments for paper, 70 percent for oil, and 65 percent for steel.

We use the value of shipments (adjusted for inventory changes and deflated by the industry price of shipments) to measure a plant's output. Labor productivity is given by:

(1) $LP = \log(q) - \log(L)$,

where L is the number of production worker hours. To calculate total factor productivity, we supplement the labor input with materials and energy expenditures (M) and the plant's capital stock (k):

(2) $TFP = \log(Q) - a_L \log(L) - a_M \log(M) - a_K \log(K)$.

These productivity calculations assume that all of the measured inputs are used to produce output. When some inputs are used for compliance with regulation (such as pollution abatement

[8] We also dropped from each industry sample a few plants which had implausible values for key variables.

expenditures), the measured inputs will overstate the amounts of inputs actually used in production, understating 'true' productivity. This is the 'mismeasurement' effect of regulation on productivity described earlier. The effect on measured TFP can be approximated by the share of compliance costs in total costs, as shown in Gray (1987). Using '*' to represent TFP and inputs excluding compliance costs, we have:

$$\begin{aligned} (3) \quad TFP^* &= \log(Q) - a_L\log(L^*) - a_M\log(M^*) - a_K\log(K^*) \\ &= \log(Q) - a_L\log(L-L_R) - a_M\log(M-M_R) - a_K\log(K-K_R) \\ &= TFP + a_R, \end{aligned}$$

where the R subscript refers to inputs used for regulatory compliance, and a_R indicates the share of compliance costs in total costs.

Since our TFP measure is already in logarithmic form, differences across plants in compliance cost shares translate into percentage differences across plants in measured TFP. If plants A and B are otherwise identical, but plant A spends one percent of total cost on compliance and plant B spends two percent of total cost on compliance, we would expect the level of measured TFP at plant A to be one percentage point higher than at plant B. Changes over time in compliance cost shares would influence measured TFP growth rates. If plant A spends one percent of total cost on compliance in year t and two percent in year t+1, its measured TFP growth should be reduced by one percentage point.

These calculations indicate that a regression of measured TFP levels on compliance costs shares, or a regression of measured TFP growth on changes in compliance cost shares, should result in a coefficient of minus one on the compliance cost variable. This assumes that the only impact of regulation on productivity is the mismeasurement of inputs. If regulation adversely affects 'true' productivity or plants understate their compliance costs, we would see coefficients greater than one in magnitude. If plants overstate their compliance costs or if compliance expenditures have some beneficial effects on productivity, we would see coefficients with magnitudes less than one.

We obtain the factor weights for the TFP calculation by regressing log(Q) on log(L), log(M), log(K) and year dummies for each of the three industries, using the 1979 to 1985 LRD data. The results of these regressions are as follows.[9]

paper: log(Q)	= 1.255	+ 0.206*log(L)	+ 0.668*log(M)	+ 0.103*log(K)	R^2=.94
	(.089)	(.017)	(.021)	(.011)	N=854,
oil: log(Q)	= 0.886	+ 0.042*log(L)	+ 0.870*log(M)	+ 0.049*log(K)	R^2=.97
	(.078)	(.015)	(.014)	(.012)	N=749,
steel: log(Q)	= 1.650	+ 0.263*log(L)	+ 0.643*log(M)	+ 0.071*log(K)	R^2=.97
	(.108)	(.020)	(.027)	(.020)	N=418,

We estimate the impact of regulation by regressing productivity levels (both LP and TFP) on compliance cost shares,

[9] The factor weights derived from these regressions are similar to those that would be obtained if we used ex-post cost shares to calculate weights.

and productivity growth rates on changes in compliance cost shares. We first do the analysis in cross-section form with one observation per plant, averaging over the 1979 to 1985 data. This has the advantage of minimizing the impact of year-to-year cyclical fluctuations in the data, at the cost of limiting our sample size. We then do similar regressions using the annual data. This greatly expands the sample size and allows us to use a fixed-effect estimation to allow for unobserved plant-specific characteristics that affect productivity. The fixed-effect estimates have the disadvantage of ignoring cross-sectional differences in regulation, which make up the bulk of regulatory variation in our data.

