The Role of Financial Constraints in Firm Investment under Pollution Abatement Regulation*

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ABSTRACT

This paper empirically analyzes pollution abatement regulation within the context of the Clean Air Act's nonattainment status designation and shows that financial constraints are an important determinant of whether spending on mandatory pollution abatement crowds out or stimulates R&D investment and capital expenditure. We show that spending on mandatory pollution abatement and other investments are complements for financially unconstrained firms but substitutes for constrained firms. Financially unconstrained firms invest more and have lower current profits but higher future profits; financially constrained firms invest less and have stable current profits but lower long-term profits. (JEL: G32, G38, Q58)

Keywords: Mandatory Pollution Abatement, Financial Constraints, R&D, Capital Expenditure

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1. Introduction

Controversial views on environmental regulation are often linked to the effect of regulation on firm competitiveness and market performance. Opponents of environmental regulation argue that mandatory pollution abatement spending crowds out other investments and reduces the competitiveness of regulated firms (Gray and Shadbegian, 1998; Jaffe, Peterson, Portney, and Stavins, 1995). In contrast, proponents point out that environmental regulation can induce profit-maximizing firms to invest more than they would otherwise (especially in innovation) and earn higher future profits (Leiter, Parolini and Winner, 2011; Porter and van der Linde, 1995). This paper conducts empirical analyses of this question and provides a differentiated answer based on firms' financial resources.

We show that a firm's financial resources are an important determinant of whether environmental regulation crowds out or stimulates R&D investment and capital expenditure. When the government implements mandatory pollution abatement, financially unconstrained firms invest more in R&D and capital expenditure and have lower current profits but higher future profits; correspondingly, constrained firms invest less in R&D and capital expenditure but have stable current profits and lower long-term profits.

Our empirical analysis distinguishes firms by financial constraints and analyzes how the designation of nonattainment status, a specific aspect of the Clean Air Act, affects capital expenditure, R&D investment, and firm profits. When a U.S. county is designated "nonattainment," the pollution-emitting plants located in that county are required to comply with mandatory requirements. Regulatory compliance brings extra costs to the plants, including specific equipment requirements. Specifically, under federal guidelines, plants located in nonattainment counties are required to install the cleanest available technology (Becker and Henderson, 2000; Greenstone, List, and Syverson, 2012).

These compliance costs are not trivial. The U.S. Environmental Protection Agency (EPA) states that "The costs of complying with Clean Air Act requirements through the 1970 to 1990 period affected patterns of industrial production, capital investment, productivity, consumption, employment, and overall economic growth" (U.S. EPA, 1997). For example, the total pollution control capital investment in the U.S. was $41 billion or 2.8% of total capital investment in 1990 (U.S. EPA, 1990). Total costs for all pollution control activities in the U.S. were $115 billion or 2.1% of Gross National Product in 1990 (U.S. EPA, 1990). The direct costs of implementing the Clean Air Act from 1970 to 1990, including annual compliance expenditures in the private sector and program implementation costs in the public sector, totaled $628 billion (U.S. EPA, 1997). In 2005, $3.88 billion of pollution abatement capital expenditures was attributed to just air emissions abatement. In the U.S. food manufacturing industry alone, pollution abatement operating costs amounted to $1.52 billion in the same year (Table 1, U.S. Bureau of Census, 2008).

To conduct the empirical analysis, we construct a dataset by merging eight different databases with county and firm-plant level information. The U.S. EPA records a full list of plants emitting pollutants above a certain level and each plant's parent firm in its Toxics Release Inventory (TRI) database. Using this data, we create a sample using firm names and obtain each firm's list of subsidiary toxics-releasing plants and their location in each year. We also obtain the list of pollutants that each plant emits to identify whether it is regulated by certain mandatory pollution abatement requirements. We hand-collect each county's attainment and nonattainment status for the regulated pollutants from Title 40 of the Code of Federal Regulations (CFR) from 1994 to 2016.

Based on this information from the EPA and the CFR, we count the number of plants owned by each firm that are located in nonattainment areas in each year. Combined with the total number of plants that each firm owns every year in the National Establishment Time-Series (NETS) dataset, we are able to calculate the proportion of plants affected by an announcement for each firm-year observation. As our main exogenous variable, we use the ratio of the number of regulated pollution-emitting plants located in nonattainment areas owned by a firm divided by its total number of plants; this ratio captures the impact of a nonattainment status designation. Intuitively, if a larger fraction of plants held by a firm faces this regulation, the firm is arguably more affected.

We obtain information on pollution abatement efforts from the MSCI ESG database. As a proxy for financial constraints, we adopt the financial constraint index proposed by Bodnaruk, Loughran, and McDonald (2015), which is based on the frequency of financial constraint-related words in a firm's 10-K filings.[1] We sort firms according to their financial constraint index. Firms are defined as financially constrained if their financial constraint index is in the top one-third (the top tertile). Firms in the bottom tertile are defined as financially unconstrained.

We find that firms invest more in pollution abatement[2] when they have pollution-emitting plants in nonattainment areas and higher regulated plant ratios. Consistent with theoretical implications, we show that financially constrained firms reduce their current capital expenditure and R&D investment. In contrast, financially unconstrained firms increase their current capital expenditure and R&D investment. Although financially unconstrained firms experience a significant decline in short-term profitability, measured by profit margin and return to assets, these firms have higher future profits. We also test a potential alternative story that may contribute to unconstrained firms' higher future profitability other than their higher capital and technological investments incurred by regulation: that constrained firms' business may shrink because their investments decrease in response to regulations. However, this alternative lacks enough empirical support because neither constrained firms' market share nor their plant closures significantly change following a nonattainment status designation.

We also find that while short-term profits of financially constrained firms do not experience this decline in short-term profitability, these firms have lower future profits. Notably, financially unconstrained firms (voluntarily) increase their pollution abatement spending in the future, while the opposite is observed for financially constrained firms. From a stock market perspective, the current stock price of regulated firms declines; meanwhile, the drop in market valuation for financially unconstrained firms is smaller.

We also explore three possible behaviors when firms face regulation: Closing the plants, violating regulations and paying penalties, and strategically delaying pollution abatement investment. Our empirical analyses show: 1) on average, regulation does not have a significant

[1] In unreported analysis we use the following proxies for financial constraint: firm size (Erickson and Whited, 2000), dividend payout ratio (Fazzari, Hubbard, and Petersen, 1988), Size-Age Index (Hadlock and Pierce, 2010), and WW index (Whited and Wu, 2006). The results are available upon request.

[2] In this paper, the terms "mandatory pollution abatement", "regulatory enforcement", "change of attainment status" and "designation of nonattainment status" all mean that a county's status was designated as attainment and changed to nonattainment. The relevant polluting plants located within the county are required to install or update the pollution abatement equipment with "lowest achievable emission rates" (LAER) Technologies.

impact on plant closure for constrained firms, unconstrained firms, or the whole sample; 2) right after the implementation of regulations, firms on average receive fewer, rather than more, penalties; and 3) large polluting plants do not strategically delay pollution abatement, but small polluting plants may strategically delay pollution abatement.[3]

Our paper contributes to the literature on environmental regulation and firm investment by highlighting the importance of financial constraints. Much of this literature documents the negative effects of environmental regulation often in relation to the nonattainment status designation, such as specific equipment requirements (Becker and Henderson, 2000), loss of jobs, capital stock and industry output (Greenstone, 2002), lower total factor productivity (Greenstone, List, and Syverson, 2012), and reduced local employment (Walker, 2011; Walker, 2013). Alongside studies that document negative effects, Leiter, Parolini and Winner (2011) show that an industry's total current expenditure on environmental protection is positively correlated with gross investment in tangible goods, new buildings, and machinery.[4] To complement the existing literature, our paper shows that mandatory pollution abatement regulation affects financially constrained and unconstrained firms very differently in terms of investment and (current and future) profitability.

Our paper also contributes to the literature on the determinants of innovation and firm investment. This literature has shown that R&D investment and capital expenditures are affected differently by various economic factors, such as financial market development, stock liquidity, and short selling (Becker-Blease and Paul, 2006; Brown, Martinsson, and Petersen, 2013; Fang, Tian, and Tice, 2014; Grullon, Michenaud, and Weston, 2015). Dang and Xu (2018) show that market sentiment affects investment differently for financially constrained and unconstrained firms. They show that financially constrained firms invest more in R&D when market sentiment is high, while investment for unconstrained firms is not responsive. Our paper shows that when faced with a nonattainment status designation, financially unconstrained firms invest more in R&D and capital expenditure, while constrained firms reduce both types of investment.

[3] We sincerely thank the anonymous referee for pointing out these three possibilities. Incorporating them into our paper substantially improves the quality of research.
[4] See also the survey in Currie and Walker (2019).

Our paper is additionally related to the large literature on corporate social responsibility (CSR), in particular, on the relationship between pollution abatement efforts and firm performance, the study of which can be traced back to Bragdon and Marlin (1972). Most studies examining this relationship have concluded with a positive correlation (e.g., Ferrell, Liang, and Renneboog, 2016; King and Lenox, 2001), with only a few documenting a concurrent negative correlation between pollution emission and firm performance (e.g., Turban and Greening, 1997).[5] Our paper shows that the overall effect of a nonattainment status designation on firm value is negative, while short-term and long-term profits are affected differently for financially constrained and unconstrained firms.