IV. RESULTS

The variables used in the analysis are described in Table 1, with means and standard deviations presented in Table 2. The productivity and compliance cost measures are available as both annual and average values for the 1979-1985 period and can be used in both the cross-section and panel regressions. The other regulatory measures are only available in average form, and are used only in the cross-section regressions. Note that the annual growth rate variables (GTFP, GLP, and GPAOC) can only be defined for six years, rather than seven, starting with the 1979-1980 growth rates.

Comparing the three industries, we see that paper shows the greatest productivity growth over the period: TFP grows by 4 percent per year, while LP grows by 4.7 percent per year. Steel's productivity declines during the period: by 1.9 percent per year for TFP and 0.2 percent per year for LP. Oil's performance is intermediate: TFP grows by 1.9 percent per year, while LP grows by only 0.4 percent per year. New investment is higher in oil and paper (comprising about 11 percent of the 1982 capital stock) than for steel (about 7 percent).

The average paper and steel mill spends 1.9 percent of total costs on pollution abatement, while oil refineries spend less than half as much (0.8 percent). Steel has more rapidly growing PAOC (increasing by .15 per year) than either oil (.06) or paper (.03). Oil and paper show higher compliance rates (steel mills have particularly low compliance rates with air pollution regulations). The average paper mill faces less regulatory activity (perhaps due to its smaller size), but has higher pollution emissions relative to output, with steel mills fairly high on air pollution but lower on water pollution, and oil refineries lower on both pollution measures.

Spearman correlations among the key variables are presented in Tables 3 and 4. Spearman correlations are less sensitive to outliers than regular Pearson correlations, and provide a 'robust' view of the data. The correlations indicate that plants with higher and growing compliance costs tend to have lower productivity levels and slower productivity growth rates. These results are stronger for paper than for oil or steel in the average measures, and more significant for the annual productivity measures than for the average productivity measures. The other regulation measures, enforcement and compliance, do not show a consistently significant relationship with the productivity measures, but we do see that enforcement is positively related to compliance expenditures across plants. The new investment measure only shows the expected (productivity-increasing) results for paper, with oil showing little relationship to productivity and steel showing that plants with more new investment actually have significantly lower productivity growth.

The cross-section regression results for compliance costs are given in Table 5. The results are similar to the correlations in Table 3. Plants with high compliance expenditures tend to have lower total factor productivity levels; plants with growing compliance expenditures tend to have slower productivity growth rates for both total factors and labor productivity. The coefficients for the oil industry regressions are similar in magnitude to those for steel and paper, but are not generally significant. This may be due to pollution abatement operating costs being much smaller (relative to shipments) for oil than for steel or paper. It may also be related to problems with productivity measurement for oil refineries, given the large fluctuations in oil prices in the late 1970s.[10] Note that the new investment variable shows an unexpected negative relationship to productivity for the steel regressions (and sometimes for oil), as we saw earlier in the correlations.

Table 6 presents the panel regressions, using annual productivity and compliance cost data. The regressions for productivity levels give results similar to those found earlier: plants with higher compliance costs have significantly lower productivity. These results hold up for paper and steel when plant-specific fixed-effects are included in the regression, even though most of the variability in PAOC is found across plants. The regressions for productivity growth rates are less often significant, at least in part because of the enormous variability in year-to-year growth rates for productivity growth and compliance costs (note the huge standard deviations for annual GTFP and GPAOC in Table 2). To the extent that a large part of these year-to-year fluctuations in GPAOC represent 'noise' rather than true variability, the GPAOC coefficients are biassed towards zero.

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[10] To test the impact of the 1979 oil price changes on the measurement of productivity growth, we re-did the GTFP regression from Table 5 for the oil industry using the average TFP growth over the 1978-1985 period (rather than 1979-1985). The GPAOC coefficient becomes slightly larger (-6.0) and is statistically significant.

The results for other regulatory measures in Table 7 are not very strong, and rarely consistent across industries. For the paper industry, high-enforcement and low-compliance plants show significantly slower TFP growth, but oil and steel show no significant impacts. The emissions measures usually have negative coefficients, indicating that heavier polluters tend to have lower productivity levels and slower productivity growth, but the coefficients are rarely significant.

We can use the magnitude of the pollution abatement cost coefficients in the TFP and GTFP equations to distinguish between the 'mismeasurement' of productivity (which would lead to a PAOC coefficient of -1.0) and any additional 'true' impact of regulation on productivity. In all of the total factor productivity regressions in Tables 5 and 6, the PAOC coefficient substantially exceeds unity in magnitude, with coefficients generally in the range of -2.5 to -6. This suggests the presence of a 'true' impact of regulation on productivity. Statistical tests confirm this: of the 18 relevant coefficients in Table 5 and 6, 10 are significantly different from -1.0. Thus we conclude that the impact of regulation on productivity exceeds that attributable to measured abatement costs.

We can also calculate the overall effect of compliance costs on average productivity levels in an industry, multiplying each regression coefficient by the mean value of PAOC for the industry. This gives the reduction in productivity due to the existing levels of the PAOC variable, compared to the predicted level if PAOC were zero for all plants. To get a representative PAOC coefficient for each industry, we average the six coefficients from the TFP and GTFP regressions in Tables 5 and 6. For paper, the average coefficient is -2.85; multiplied by the average PAOC of 1.87 percent gives us a reduction in productivity level of 5.3 percent. The predicted reduction in TFP level for oil is 3.1 percent (coefficient of -4.15 and average PAOC of 0.77 percent); for steel it is 7.6 percent (coefficient of -3.99 and average PAOC of 1.91 percent).

Note that the average coefficients of -3 and -4 translate into impacts of regulation on productivity which are three to four times as large as those we would have obtained using the growth accounting method (which is equivalent to assuming a coefficient of -1.0). This difference could arise either from a general tendency of survey respondents to understate their compliance costs, or from some impact of regulations on the productivity of non-compliance inputs. In either case, the usual measure would substantially underestimate the impact of regulation on productivity.

V. SUMMARY AND FUTURE WORK

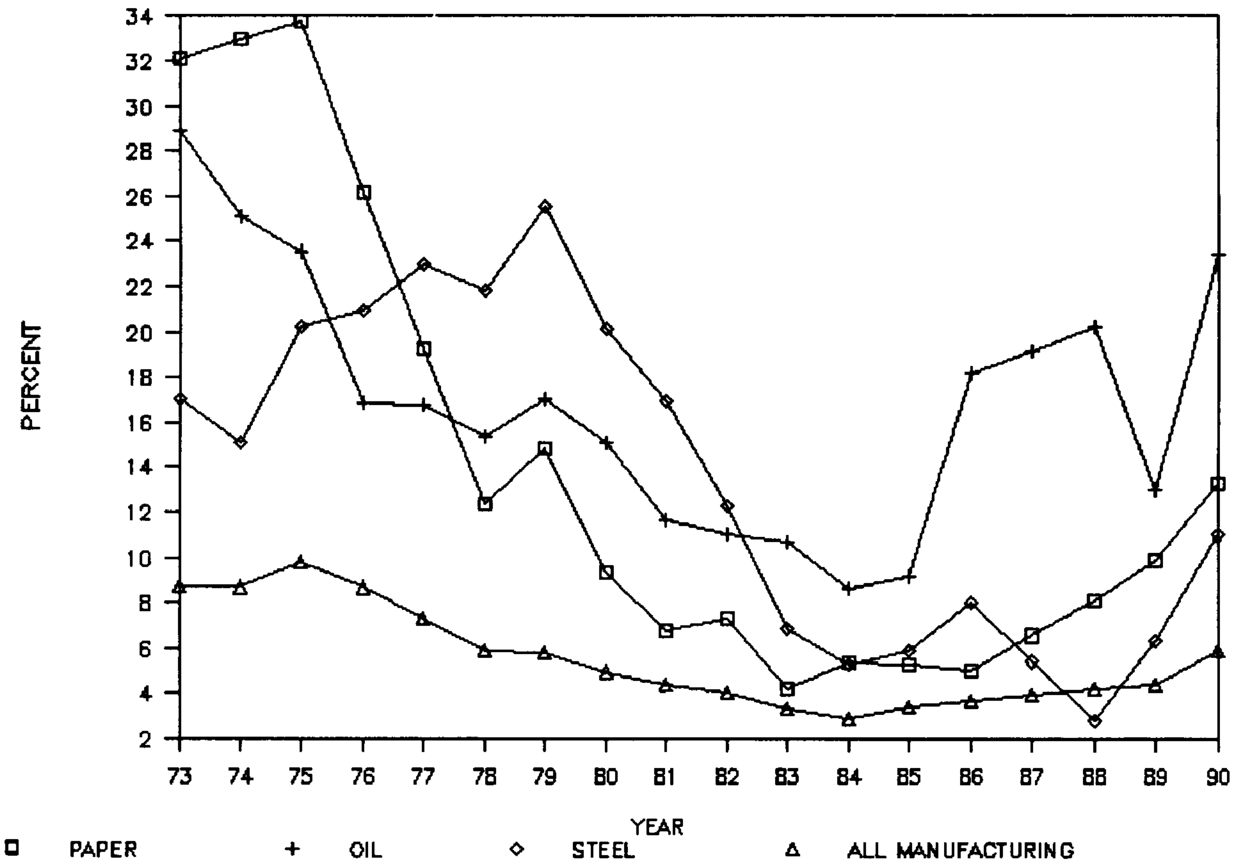
Using plant-level data for three manufacturing industries, we have found a significant negative relationship between a plant's pollution abatement costs and its total factor productivity level and growth rate. Abatement costs are also negatively associated with labor productivity growth. In the cross-sectional analysis, plants spending a greater fraction of their total costs for pollution abatement have significantly lower TFP levels than other plants, and plants with increases in their pollution abatement cost shares have slower TFP growth rates. Similar results are found for the panel analysis of TFP levels and growth rates, even when we control for plant-specific fixed-effects.