The remainder of this paper is organized as follows. Section 2 provides background information on the designation of nonattainment status and regulatory enforcement. Section 3 develops testable hypotheses. Section 4 describes the data sources and sample. Section 5 describes variable construction. Section 6 and 7 present the empirical results. Section 8 concludes.

2. History of U.S. Federal Air Protection Legislation

The history of U.S. federal air protection legislation dates back to the Air Pollution Control Act of 1955, which also provided funds for federal research on air pollution. The first federal regulations that aimed to control air pollution were codified in the Clean Air Act of 1963 and later the Air Quality Act of 1967. While this legislation expanded federal government activities, it lacked the power of enforcement because it did not set any standards, deadlines, or enforcement mechanisms.

The 1970 Clean Air Act (CAA) established a framework for attaining and maintaining clean and healthful air quality levels and contained a number of key provisions. First, the Environmental Protection Agency (EPA) was set up and directed to establish National Ambient

[5] See also Barth and McNichols (1994); Blacconiere and Patten (1994); Chen and Metcalf (1980); Dowell, Hart, and Yeung (2000); Klassen and McLaughlin (1996); Konar and Cohen (2001); Manchiraju and Rajgopal (2017); Nehrt (1996); Spicer (1978).

Air Quality Standards (NAAQS) for six pollutant criteria (carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, particulate matter, and lead). Second, the CAA required states to develop State Implementation Plans (SIPs) which would be approved by the EPA. For stationary sources, such as steel mills and power plants, the SIPs had to set a specific limit on the pollution that could be discharged. These limits would be enforced by a set of civil and criminal sanctions. Third, the 1970 Act forced new sources to meet standards based on the best available technology. Finally, the CAA addressed hazardous pollutants and automobile exhausts.

The CAA was later amended twice in 1977 and in 1990. Since the 1977 Clean Air Act Amendments (1977 CAAA), each year on July 1, Title 40 of the Code of Federal Regulations (CFR) is officially updated with attainment/nonattainment designations for each county in the US. The 1977 CAAA require states with counties designated as nonattainment to propose SIPs which detail how they plan to bring the nonattainment areas back to attainment status. Failure to comply with these requirements can lead to withholding federal grants and banning construction of new polluting plants in the designated areas. Firms in such areas are required to adopt technologies with the "lowest achievable emission rates" (LAER). These technologies have to be used *irrespective of their cost*. In comparison, in the attainment areas, large polluters (those emitting over 100 tons per year) are to use "best available control technology" (BACT), which impose a lower cost on the firms as compared to LAER.

Polluting plants in nonattainment areas can also be required to redesign their production processes, and such redesigns have to be approved by the regulator, which entails an additional cost burden on these plants. Plants in nonattainment areas have a higher likelihood of being inspected and fined than those in attainment areas.

The 1990 Clean Air Act Amendments considerably strengthened the earlier versions of the Act. The most notable regulatory procedural change is the new permit program, which requires all major emitting sources to obtain an operating permit. States can issue such permits, but the EPA can veto them in some instances. The 1990 amendments also strengthened the EPA's enforcement powers, enabling the agency to impose penalties of up to 25,000 US dollars per day for each violation. Specific criminal penalties also became more severe, and citizen were allowed suits against polluting units.

Finally, the current CAA requires the EPA to review the standards for each pollutant every five years and if required, to revise them. With every revision, the EPA must determine once again which counties across the US are in attainment or nonattainment of these standards. Yearly revisions of the attainment/nonattainment status of counties in the previous year are published officially on July 1 under Title 40 of the CFR.

We hand-collect the nonattainment status of each county in every year and use the data in 2003 and 2004 to generate Figure 1, which shows U.S. counties with different attainment and nonattainment statuses in 2003 and 2004. The counties in white are attainment areas in both years. Counties in red represent nonattainment in both years. Counties in yellow are attainment areas in 2003 that have switched to nonattainment in 2004, and counties in green have nonattainment status in 2003 and move to attainment status in 2004.

Some nonattainment counties change to attainment status after one or two years, while some counties in Southern California retained the nonattainment status for over a decade. Our data show that it is very rare for a county to be designated as nonattainment for the second time after it changes from the nonattainment to attainment status.

[Insert Figure 1]

3. Hypotheses Development

a. Maximization of Firm Value Under Mandatory Pollution Abatement

A theoretical analysis is provided in the Online Appendix. A firm's pollution abatement spending is partially related to quantity demand and price. (Servaes and Tamayo, 2013). The firm's sales revenue depends on historical investment, which determines the good's quality and concurrent pollution. Higher pollution abatement spending increases both revenue and cost, and there exists a profit-maximizing level of voluntary pollution abatement spending.

The new regulations imposed by nonattainment status require more pollution abatement spending than the profit-maximizing level. Such deviation leads to decreased firm profit and value. Because future sales depend on current investment and future pollution, the marginal benefit of current investment on future sales increases when future pollution decreases due to regulation. While the marginal cost of current investment is the same under no regulation, the marginal benefit increases, therefore the firm makes more current investment.

Although not immediately obvious, the explanation for why a firm voluntarily spends more on pollution abatement in the future is also intuitive. Higher current pollution abatement spending leads to higher current investment, which increases the marginal benefit of future pollution abatement spending on future sales. Since the marginal cost of future pollution abatement spending is the same with or without regulation but the marginal benefit increases, the firm invests more in future pollution abatement spending.

Hypothesis 1 summarizes the above rationale.

Hypothesis 1*: Mandatory extra pollution abatement effort leads to (i) more current pollution abatement effort; (ii) more voluntary pollution abatement spending in the future; (iii) more profit in the future; and (iv) lower value of the firm.*

b. Mandatory Pollution Abatement and Financial Constraints

The mandatory pollution abatement requirements faced by firms in nonattainment counties brings additional costs to these firms. The firms must either pay for equipment upgrading or face potential penalties for law violations. Alternatively, firms may shut down plants when they find that payment exceeds potential benefits.[6]

When firms pay for pollution abatement, they may either use their cash reserves or credits or divert resources that could be used for capital and R&D investment. Unconstrained firms can increase current pollution abatement spending while maintaining current capital and R&D investment; financially constrained firms have to sacrifice their current investments and divert resources to increase current pollution abatement spending to comply with regulations. Unconstrained firms may even increase their current investments because the marginal benefits of current investments are higher as pollution abatement spending is higher.

[6] Our empirical results in Section 7 show that, in general, firms do not shut down plants when plants' counties are designated as nonattainment.

The current profit of unconstrained firms is expected to be lower than that of constrained firms because unconstrained firms' total investment expenditure is higher.

Compared to constrained firms, unconstrained firms' future products have higher quality because of higher current investment. Because future revenue depends on current investment and future pollution abatement spending, unconstrained firms should increase future pollution abatement spending because the marginal benefit from having a higher voluntary pollution abatement spending is greater when current investment is higher. The model in our Online Appendix has formulated derivation of this relationship. Due to lower current R&D investment and capital expenditure, constrained firms should have lower future pollution abatement spending because of the lower marginal benefit to sales revenue.

Unconstrained firms have higher future pollution abatement spending and higher revenue; net profit may also be higher when increases in future revenue exceed increases in higher future costs. Constrained firms' future pollution abatement spending should also be lower because of lower future profitability. Constrained firms' future profit may be lower due to lower future revenue and business contraction from lower current investment.[7]

Firm value decreases because newly required pollution abatement spending imposes an extra cost on both constrained and unconstrained firms and makes their spending deviate from the value-maximizing level.

In sum, mandatory pollution abatement spending and capital and R&D investment are complements for financially unconstrained firms but substitutes for financially constrained firms. When the government implements mandatory pollution abatement, financially unconstrained firms invest more in R&D and capital expenditure and have lower current profits but higher future profits; correspondingly, constrained firms invest less in R&D and capital expenditure but have stable current profits and lower long-term profits. Hypothesis 2 summarizes this rationale.

[7] Our model in the Online Appendix proves that under some conditions, financially constrained firms' future profit is lower under regulation than their profit under no regulation.

Hypothesis 2*: When a firm is financially constrained, mandatory extra pollution abatement effort leads to (i) less current investment; (ii) less pollution abatement effort in the future ; (iii) less profit in the future; and (iv) lower value of the firm.*

The implications of mandatory pollution abatement for current profit and market value are the same for both types of firms. Current profits decline as does market value. But our discussion also predicts the magnitude.[8] From the above analysis, we have the following two testable corollaries.

Corollary 1*: When there is mandatory extra pollution abatement effort, the current profit of financially constrained firms drops less than that of financially unconstrained firms.*

Corollary 2*: When there is mandatory extra pollution abatement effort, the market value of financially constrained firms drops more than that of financially unconstrained firms.*

Table 1 summarizes the set of testable hypotheses and corollaries.