The magnitudes of the estimated coefficients suggest a large impact of regulation on total factor productivity. Existing compliance costs appear to have reduced the average level of TFP by 5.3 percent for paper, 3.1 percent for oil, and 7.6 percent for steel. These impacts are roughly three or four times as large as would be predicted by the usual growth accounting calculation.

We did not find such strong results for other regulatory measures, obtained from EPA regulatory datasets. Paper mills with higher enforcement or lower compliance tended to have slower productivity growth, but the effects are rarely significant or consistent across industries.

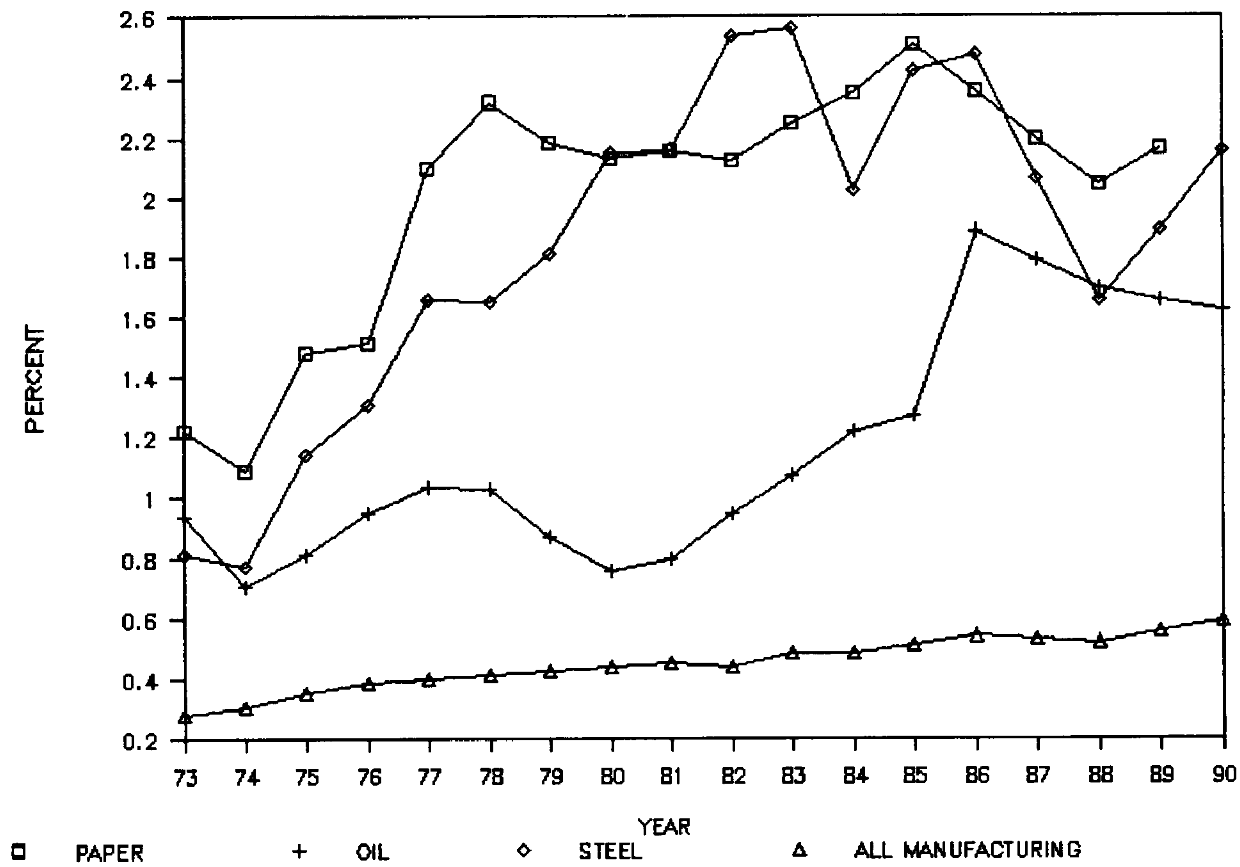
Several avenues of research remain to be pursued. We are extending our analysis further into the 1980s and adding more control variables to our current regressions. We will try to gather more data on the particular production processes in use at different plants, to control for plant-level heterogeneity. Finally, we will model the production process in more detail, estimating the effect of regulation on employment and investment, as well as testing possibly explanations of why regulation affects productivity.