[Insert Table 1]

4. Data Sources and Sample Construction

The data used in this paper are obtained from eight different databases. 1) We hand-collect every county's attainment/nonattainment status from the Code of Federal Regulations (CFR). 2) A firm's establishment-level information for polluting plants is from the Toxics Release Inventory (TRI) database of the Environmental Protection Agency (EPA). We use the TRI database *only* to identify polluting plants; we do not use its self-reported pollution data, which have been widely criticized for pollution measurement accuracy.[9] 3) The total number of plants and the employee numbers for each plant are from National Establishment Time-Series (NETS). 4) Information on pollution abatement investment is from MSCI ESG. 5) Information on R&D investment and capital expenditure is from Compustat. 6) Stock returns data are from CRSP. 7) A firm's financial constraint index and environmental awareness are constructed via

[8] The discussion of magnitude is more obvious in the model in the Online Appendix.
[9] See De Marchi and Hamilton (2006) and Koehler and Spengler (2007).

textual analysis of the 10-K and other filings from SEC EDGAR. 8) A firm's lobbying activities on environmental protection policies are hand-collected from the Office of the Clerk of the U.S. House of Representatives, the U.S. Senate Query the Lobbying Disclosure Act Database, and OpenSecrets. The lobbying dataset is used to control for a potential endogeneity issue.

Because the 10-K filings on the SEC EDGAR dataset begin in 1994, we start constructing our data from a complete list of U.S. firms in Compustat between 1994 and 2016, a database that contains detailed firm-level accounting and financial information for each firm-year observation. We then match the list with CRSP, a database containing the stock prices of all publicly traded firms. Most of the Compustat firms can be matched with CRSP in this step.

The Environmental Protection Agency (EPA) records a full list of plants emitting pollutants above a specified level and each plant's parent firm. Therefore, we manually match our sample with the EPA Toxics Release Inventory (TRI) database using firm names and obtain each firm's list of subsidiary toxics-releasing plants and their location in each year. We also obtain the list of pollutants that each plant emits.

In the next step, we hand-collect each county's attainment and nonattainment status for the regulated pollutants from Title 40 of the Code of Federal Regulations (CFR). For accurate statuses in the early years, we check scanned copies of the reports. Combining the information from the EPA and the CFR, we count the number of each firm's plants located in new nonattainment areas in each year. Combined with the total number of plants that each firm owns every year in the dataset National Establishment Time-Series (NETS), we are able to calculate the proportion of plants affected by the status announcement for each firm-year observation. Because many Compustat firms do not have toxics-releasing plants and therefore are not regulated by the EPA and CFR, they cannot be matched with the EPA TRI dataset by name. After the matching process, we obtain 1,071 firms and 10,082 firm-year observations with plants under potential regulation.

To examine whether our empirical results may be affected by firm lobbying, we also collect lobbying data from the Office of the Clerk of the U.S. House of Representatives and the U.S. Senate Query the Lobbying Disclosure Act Database and then cross-check with

OpenSecrets. We construct a firm-year level dummy variable indicating whether a firm has been involved in lobbying activities on environmental issues and exclude all firms with lobbying activities in our main analyses.

5. Variable Construction

a. Variables that Measure Investment, Pollution Abatement Efforts, Environmental Awareness, Profit, and Firm Value

To capture firm investment behaviors, we use the ratio of R&D expenditure to total assets (R&D) and the ratio of capital expenditure to total assets (Capex). To proxy pollution abatement investment, we employ two indicators from the MSCI ESG database, all of which are widely used to measure corporate social responsibility (CSR). One indicator variable, "Pollution Reduction" (ENV-STR-B in KLD), indicates whether firms have active programs and performance in reducing toxic emissions. The other indicator, "Clean Energy Investment" (ENV-STR-D in KLD), equals one if the firm proactively invests in clean technologies.

We define the environmental awareness index as the frequency of mentioning environment-related words in a firm's 10-K, 10-K405, 10KSB and 10KSB40 filings, which measures the firm's communication on environment and pollution issues (see Dhaliwal, Li, Tsang, and Yang (2011) and Dhaliwal, Radhakrishnan, Tsang, and Yang (2012)). Construction of this index has four steps. First, we download all 10-K filings from the Securities and Exchange Commission (SEC) EDGAR database from 1994 to 2016, including 10-K405, 10KSB and 10KSB40 filings but excluding amended filings. Second, we remove ASCII-encoded segments (e.g., graphics files, etc.), HTML tags (e.g., <DIV>, <TR>, <TD>, etc.), tables, and other unrelated elements. Third, we count the number of times that environment-related words appear in the cleaned text. Environment-related words include those with the stem "environ-," such as "environment" and "environmental", and words with the stem "pollut-," such as "polluting" and "pollutant." Fourth, we divide the above number by the total number of words in the cleaned text to generate the frequency, which is our measure. This variable has a positive value for most EPA-matched Compustat firms.

We use profit margin and ROA to measure firm profits. The firm value is measured by Tobin's Q and cumulative abnormal returns (CARs). We define Tobin's Q as the market value of assets divided by the book value of assets. We also construct 1-, 3- and 4-factor CARs on the windows (-2, 2) and (-5, 5), where day 0 is the publishing date of the nonattainment status of each county, which is July 1 in each year. We define abnormal returns by using the difference between actual and projected returns, where we estimate projected returns as follows: (1) regress the daily stock return on the returns on the CRSP value-weighted market portfolio over the 200-day period from the 210th trading day through the 11th trading day before the publishing date of the nonattainment status and collect the estimated coefficients and (2) use the estimated coefficients to compute the projected returns during the 5-day window (-2, +2) or the 11-day window (-5, +5). The 3-factor and 4-factor models' factors data are from the website of Kenneth R. French. To estimate the impact of nonattainment status announcements on stock returns, we compute each firm's cumulative abnormal return (CAR) around July 1 in each year—the publishing date of each county's nonattainment status. [10]

b. The Variable that Reflects the Change of Attainment Status

We construct the main exogenous independent variable as follows. We use the proportion of plants affected by a nonattainment status designation for each firm-year observation to measure the impact of this regulation. A regulated plant refers to a TRI (Toxics Release Inventory) plant located in a non-attainment county. In particular, we use the list of pollutants that each plant emits to identify whether it emits one or more of the criteria pollutants and thus is regulated by a specific mandatory pollution abatement requirement. We construct a firm's percentage of plants in nonattainment counties, *Regulated_Plant_Ratio,* as the number of relevant pollution-emitting (regulated) plants located in nonattainment areas divided by the total number of plants,

$$ratio_{ft} = \frac{\sum_{i=1}^{N_{ft}} r_{fit}}{N_{ft}}$$

[10] We use the next trading day when July 1 is a non-trading day.

where r_{fit} is a dummy variable that equals one if plant i of firm f is a pollution-emitting plant and located in a nonattainment county in year t and zero otherwise; N_{ft} is the total number of plants owned by firm f in year t. For example, if firm f has many relevant pollution-emitting plants $\{i\}$, but none are located in counties designated as nonattainment areas in year t, then $ratio_{ft}$=0. If a firm has ten plants and two are both pollution-emitting and located in a county designated as a nonattainment area in year t, then $ratio_{ft}$=0.2. This ratio is calculated for each firm in each year.[11]

c. The Financial Constraint Measurement Variable

The literature has proposed various proxies for financial constraints. Following Bodnaruk et al. (2015), we construct the financial constraint index as the frequency of financial constraint-related words in 10-K filings. Similar to our construction of the environmental awareness index, we follow four steps. First, we download all 10-K filings from the SEC EDGAR database from 1994 to 2016, including 10-K405, 10KSB, 10KSB40 and 10-KSB filings but excluding amended filings. Second, we remove ASCII-encoded segments (e.g., graphics files etc.), HTML tags (e.g., <DIV>, <TR>, <TD> etc.), tables, and other unrelated elements as defined in Bodnaruk et al. (2015). Third, we count the number of times that the financial constraint-related words appear in the cleaned text. A list of 184 financial constraint-related words is given in Bodnaruk et al. (2015). Fourth, we divide the above number by the total number of words in the cleaned text to generate the frequency, which is our constructed financial constraint index. Nessa (2017) validates the predictive power of this financial constraint measure.

d. Variables that May Affect Pollution Abatement Regulation

The nonattainment status of each county in year t is designated in every year based on pre-specified rules and factors. Attainment status under the NAAQS is determined by the US EPA using monitored air quality data for the criteria pollutants (i.e., PM, SO2, NOx, O3, Pb, and CO). Nevertheless, a possible endogeneity concern is that firms may lobby against such regulation. We collect lobbying data from the Office of the Clerk of the U.S. House of Representatives and the U.S. Senate Query the Lobbying Disclosure Act Database and then

[11] It is worth noting that while a plant that emits one or more of the criteria pollutants may be located in an attainment area, it may still be regulated. However, it does not face the additional and more stringent regulations of nonattainment areas.

cross-check with OpenSecrets. We construct a firm-year level dummy variable indicating whether a firm has been involved in lobbying activities on environmental issues and exclude all firms with lobbying activities (around 15% of the total sample) in our primary analyses.

e. Firm-year Level Control Variables

We control for the firm's financial leverage, cash flow volatility, and operating cash flow ratio following existing literature. We also control for total assets and sales growth because these two variables are correlated with CSR based on prior research (McGuire, Sundgren, and Schneeweis, 1988). Other variables used in the literature, such as assets growth and operating income growth, we do not control because they are highly correlated with the five controls that are already included in our regression models.

In addition, we control for firm fixed effects. Though not presented in the tables, the results are also robust when Metropolitan State Area (MSA), industry, and year fixed effects are all or partially included.

f. Summary Statistics of Variables

The definitions of all variables in our analyses are detailed in Appendix Table A1. Table 2 presents summary statistics of the variables for the full sample and the subsamples of firms that do not lobby and are either financially constrained or unconstrained (i.e., the top or bottom one-third of firms ranked by the financial constraint index of the full sample). As discussed in Section 4, our sample only includes firms with at least one toxics-releasing plant, i.e., firms that face potential regulation. The full sample contains 1,071 firms and 10,082 firm-year observations.

Since lobbying firms constitute 15.7% of total firm-year observations of the full sample, our main analysis is based on 84.3% of available observations. It is worth mentioning the variation in the number of observations among the variables. This variation can be explained by the count of observations in the subsample for each variable, which is constructed as an intersection of three characteristics (e.g., non-lobbying ∩ financial constraint index group ∩ variable of interest).

A key variable in our analysis is the independent variable, *ratio*. In the main analysis we use *Regulated_Plant_Ratio* defined as the number of regulated plants divided by the total number of plants owned by a firm in a given year. A regulated plant means a TRI plant located in a non-attainment county that emits one or more of the criteria pollutants. Table 2 shows the average *ratio* is 0.02. This means that on average around 2% of plants are subject to regulation each year. Note, this is the unconditional mean and includes *ratio*=0 for all firms without any TRI plants in counties designated as nonattainment counties in a year. Conditional on a firm's plant being regulated, the *ratio* (i.e., average[*ratio*| *ratio*>0]) has an average of 0.10 and is significantly larger than the unconditional average. In other words, if a firm is subject to regulation, on average around 10% of its plants are being regulated.

[Insert Table 2]

6. Empirical Results

In the following subsections (a) to (h), we test Hypotheses 1 and 2 as well as Corollaries 1 and 2 by analyzing how mandatory pollution abatement affects a firm's pollution abatement efforts, investment (capital expenditure and R&D), profitability, firm value, and environmental awareness. In addition, we examine how the effects are different for financially constrained and unconstrained firms.

a. The Overall Effects of Mandatory Pollution Abatement

We use the following baseline empirical specification to examine the effects of a nonattainment status designation on the various dependent variables of interest,

$$Dep_{ft} = \alpha + \beta R_{ft} + \chi_{ft} + \Phi_t + \Phi_f + \epsilon_{ft} \#(1)$$

where Dep_{ft} includes the firm value (Tobin's Q and CAR), firm investment (R&D and capital expenditure), profitability (profit margin and return on assets), and pollution abatement efforts (clean energy investment and pollution reduction). R_{ft} is the variable that reflects the exogenous regulatory shock. For each firm f in year t, R_{ft} is defined as the number of regulated plants divided by the total number of all firm f's plants in year t. In Table 3, R_{ft} is *Regulated_Plant_Ratio*. A regulated plant refers to a TRI (Toxics Releasing Inventory) plant located in a county with nonattainment status that emits one or more of the criteria pollutants in a given year. χ_{ft} represents the firm-year control variables, including Cash Flow, Leverage, Sales Growth, ln(Total Assets), and dummy(Lobbying). Φ_t is year fixed effects, and Φ_f is firm fixed effects.

Table 3 shows that for the whole sample of firms, both clean energy investment and pollution reduction increase after a nonattainment status designation, which is understandable because the designation imposes more regulatory requirements for firms' pollution abatement efforts. Accompanied with this increase, Tobin's Q and CAR both decrease. However, we do not observe a significant change in firm investment, including R&D and capital expenditure, or a significant change in profitability, including profit margin and ROA, which is puzzling because it is difficult to explain why firm value changes when investment and profitability do not.

To more deeply understand the effects of regulation on different categories of firms, we conduct the following analyses on constrained and unconstrained firms.

b. The Effects on Pollution Abatement Effort for Constrained and Unconstrained Firms

We examine the effects of a nonattainment status designation on constrained and unconstrained firms using the following empirical specification, which introduces two interaction terms between constrained/unconstrained indicators and *Regulated_Plant_Ratio*, or R_{ft} in Equation (1),

$$Dep_{ft} = \alpha + \beta_1 C_{ft} R_{ft} + \beta_2 C_{ft} + \beta_3 U_{ft} R_{ft} + \beta_4 U_{ft} + \beta_5 R_{ft} + \chi_{ft} + \Phi_t + \Phi_f + \epsilon_{ft} \#(2)$$

Table 4 presents the results. As in Table 3, we use two indicators from the MSCI ESG database, namely pollution reduction and clean energy investment, to measure spending on pollution abatement in Table 4. C_{ft}, or *dummy(Constrained)*, in Table 4 is an indicator variable that equals one if the firm-year observation's financial constraint index falls in the top one-third, and zero otherwise. U_{ft}, or *dummy(Unconstrained)*, in Table 4 is an indicator variable that equals one if the firm-year observation's financial constraint index falls in the bottom one-third, and zero otherwise. The middle one-third firm-year observations are also included in the regression sample.

The estimated coefficient of *Regulated_Plant_Ratio*, β_5, is significant and positive, and the coefficients of the two interaction terms, β_1 (coefficient of dummy(Constrained)* Regulated_Plant_Ratio) and β_3 (coefficient of dummy(Unconstrained)* Regulated_Plant_Ratio), are both insignificant. The results indicate that both financially constrained and unconstrained firms significantly increase their efforts in pollution abatement; there are no significant differences between the two categories. Our results are consistent with the prediction (*i*) in Hypothesis 1.

The results are consistent when using either pollution reduction or clean energy investment as the dependent variable. The economic magnitude is also sizable. Regression (1) in Table 4 shows that a 0.11 (one standard deviation) increase in *Regulated_Plant_Ratio* leads to a 0.1669*0.11 = 0.0184 increase in the *Clean Energy Investment* index. Note that the mean of the *Clean Energy Investment* index is 0.07, which means that the index increases by 26.29% (=0.0184/0.07). Regression (2) in Table 4 shows that a 0.11 (one standard deviation) increase in *Regulated_Plant_Ratio* leads to a 0.1638*0.11 = 0.018 increase in the *Pollution Reduction* index. Note that the mean of the *Pollution Reduction* index is 0.14, which means that the index increases by 12.87% (=0.018/0.14).

[Insert Table 4]

c. R&D Investment and Capital Expenditure

Since both financially constrained and unconstrained firms increase pollution abatement efforts, we investigate if these increased efforts crowd out other investments. We analyze spending on R&D investment and capital expenditure as the dependent variables in Equation (2). The empirical specification is the same as before.

As shown in Table 5, the overall effects of regulation on both R&D investment and capital expenditure are insignificant, reflected by the insignificant estimate of β_5; this is consistent with the insignificant results in regressions (3) and (4) of Table 3. However, Table 5 shows opposite firm investment behaviors when firms are facing a nonattainment status designation, reflected by the significant estimated coefficients of negative β_1 (-0.0027 for R&D and -0.0092 for Capex) and positive β_3 (0.0036 for R&D and -0.0141 for Capex). Financially constrained firms experience a significant decrease in both R&D investment and capital expenditure when their regulated plant ratio increases, while financially unconstrained firms' R&D investment and capital expenditure increase with the fractions of their plants being regulated. These findings confirm our prediction (i) in Hypothesis 2.

[Insert Table 5]

d. Current Profitability

We use profit margin and return on assets (ROA) as a measure of firm profitability and the dependent variable in Equation (2). As shown in Table 6, the overall effects of regulation on both profit margin and ROA are insignificant, reflected by the insignificant estimate of β_5; this is consistent with the insignificant results in regressions (5) and (6) in Table 3.

The insignificant coefficient of dummy(Constrained) * Regulated_Plant_Ratio, or β_1, in Equation (2) shows that financially constrained firms do not experience a statistically significant change in profitability when their regulated plant ratio increases, while the profitability of financially unconstrained firms does decrease with their fraction of regulated plants, reflected by the significantly negative estimate of β_3 (-0.0573 for Profit Margin and -0.0185 for ROA). The results are consistent with Corollary 1 in that the drop of current profits for financially constrained firms is insignificantly different from zero and therefore is less than the drop for financially unconstrained firms.

One possible explanation for why the profits of financially constrained firms do not decline is that they reduce R&D investment and capital expenditure. Since financially unconstrained firms do not scale back other investments, their current profits decline.

[Insert Table 6]

e. Communication of Firms' Environmental Awareness

If consumers value environmentally friendly products and clean technology, do firms communicate their environmental spending and awareness to consumers and investors? We test if firms' environmental awareness increases in response to a higher ratio of regulated plants and present the results in Table 7. The dependent variable is the environmental awareness index, defined as the frequency of mentioning environment-related words in a firm's 10-K, 10-K405, 10KSB, and 10KSB40 filings to measure its communication on environment and pollution issues. With the exception of the dependent variable, other empirical settings, including the independent variable, control variables, and fixed effects, are the same as in Tables 4–6 and Equation (2).

Both financially constrained and unconstrained firms experience a significant increase in the environmental awareness index (0.0141) when their regulated plant ratio increases, reflected by the significantly positive estimates of *Regulated_Plant_Ratio*. The insignificant estimates of both interaction terms (β_1 and β_3) indicate that the increase in the environmental awareness index following regulation is not significantly different between constrained and unconstrained firms.