FIGURE 1
(POLLUTION ABATEMENT CAPITAL EXPENDITURES)/(TOTAL NEW CAPITAL EXPENDITURES)



(SOURCE: CENSUS BUREAU, POLLUTION ABATEMENT COSTS AND EXPENDITURES SURVEY, MA(200), 1973-1990)

FIGURE 2
(POLLUTION ABATEMENT OPERATING COSTS)/(TOTAL VALUE OF SHIPMENTS)



(SOURCE: CENSUS BUREAU, <u>POLLUTION ABATEMENT COSTS AND EXPENDITURES SURVEY</u>, MA(200), 1973-1990)

Table 1
VARIABLE NAMES AND DEFINITIONS

BOTH ANNUAL DATA AND AVERAGE DATA 1979-1985	
TFP	Total factor productivity level.
CTFP	Annual total factor productivity growth rate, in percentage points per year.
LP	Labor productivity level.
GLP	Annual labor productivity growth rate, in percentage points per year.
PAOC	Pollution abatement operating costs, as a percent of average value of shipments.
GPAOC	Annual change in PAOC.
AVERAGE ONLY	
INVEST	Total expenditures on new capital equipment, 1979-1985, as a percent of 1982 capital stock.
INSP	Average pollution inspections per year, 1979-1985 (both federal and state inspections, both air and water pollution).
COMP	Percentage of times observed in compliance in 1981-1989 CDS and 1986-1989 PCS data. (100=always in compliance)
AIR PT	Total plant level particulate emissions (median value from 1981-1989 CDS data) divided by 1983 total value of shipments.
AIR S2	Total plant level sulfur dioxide emissions (median value from 1981-1989 CDS data) divided by 1983 total value of shipments.
AIR N2	Total plant level nitrogen dioxide emissions (median value from 1981-1989 CDS data) divided by 1983 total value of shipments.
WATER BOD	Total plant Biological Oxygen Demand discharges (median value from 1986-1991 PCS data) divided by 1983 total value of shipments
WATER TSS	Total Suspended Solids discharged by the plant (median value from 1986-1991 PCS data) divided by 1983 total value of shipments.