[Insert Table 7]

f. Future Pollution Abatement Efforts and Environmental Awareness

Hypothesis 1 (*ii*) and Hypothesis 2 (*ii*) predict opposite future voluntary pollution abatement efforts for financially unconstrained and constrained firms. Table 8 tests these predictions. The dependent variables are clean energy investment (from the MSCI ESG database), pollution reduction (from MSCI ESG), and the environmental awareness index (constructed from the SEC EDGAR) in 3 years.[12] All regressions control for year fixed effects and firm fixed effects.

As predicted, Table 8 shows opposite results for constrained and unconstrained firms. Financially constrained firms experience a significant decrease in their future pollution abatement efforts and environmental awareness when their regulated plant ratio increases (β_1 is negative), while financially unconstrained firms increase their future pollution abatement efforts and environmental awareness (β_3 is positive).

[Insert Table 8]

g. Future Profitability

Hypothesis 1 (*iii*) and Hypothesis 2 (*iii*) predict opposite future profitability for financially unconstrained and constrained firms. We test this prediction in Table 9. The dependent variables are profit margin and ROA in three years. Both regressions control for year fixed effects and firm fixed effects.

Consistent with predictions, the results in Table 9 show opposite results for constrained and unconstrained firms. Financially constrained firms experience a significant decrease in their future profitability when their regulated plant ratio increases, while the profitability of financially unconstrained firms increases. This difference is reflected by the significantly negative estimates of dummy(Constrained) * Regulated_Plant_Ratio (β_1 is negative) and the significantly positive estimates of dummy(Unconstrained) * Regulated_Plant_Ratio (β_3 is positive). These results confirm the predictions of our two hypotheses.

[Insert Table 9]

In our view, two potential reasons may contribute to the higher future profitability of unconstrained firms. First, the regulations imposed by a nonattainment status incur more capital and technological investments for unconstrained firms (Table 5). Second, the constrained firms may go out of business, or their business may shrink because their

[12] The results are robust with these variables in four and five years and available upon request. We present the results for three years because they have a larger sample size.

investments decrease in response to regulation.

To test whether constrained firms' business shrinks because their investments decrease in in response to regulation, we conduct another analysis and focus on firms' market share as a dependent variable. As shown in Table 10, we do not see a significant drop in market share for constrained firms from year *t* to *t+3*. Table 12 in Section 7 (a) shows that regulation does not have a significant impact on plant closure for either constrained or unconstrained firms.

[Insert Table 10]

Given these results, we think it's more likely that capital and technological investment are contributing to the higher future profitability of unconstrained firms; the second potential reason—that constrained firms' shrinking business causes unconstrained firms' higher future profitability - does not have enough empirical support.

h. Tobin's Q and Cumulative Abnormal Return

Hypothesis 1 (i*v*) and Hypothesis 2 (i*v*) predict that both financially unconstrained and constrained firms' value decreases when facing mandatory pollution abatement regulation. We test this prediction in Table 11. The dependent variables are Tobin's Q, 1-, 3- and 4-factor cumulative abnormal returns (CAR) with windows (-2, +2) and (-5, +5) around a nonattainment status announcement.[13]

Consistent with the predictions, the results show that both constrained and unconstrained firms experience a significant decrease in their Tobin's Q and CARs when their regulated plant ratio increases, reflected by the significantly negative estimates of *Regulated_Plant_Ratio* (β_5 is negative). These results confirm our prediction (i*v*) in Hypothesis 2.

[13] We are unable to verify if the nonattainment status designation information was uploaded online in the early 1990s and was immediately available to the investors after its release on July 1st. We are more certain that the information was required to be upload online after 2002 because of Section 207(f)(2) of the E-Government Act of 2002. This Act requires all federal agencies to develop an inventory of information to be published on their websites, establish a schedule for publishing information, make those schedules available for public comment, and post the schedules and priorities on their websites. We did a robustness test for CARs using the subsample after 2002, and the results remain consistent.

Moreover, the estimated β_1 is significantly negative, but β_3 is insignificant, indicating that the negative effect of *Regulated_Plant_Ratio* on firm value is stronger for constrained firms. This result is consistent with Corollary 2.

[Insert Table 11]

i. Alternative Fixed Effects and Winsorization

In unreported results, the direction of the signs and the statistical significance are the same when we control for the MSA-year, industry-year, and firm fixed effects in all regressions and cluster the standard deviation by firm. These results are available upon request.

Another potential concern is that some variables in our analyses may have extreme values. We test the robustness of our results by winsorizing the values of all dependent variables at the 1% and 5% levels. We additionally winsorize all dependent and independent variables. All of these robustness tests generate consistent and significant results, which are available upon request.

7. Plant Closure, Penalties, and Strategic Delay

In this section, we discuss three possible responses when firms are facing mandatory pollution abatement requirements: Shut down affected plants, violate the new law and pay the penalties, or for small plants, they strategically delay pollution abatement spending and upgrading and wait for large plants to make pollution abatement first.[14]

a. Plant Closure

Firms may choose to close plants in response to mandatory pollution abatement regulations. For example, Mohave Generating Station near Laughlin, Nevada closed down in 2005. Similarly, State Line Generating Plant in Hammond, Indiana closed down in June, 2012

[14] We sincerely thank the anonymous referee for pointing out these three possibilities. Incorporating them into our paper substantially improves the quality of research.

due to falling profitability and regulatory scrutiny.[15] If most firms close plants when facing regulation, self-selection bias will occur.

To test whether plant closure is the case in general, we obtain all plants' operation information from the NETS and TRI databases and conduct regression analysis with two dependent variables: 1) the natural logarithm of the number of plants closed by a firm in a given year, ln(Close Plant Num), and 2) dummy(Close Plant) that equals one if a firm closes at least one plant in a given year and zero otherwise.

Table 12 presents the results. Despite anecdotal cases of plant closure for some firms following regulation, such as the two aforementioned examples, on average this closure phenomenon is not prevalent enough to make the estimated coefficients statistically significant. Our sample for regressions contains 10,015 observations. The regression results show that the effects of the main explanatory variable, Regulated_Plant_Ratio (β_5), as well as the two interactions, dummy(Constrained) * Regulated_Plant_Ratio (β_1) and dummy(Unonstrained) * Regulated_Plant_Ratio (β_3), are all insignificant, indicating that the regulations imposed by a nonattainment status designation do not have a significant impact on plant closure for constrained firms, unconstrained firms, or the whole sample. Therefore, our main conclusion should not suffer from severe survivorship bias due to plant closures.

[Insert Table 12]

b. Paying Penalties

Some firms may find it more advantageous to violate the implementation of regulations and pay the corresponding penalties rather than comply with the new onerous rules. For example, in 2020, Ford agreed to pay $1.1 million in penalties for violation of the Clean Air Act. In 2009, Kentucky Utilities was fined $1.4 million and agreed to spend $135 on pollution controls to resolve CAA violations.[16] In this subsection, we empirically test if new regulation leads to a significant change in the penalties for violating regulations.

[15] We sincerely thank the anonymous referee for the two motivating examples of plant closure.
[16] We sincerely thank the anonymous referee for the two motivating examples of violation and penalty payment.

We conjecture that there may be two opposite effects of regulation on penalties. First, if firms find it more costly to comply with stricter regulations than to pay penalties, they will violate the regulations, which leads to more penalties. Second, if firms comply with the new regulations, then pollution and the penalties will drop. We empirically test if penalties increase or decrease, and whether there is a difference between constrained and unconstrained firms.

From the EPA's ECHO database, we obtain all firms' penalty information and conduct regression analysis with two new dependent variables of penalty measures. The first measure is ln(Total Penalty), defined as the natural logarithm of one plus the dollar amount of penalties, including both federal and state/local penalties. Federal penalties are the total amount assessed or agreed to for federal enforcement actions. State/local penalties are the dollar penalty amount paid to a state or local enforcement authority. The second measure is ln(Penalty Num), defined as the natural logarithm of one plus the number of all enforcement cases with penalty records.

The results presented in Table 13 show that the regulations imposed by a nonattainment status, in general, reduce penalties in year t; the coefficients of Regulated_Plant_Ratio (β_5) are significantly negative for both regressions. There are no significant differences between the constrained and unconstrained firms because the coefficients of interaction terms (β_1 and β_3) are statistically insignificant, indicating that right after the implementation of the regulations, firms on average receive fewer penalties.

[Insert Table 13]

c. Strategic Delay

The EPA may revert the status of nonattainment counties to attainment due to improved air quality, which is determined by the pollution of all plants in that county. Large plants' pollution abatement efforts have a greater contribution to the total air quality than small plants. Therefore, small polluting plants in nonattainment counties may choose to strategically delay their own pollution abatement investment in anticipation of air quality improvement due to the actions of other polluting plants.

We empirically test this possibility by examining whether a firm's pollution abatement activities in one county, measured by four firm-county-year level variables, are affected by the share of pollution from that firm's plants in that county-year, which is also a firm-county-year level variable. In other words, if a firm's pollution in a given county is only a small portion of the total pollution in that county, is this firm's pollution abatement lower?

We use the following empirical specification to test the strategic delay hypothesis,

$$PollutionAbatement_{fct} = PollutionShare_{fct} + \chi_{ft} + \Phi_f + \Phi_{ct} + \epsilon_{fct} \#(3)$$

where $PollutionAbatement_{fct}$ is one of the four abatement measures detailed in the next paragraph, and the main independent variable of interest $PollutionShare_{fct}$ is the total pollution amount of firm f divided by the total pollution amount in county c in year t. χ_{ft} represents the firm-year control variables, including total assets, sales growth, leverage, cash flow volatility, and operating cash flow ratio. Φ_{ct} is county*year fixed effects, and Φ_f is firm fixed effects. We limit our sample to the nonattainment counties.

From the EPA's Pollution Prevention P2 database, we collect each plant's pollution abatement activities at the chemical level. We focus on two types of activities: "Good operating practices," which indicates improving maintenance or quality control; and "process modification," which refers to improving chemical reaction conditions or implementing better process controls. We count the number of these two abatement activities for each firm in every county in which the firm has at least one plant and construct the following four firm-county-year level dependent variables: 1) *ln(Reduction Operation Num)*, the natural logarithm of one plus the total number of "good operating practices" activities of a firm's plants in one county; 2) *ln(Reduction Process Num)*, the natural logarithm of one plus the total number of "process modification" activities of a firm's plants in one county; 3) *dummy(Reduction Operation)*, an indicator variable that equals one if a firm has at least one "good operating practices" activity in the county and zero otherwise; 4) *dummy(Reduction Process)*, an indicator variable that equals one if a firm has at least one "process modification" activity in the county and zero otherwise.

We use the EPA's Toxic Release Inventory (TRI) database to construct our pollution share measure. TRI data are self-reported, but the EPA conducts audits to secure its quality and enforces criminal and civil penalties if any misreporting is detected (Xu and Kim, 2022). The differences in the pollution estimations between facilities and EPA surveyors are negligible for most industries (Akey and Appel, 2021). We drop the records of chemicals that are not regulated by the Clean Air Act and construct *Pollution Share*, defined as the firm's pollution amount in a county-year divided by the total pollution amount in that county-year.

We present regression estimates of 20,414 observations in Table 14. For all pollution abatement activity measures, higher pollution levels are associated with more pollution abatement activity measures. These results suggest that large polluting plants do not strategically delay pollution abatement, but small polluting plants may strategically delay pollution abatement.

[Insert Table 14]

8. Conclusion

Differing views on the impact of environmental regulation on firm competitiveness can influence policy design and the stringency of regulations. This paper conducts an empirical analysis of the Clean Air Act's nonattainment status designation and shows that whether firms are financially constrained or not is a determinant of whether mandatory pollution abatement spending crowds out or stimulates corporate investment. Consistent with theoretical predictions, this paper documents that environmental regulation crowds out capital and R&D investment for financially constrained firms but stimulates more R&D investment and capital expenditure for financially unconstrained firms. In addition, unconstrained firms invest more in future pollution abatement. Financially constrained firms have stable current profit and lower future profit, while financially unconstrained firms have lower current profit but higher future profits.

This paper shows that firms' financial constraints play an important role in how environmental regulation affects corporate investment behavior. Therefore, policy discussions and proposals concerning environmental regulation should take this factor into account.

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Tables and Figures

Figure 1: Counties with nonattainment status in 2003 and 2004

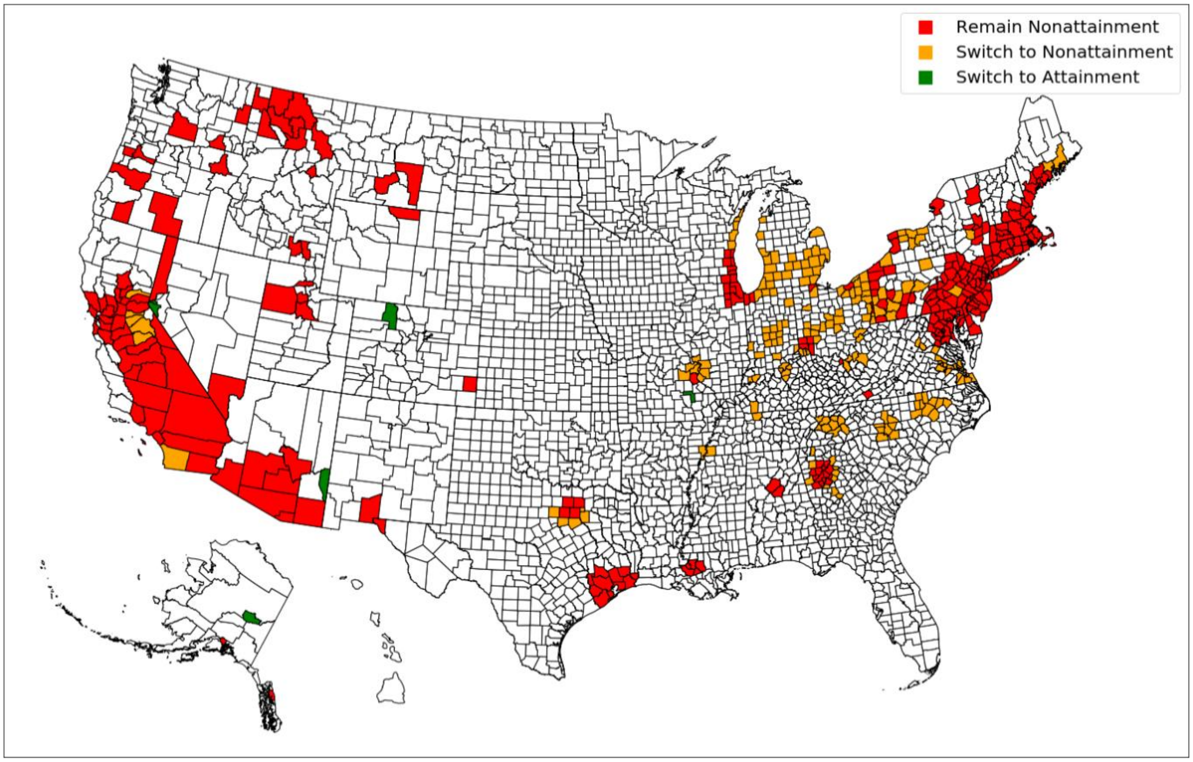

Table 1: Tabulating the predictions

Notes: The sign "+" indicates that we predict an increase in the variable after nonattainment status is designated (e.g., the mandatory pollution abatement regulation is implemented). The sign "-" indicates a decrease, and the sign "- -" indicates a decrease in greater magnitude than "-".

	Financial unconstrained firms (Hypothesis 1)	Financial constrained firms (Hypothesis 2)
Current pollution abatement effort	+	+
Future pollution abatement effort	+	–
Current investment (R&D and CAPEX)	+	–
Current profit	Smaller	Larger
Future profit	+	–
Firm value	–	– –

Table 2: Summary statistics

Dependent Variables	**Obs**	**Mean**	**Std**	**25%**	**Median**	**75%**
1 Factor CAR (-2, 2)	9,568	0.00	0.05	-0.02	0.00	0.02
1 Factor CAR (-5, 5)	9,568	0.00	0.07	-0.03	0.00	0.04
3 Factor CAR (-2, 2)	9,568	0.00	0.05	-0.02	0.00	0.02
3 Factor CAR (-5, 5)	9,568	0.00	0.07	-0.03	0.00	0.03
4 Factor CAR (-2, 2)	9,568	0.00	0.05	-0.02	0.00	0.02
4 Factor CAR (-5, 5)	9,568	0.00	0.07	-0.03	0.00	0.03
Capex	9,919	0.05	0.04	0.02	0.04	0.07
Clean Energy Investment	6,692	0.07	0.26	0.00	0.00	0.00
dummy(Close Plant)	10,015	0.08	0.28	0.00	0.00	0.00
Environmental Awareness	9,889	0.08	0.06	0.04	0.07	0.11
ln(Close Plant Num)	10,015	0.13	0.48	0.00	0.00	0.00
ln(Penalty Num)	10,015	0.24	0.52	0.00	0.00	0.00
ln(Total Penalty)	10,015	2.34	4.54	0.00	0.00	0.00
Market Share	10,000	0.02	0.05	0.00	0.00	0.02
Pollution Reduction	6,692	0.14	0.34	0.00	0.00	0.00
Profit Margin	10,014	0.30	0.28	0.20	0.29	0.38
R&D	9,925	0.02	0.03	0.00	0.01	0.02
ROA	10,005	0.04	0.13	0.02	0.05	0.08
Tobin's Q	9,901	3.44	3.88	1.72	2.47	3.77
Independent Variables	**Obs**	**Mean**	**Std**	**25%**	**Median**	**75%**
Regulated_Plant_Ratio	10,015	0.02	0.11	0.00	0.00	0.00
dummy(Constrained)	10,015	0.33	0.47	0.00	0.00	1.00
dummy(Unconstrained)	10,015	0.33	0.47	0.00	0.00	1.00
Control Variables	**Obs**	**Mean**	**Std**	**25%**	**Median**	**75%**
Cash Flow	10,015	0.08	0.24	0.06	0.09	0.12
Leverage	10,015	0.58	0.31	0.44	0.58	0.71
Sales Growth	10,015	0.11	2.02	-0.03	0.06	0.15
ln(Total Assets)	10,015	7.54	1.79	6.28	7.48	8.74
dummy(Lobbying)	10,015	0.16	0.36	0.00	0.00	0.00

Table 3: The effects of mandatory pollution abatement regulation

This table presents the results of the effects of mandatory pollution abatement regulations on firm value, investment, profitability, the pollution reduction index, and the clean energy investment index. The sample period is from 1994 to 2016. The dependent variables are *Tobin's Q, 1 Factor CAR (-2, 2), R&D, Capex, Profit Margin, ROA, Clean Energy Investment*, and *Pollution Reduction* in year t and are defined in Appendix Table A1 The independent variable, *Regulated_Plant_Ratio*, is the number of regulated plants located in nonattainment areas divided by the total number of plants. Year fixed effects, firm fixed effects, and firm-year controls, including *Cash Flow*, *Leverage*, *Sales Growth*, *ln(Total Assets)*, and *dummy(Lobbying)*, are included in all regressions. Robust t-statistics are clustered at the firm level and presented in parentheses. ***, ** and * denote 1%, 5% and 10% significance, respectively.