Table 2

SUMMARY STATISTICS

	PAPER	OIL	STEEL
VARIABLE	MEAN (STD DEV)	MEAN (STD DEV)	MEAN (STD DEV)
AVERAGE	N=122	N=107	N=60
TFP	133.63 (17.96)	96.74 (12.38)	156.12 (15.34)
GTFP	3.95 (4.14)	1.88 (3.76)	-1.87 (4.50)
LP	351.19 (33.64)	537.19 (51.97)	350.08 (30.69)
GLP	4.71 (5.25)	.044 (5.50)	-.024 (5.11)
PAOC	1.87 (1.44)	0.77 (0.74)	1.91 (1.03)
GPAOC	0.03 (0.24)	0.06 (0.10)	0.15 (0.21)
INVEST	10.70 (7.68)	11.16 (10.49)	7.31 (3.94)
INSP	2.09 (1.17)	2.71 (2.42)	3.66 (4.90)
COMP	87.08 (14.68)	88.79 (9.00)	79.77 (8.32)
AIR PT	0.01 (0.03)	0.001 (0.002)	0.02 (0.04)
AIR S2	0.02 (0.02)	0.01 (0.01)	0.02 (0.05)
AIR N2	0.01 (0.01)	0.004 (0.01)	0.01 (0.04)
WATER BOD	0.05 (0.11	0.002 (0.002)	(0.001 (0.01)
WATER TSS	0.07 (0.14)	0.0004 (0.001)	0.01 (0.01)
ANNUAL	N=854	N=749	N=420
TFP	133.64 (23.80)	96.73 (20.00)	156.02 (25.29)
LP	351.19 (38.54)	537.19 (55.14)	350.00 (38.27)
PAOC	1.91 (1.64)	0.78 (0.82	2.03 (1.43)
ANNUAL	N=732	N=642	N=360
GTFP	3.95 (25.18)	1.88 (24.18)	-1.95 (31.51)
GLP	4.71 (19.62)	0.44 (22.48)	-0.35 (32.47)
GPAOC	0.027 (0.73)	0.06 (0.34)	0.15 (1.14)

Table 3

SPEARMAN CORRELATIONS - AVERAGE PRODUCTIVITY

PAPER

	TFP	GTFP	LP	GLP	COMP	INSP	PAOC	GPAOC
INVEST	.2200**	.2274**	.0204	.3217**	.0906	-.1373	.0136	-.0822
GPAOC	-.2945**	-.3776**	-.1584*	-.2861**	.0370	.1850**	.3577*	
PAOC	-.1893**	-.3316	.0277	-.1850**	-.2008*	.4273**		
INSP	-.1348	-.2877**	.1005	-.2024**	.0617			
COMP	.1489	.2700**	.0481	.1443				
GLP	.4230**	.6537**	-.0922					
LP	.3129**	-.1643*						
GTFP	.3158**							

OIL

	TFP	GTFP	LP	GLP	COMP	INSP	PAOC	GPAOC
INVEST	.1214	-.0921	.0079	.1125	.0343	.2634**	-.1405	-.0461
GPAOC	-.0678	-.1937**	-.1438	-.2586**	.1254	.1538	.4652**	
PAOC	-.1215	-.1107	-.0475	-.3997**	.0348	.1919**		
INSP	.1316	.0643	-.0558	-.0213	.0706			
COMP	.0512	.0564	.0013	-.1022				
GLP	-.0203	3969**	-.1247					
LP	.5250**	-.0962						
GTFP	-.0849							

STEEL

	TFP	GTFP	LP	GLP	COMP	INSP	PAOC	GPAOC
INVEST	-.2090	-.3971**	-.1275	-.3401**	.2933	-.0706	-.3280**	.1279
GPAOC	-.3842**	-.3424**	-.2929**	-.4341**	-.0350	.0167	.3508**	
PAOC	-.1626	-.1126	.0088	-.1165	-.0877	.2598*		
INSP	-.1390	-.1018	.1118	-.0857	-.2078			
COMP	.0616	.0015	.0961	-.0567				
GLP	.1226	.6789**	-.0006					
LP	.4514**	-.0159						
GTFP	.2483							

* Significant at the 10% level
** Significant at the 5% level

Table 4

SPEARMAN CORRELATIONS - ANNUAL PRODUCTIVITY

PAPER

	TFP	GTFP	GLP	LP	PAOC
GPAOC	-.0744**	-.0241	-.1386**	-.0872**	.2335**
PAOC	-.1769**	-.0798**	-.0579	-.0433	
LP	.3415**	.0753**	.2569**		
GLP	.1497**	.2793**			
GTFP	.5949**				

OIL

	TFP	GTFP	GLP	LP	PAOC
GPAOC	-.0840**	-.1720**	-.2477**	-.0998*	.3706**
PAOC	-.0449	-.0540	-.1039**	-.0810**	
LP	.4480**	.0548	.1818**		
GLP	.1612**	.3019**			
GTFP	.4194**				

STEEL

	TFP	GTFP	GLP	LP	PAOC
GPAOC	-.1739**	-.2112**	-.2508**	-.1437**	.4284**
PAOC	-.2499**	-.0760	-.0720	-.1421**	
LP	.4886**	.2450**	.3940**		
GLP	.3773**	.6651**			
GTFP	.5388**				