	(1) Tobin's Q	(2) 1 Factor CAR (-2, 2)	(3) R&D	(4) Capex	(5) Profit Margin	(6) ROA	(7) Clean Energy Investment	(8) Pollution Reduction
Regulated_Plant_Ratio	-0.6709***	-0.0299***	-0.0020	0.0011	-0.0246	0.0067	0.1722**	0.1343**
	(-2.93)	(-4.90)	(-1.30)	(0.28)	(-0.92)	(0.79)	(2.40)	(2.11)
Cash Flow	4.2561***	0.0178***	-0.0034	0.0397***	0.0933	0.4843***	-0.0529	0.0410
	(5.69)	(2.63)	(-0.86)	(4.18)	(1.42)	(9.77)	(-1.23)	(0.64)
Leverage	-7.1412***	0.0093	-0.0029	-0.0121*	0.0641	0.1197***	-0.0473	0.1473**
	(-9.27)	(1.43)	(-0.77)	(-1.81)	(1.15)	(4.94)	(-0.94)	(2.45)
Sales Growth	0.0163	-0.0005***	0.0000	-0.0005***	0.0253***	0.0007	-0.0005	-0.0067
	(1.56)	(-4.32)	(0.64)	(-8.21)	(60.35)	(1.23)	(-0.05)	(-0.42)
ln(Total Assets)	-0.6171***	-0.0019	-0.0032***	-0.0033*	0.0106*	0.0040	0.0254	-0.0132
	(-4.53)	(-1.28)	(-3.37)	(-1.94)	(1.71)	(1.46)	(1.47)	(-0.64)
dummy(Lobbying)	0.2810**	0.0036**	0.0006	0.0046***	0.0020	0.0043*	0.0118	-0.0091
	(2.36)	(2.03)	(0.87)	(2.69)	(0.39)	(1.96)	(0.72)	(-0.38)
Constant	11.8508***	0.0097	0.0446***	0.0780***	0.1719**	-0.1002***	-0.1083	0.1536
	(9.81)	(0.78)	(5.24)	(5.54)	(2.33)	(-3.75)	(-0.79)	(0.93)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Observations	9,901	9,579	9,925	9,919	10,014	10,005	6,692	6,692
R-squared	0.70	0.22	0.89	0.52	0.72	0.84	0.41	0.48

Table 4: The effects of mandatory pollution abatement regulation on pollution abatement investment

This table presents the results of the effects of mandatory pollution abatement regulation on pollution abatement investment. The sample period is from 1994 to 2016. The dependent variables are *Clean Energy Investment* and *Pollution Reduction* in year t and are defined in Appendix Table A1. The independent variable, *Regulated_Plant_Ratio*, is the number of regulated plants located in nonattainment areas divided by the total number of plants; *dummy(Constrained)* (*dummy(Unconstrained)*) is an indicator variable that equals one if the firm-year observation's financial constraint index falls in the top (bottom) one-third, and zero otherwise. Year fixed effects, firm fixed effects, and firm-year controls, including *Cash Flow*, *Leverage*, *Sales Growth*, *ln(Total Assets)*, and *dummy(Lobbying)*, are included in all regressions. Robust t-statistics are clustered at the firm level and presented in parentheses. ***, ** and * denote 1%, 5% and 10% significance, respectively.

	(1) Clean Energy Investment	(2) Pollution Reduction
dummy(Constrained) * Regulated_Plant_Ratio	-0.0375	-0.1098
	(-0.52)	(-1.41)
dummy(Constrained)	0.0044	-0.0198*
	(0.53)	(-1.81)
dummy(Unconstrained) * Regulated_Plant_Ratio	0.1037	0.0527
	(1.15)	(0.55)
dummy(Unconstrained)	-0.0124	-0.0043
	(-1.00)	(-0.32)
Regulated_Plant_Ratio	0.1669**	0.1638**
	(2.02)	(2.19)
Cash Flow	-0.0509	0.0355
	(-1.17)	(0.55)
Leverage	-0.0502	0.1485**
	(-1.01)	(2.48)
Sales Growth	-0.0006	-0.0063
	(-0.06)	(-0.40)
ln(Total Assets)	0.0252	-0.0149
	(1.45)	(-0.72)
dummy(Lobbying)	0.0122	-0.0089
	(0.74)	(-0.38)
Constant	-0.1036	0.1751
	(-0.75)	(1.07)
Year FE	Yes	Yes
Firm FE	Yes	Yes
Cluster	Firm	Firm
Observations	6,692	6,692
R-squared	0.41	0.49

Table 5: The effects of mandatory pollution abatement regulation on R&D investment and capital expenditure

This table presents the results of the effects of mandatory pollution abatement regulation on firm investment. The sample period is from 1994 to 2016. The dependent variables are *R&D* and *Capex* in year t and are defined in Appendix Table A1. The independent variable, *Regulated_Plant_Ratio*, is the number of regulated plants located in nonattainment areas divided by the total number of plants; *dummy(Constrained)* (*dummy(Unconstrained)*) is an indicator variable that equals one if the firm-year observation's financial constraint index falls in the top (bottom) one-third, and zero otherwise. Year fixed effects, firm fixed effects, and firm-year controls, including *Cash Flow*, *Leverage*, *Sales Growth*, *ln(Total Assets)*, and *dummy(Lobbying)*, are included in all regressions. Robust t-statistics are clustered at the firm level and presented in parentheses. ***, ** and * denote 1%, 5% and 10% significance, respectively.

	(1) R&D	(2) Capex
dummy(Constrained) * Regulated_Plant_Ratio	-0.0027**	-0.0092**
	(-1.97)	(-2.30)
dummy(Constrained)	0.0004	0.0012
	(1.17)	(1.13)
dummy(Unconstrained) * Regulated_Plant_Ratio	0.0036**	0.0141*
	(2.01)	(1.71)
dummy(Unconstrained)	0.0001	0.0002
	(0.30)	(0.14)
Regulated_Plant_Ratio	-0.0016	0.0017
	(-0.99)	(0.40)
Cash Flow	-0.0034	0.0398***
	(-0.87)	(4.20)
Leverage	-0.0029	-0.0122*
	(-0.78)	(-1.83)
Sales Growth	0.0000	-0.0005***
	(0.65)	(-8.16)
ln(Total Assets)	-0.0032***	-0.0033*
	(-3.37)	(-1.96)
dummy(Lobbying)	0.0006	0.0046***
	(0.87)	(2.71)
Constant	0.0445***	0.0778***
	(5.19)	(5.52)
Year FE	Yes	Yes
Firm FE	Yes	Yes
Cluster	Firm	Firm
Observations	9,925	9,919
R-squared	0.90	0.52

Table 6: The effects of mandatory pollution abatement regulation on profit margin and ROA

This table presents the results of the effects of mandatory pollution abatement regulation on firm profitability. The sample period is from 1994 to 2016. The dependent variables are *Profit Margin* and *ROA* in year t and are defined in Appendix Table A1. The independent variable, *Regulated_Plant_Ratio*, is the number of regulated plants located in nonattainment areas divided by the total number of plants; *dummy(Constrained)* (*dummy(Unconstrained)*) is an indicator variable that equals one if the firm-year observation's financial constraint index falls in the top (bottom) one-third, and zero otherwise. Year fixed effects, firm fixed effects, and firm-year controls, including *Cash Flow*, *Leverage*, *Sales Growth*, *ln(Total Assets)*, and *dummy(Lobbying)*, are included in all regressions. Robust t-statistics are clustered at the firm level and presented in parentheses. ***, ** and * denote 1%, 5% and 10% significance, respectively.

	(1) Profit Margin	(2) ROA
dummy(Constrained) * Regulated_Plant_Ratio	-0.0948	0.0028
	(-1.04)	(0.26)
dummy(Constrained)	-0.0024	-0.0051***
	(-0.95)	(-2.75)
dummy(Unconstrained) * Regulated_Plant_Ratio	-0.0573*	-0.0185**
	(-1.85)	(-1.98)
dummy(Unconstrained)	0.0041	0.0039**
	(1.44)	(2.16)
Regulated_Plant_Ratio	0.0213	0.0082
	(0.89)	(1.01)
Cash Flow	0.0939	0.4852***
	(1.42)	(9.84)
Leverage	0.0647	0.1206***
	(1.16)	(4.98)
Sales Growth	0.0254***	0.0008
	(61.12)	(1.26)
ln(Total Assets)	0.0104*	0.0037
	(1.69)	(1.37)
dummy(Lobbying)	0.0021	0.0042*
	(0.41)	(1.92)
Constant	0.1719**	-0.0987***
	(2.34)	(-3.70)
Year FE	Yes	Yes
Firm FE	Yes	Yes
Cluster	Firm	Firm
Observations	10,014	10,005
R-squared	0.72	0.84

Table 7: The effects of mandatory pollution abatement regulation on environmental awareness index

This table presents the results of the effects of mandatory pollution abatement regulation on the environmental awareness index. The sample period is from 1994 to 2016. The dependent variable is *Environmental Awareness* in year t and is defined in Appendix Table A1. The independent variable, *Regulated_Plant_Ratio*, is the number of regulated plants located in nonattainment areas divided by the total number of plants; *dummy(Constrained)* (*dummy(Unconstrained)*) is an indicator variable that equals one if the firm-year observation's financial constraint index falls in the top (bottom) one-third, and zero otherwise. Year fixed effects, firm fixed effects, and firm-year controls, including *Cash Flow*, *Leverage*, *Sales Growth*, *ln(Total Assets)*, and *dummy(Lobbying)*, are included in all regressions. Robust t-statistics are clustered at the firm level and presented in parentheses. ***, ** and * denote 1%, 5% and 10% significance, respectively.