* Significant at the 10% level
** Significant at the 5% level

Table 5

AVERAGE PRODUCTIVITY REGRESSIONS

INDUSTRY	DEP VAR	CONSTANT	PAOC	GPAOC	INVEST	R^2	N
PAPER	TFP	133.82 (3.23)	-2.74 (1.11)		0.46 (0.21)	.08	122
	GTFP	2.67 (.062)		-3.88 (1.49)	0.13 (0.05)	.13	122
	LP	349.49 (6.28)	0.59 (2.16)		0.06 (0.41)	.001	122
	GLP	2.79 (.078)		-4.79 (1.87)	0.19 (0.06)	.15	122
OIL	TFP	96.87 (2.22)	-1.90 (1.61)		0.21 (0.11)	.05	107
	GTFP	3.12 (.055)		-5.52 (3.43)	-0.08 (0.03)	.08	107
	LP	529.95 (9.50)	4.36 (6.92)		0.35 (0.49)	.008	107
	GLP	0.59 (0.82)		-10.61 (5.11)	0.041 (0.05)	.05	107
STEEP	TFP	173.58 (6.26)	-4.78 (1.93)		-1.14 (0.51)	.13	60
	GTFP	1.38 (1.18)		-6.03 (2.60)	-0.32 (.014)	.17	60
	LP	369.36 (13.11)	-3.35 (4.04)		-1.76 (1.06)	.05	60
	GLP	3.29 (1.36)		-6.01 (2.99)	-0.36 (0.16)	.15	60

Standard errors in parentheses

Table 6

ANNUAL PRODUCTIVITY REGRESSIONS

INDUSTRY	DEP VAR	CONSTANT	PAOC	GPAOC	YEAR	PLANT	R^2	N
PAPER	TFP	1.53 (0.02)	-2.26 (.043)		X		.26	854
	TFP		-2.81 (0.60)		X	X	.80	854
	GTFP	0.17 (0.02)		-2.81 (0.84)	X		.58	732
	GTFP			-2.58 (0.95)	X	X	.60	732
OIL	TFP	1.04 (0.02)	-2.38 (0.87)		X		.08	749
	TFP		-3.73 (1.94)		X	X	.46	749
	GTFP	-0.002 (0.02)		-5.68 (2.68)	X		.11	642
	GTFP			-5.68 (3.05)	X	X	.13	642
STEEL	TFP	1.65 (0.04)	-4.19 (0.86)		X		.13	4.18
	TFP		-3.88 (1.23)		X	X	.45	418
	GTFP	0.04 (0.04)		-2.60 (1.54)	X		.11	356
	GTFP			-2.47 (1.71)	X	X	.13	356

Standard errors in parentheses

Table 7

ALTERNATIVE REGULATION MEASURES

REGULATION MEASURE:	TFP	GTFP	TFP	GTFP	TFP	GTFP
INSP	-0.311 (0.198)	-0.111 (.044)	0.058 (.071)	0.041 (0.021)	-0.070 (0.057)	-0.002 (0.017)
COMP	0.183 (0.129)	0.094 (.028)	0.083 (0.148)	-0.029 (0.044)	0.083 (0.121)	0.029 (0.034)
AIR PT	13.99 (52.08)	24.30 (11.48)	-636.14 (540.92)	-234.43 (161.93)	-116.26 (63.95)	-5.19 (18.67)
AIR S2	-88.41 (79.15)	-31.77 (17.53)	-182.71 (117.06)	-65.06 (34.97)	-134.02 (51.52	-6.33 (15.32)
AIR N2	-22.26 (86.96)	-151.27 (55.55)	-67.38 (151.08)	-76.53 (44.86)	-85.67 (68.95)	-3.82 (19.93)
WATER BOD	-1.29 (18.59)	-6.09 (4.16)	-2.18 (7.05)	-2.23 (2.09)	-13.46 (49.76)	2.99 (14.01)
WATER TSS	5.00 (14.18)	-4.16 (3.20)	-19.12 (13.08)	-1.05 (3.93)	0.66 (3.60)	-2.22 (.961)

Table shows coefficient and standard error on regulation measure from regressions which include a constant term and INVEST, similar to the regressions presented in Table 5.

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