	(1) Environmental Awareness
dummy(Constrained) * Regulated_Plant_Ratio	-0.0084
	(-0.89)
dummy(Constrained)	-0.0043***
	(-2.89)
dummy(Unconstrained) * Regulated_Plant_Ratio	0.0122
	(0.64)
dummy(Unconstrained)	0.0053***
	(3.41)
Regulated_Plant_Ratio	0.0141**
	(2.05)
Cash Flow	-0.0030
	(-0.68)
Leverage	-0.0039
	(-0.89)
Sales Growth	-0.0000
	(-0.88)
ln(Total Assets)	-0.0017
	(-1.00)
dummy(Lobbying)	-0.0004
	(-0.17)
Constant	0.0941***
	(7.56)
Year FE	Yes
Firm FE	Yes
Cluster	Firm
Observations	9,889
R-squared	0.70

Table 8: The effects of mandatory pollution abatement regulation on pollution abatement investment and environmental awareness index in three years

This table presents the results of the effects of mandatory pollution abatement regulation on pollution abatement investment and the environmental awareness index in three years. The sample period is from 1994 to 2016. The dependent variables are *Clean Energy Investment, Pollution Reduction,* and *Environmental Awareness* in year t + 3 and are defined in Appendix Table A1. The independent variable, *Regulated_Plant_Ratio*, is the number of regulated plants located in nonattainment areas divided by the total number of plants; *dummy(Constrained)* (*dummy(Unconstrained)*) is an indicator variable that equals one if the firm-year observation's financial constraint index falls in the top (bottom) one-third, and zero otherwise. Year fixed effects, firm fixed effects, and firm-year controls, including *Cash Flow*, *Leverage*, *Sales Growth*, *ln(Total Assets)*, and *dummy(Lobbying)*, are included in all regressions. Robust t-statistics are clustered at the firm level and presented in parentheses. ***, ** and * denote 1%, 5% and 10% significance, respectively.

	(1)	(2)	(3)
		In 3 Years	
	Clean Energy Investment	Pollution Reduction	Environmental Awareness
dummy(Constrained) * Regulated_Plant_Ratio	-0.0788**	-0.1246*	-0.0172***
	(-2.01)	(-1.87)	(-2.69)
dummy(Constrained)	0.0166**	-0.0017	0.0005
	(2.01)	(-0.15)	(0.44)
dummy(Unconstrained) * Regulated_Plant_Ratio	0.1629*	0.2374**	0.0296**
	(1.65)	(2.48)	(2.02)
dummy(Unconstrained)	-0.0110	-0.0117	0.0001
	(-1.05)	(-0.90)	(0.06)
Regulated_Plant_Ratio	0.0190	0.0388	0.0055
	(0.99)	(0.61)	(1.05)
Controls	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Cluster	Firm	Firm	Firm
Observations	6,538	6,553	7,369
R-squared	0.44	0.51	0.73

Table 9: The effects of mandatory pollution abatement regulation on profitability in three years

This table presents the results of the effects of mandatory pollution abatement regulation on firm profitability in three years. The sample period is from 1994 to 2016. The dependent variables are *Profit Margin* and *ROA* in year t + 3 and are defined in Appendix Table A1. The independent variable, *Regulated_Plant_Ratio*, is the number of regulated plants located in nonattainment areas divided by the total number of plants; *dummy(Constrained)* (*dummy(Unconstrained)*) is an indicator variable that equals one if the firm-year observation's financial constraint index falls in the top (bottom) one-third, and zero otherwise. Year fixed effects, firm fixed effects, and firm-year controls, including *Cash Flow*, *Leverage*, *Sales Growth*, *ln(Total Assets)*, and *dummy(Lobbying)*, are included in all regressions. Robust t-statistics are clustered at the firm level and presented in parentheses. ***, ** and * denote 1%, 5% and 10% significance, respectively.

	(1)	(2)
	In 3 Years	
	Profit Margin	ROA
dummy(Constrained) * Regulated_Plant_Ratio	-0.0255*	-0.0227*
	(-1.69)	(-1.73)
dummy(Constrained)	0.0024	0.0049
	(1.21)	(1.47)
dummy(Unconstrained) * Regulated_Plant_Ratio	0.0360*	0.0359**
	(1.86)	(2.39)
dummy(Unconstrained)	-0.0010	-0.0095
	(-0.49)	(-1.36)
Regulated_Plant_Ratio	-0.0496***	-0.0096
	(-2.75)	(-1.04)
Cash Flow	0.0541***	-0.0052
	(3.90)	(-0.13)
Leverage	0.0188	0.0349
	(1.58)	(0.90)
Sales Growth	-0.0039	0.0001
	(-0.99)	(0.10)
ln(Total Assets)	-0.0062	-0.0190***
	(-1.45)	(-3.03)
dummy(Lobbying)	0.0067*	0.0034
	(1.66)	(0.90)
Constant	0.3363***	0.1607***
	(10.03)	(3.72)
Year FE	Yes	Yes
Firm FE	Yes	Yes
Cluster	Firm	Firm
Observations	9,072	9,265
R-squared	0.95	0.41

Table 10: The effects of mandatory pollution abatement regulation on market share

This table presents the results of the effects of mandatory pollution abatement regulation on market share. The sample period is from 1994 to 2016. The dependent variable is Market Share from year t to t+3 and is defined in Appendix Table A1. The independent variable, *Regulated_Plant_Ratio*, is the number of regulated plants located in nonattainment areas divided by the total number of plants; *dummy(Constrained)* (*dummy(Unconstrained)*) is an indicator variable that equals one if the firm-year observation's financial constraint index falls in the top (bottom) one-third, and zero otherwise. Year fixed effects, firm fixed effects, and firm-year controls, including *Cash Flow*, *Leverage*, *Sales Growth*, *ln(Total Assets)*, and *dummy(Lobbying)*, are included in all regressions. Robust t-statistics are clustered at the firm level and presented in parentheses. ***, ** and * denote 1%, 5% and 10% significance, respectively.

	(1)	(2)	(3)	(4)
	Market Share			
	t	*t+1*	*t+2*	*t+3*
dummy(Constrained) * Regulated_Plant_Ratio	-0.0038	-0.0050	-0.0063	-0.0048
	(-0.6835)	(-1.2165)	(-1.4183)	(-1.2561)
dummy(Constrained)	-0.0018*	-0.0018*	-0.0017*	-0.0017*
	(-1.7778)	(-1.8425)	(-1.8679)	(-1.8326)
dummy(Unconstrained) * Regulated_Plant_Ratio	0.0077	0.0122*	0.0124	0.0147
	(1.5360)	(1.7015)	(1.6287)	(1.2312)
dummy(Unconstrained)	0.0002	-0.0002	-0.0003	-0.0005
	(0.3446)	(-0.3664)	(-0.6870)	(-0.8026)
Regulated_Plant_Ratio	0.0121*	0.0088	0.0076	0.0067
	(1.6945)	(1.3671)	(1.3577)	(1.1380)
Cash Flow	0.0002	-0.0001	-0.0007	-0.0002
	(0.0445)	(-0.0325)	(-0.2169)	(-0.0610)
Leverage	0.0001	-0.0004	-0.0010	-0.0004
	(0.0357)	(-0.1020)	(-0.3148)	(-0.1613)
Sales Growth	-0.0000***	-0.0000*	-0.0000	-0.0000**
	(-2.6372)	(-1.7540)	(-1.3820)	(-2.0722)
ln(Total Assets)	0.0103***	0.0098***	0.0086***	0.0076***
	(4.2124)	(4.1221)	(3.8582)	(3.7317)
dummy(Lobbying)	0.0008	0.0004	0.0004	0.0008
	(0.5100)	(0.2411)	(0.1631)	(0.4410)
Constant	-0.0574***	-0.0531***	-0.0432***	-0.0361**
	(-3.4103)	(-3.2159)	(-2.7764)	(-2.4627)
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm
Observations	10,000	9,807	9,575	9,322
R-squared	0.89	0.90	0.90	0.91

Table 11: The effects of mandatory pollution abatement regulation on Tobin's Q and cumulative abnormal return

This table presents the results of the effects of mandatory pollution abatement regulation on the Tobin's Q, 1-factor CAR for windows (-2, +2) and (-5, 5), 3-factor CAR for windows (-2, +2) and (-5, 5), and 4-factor CAR for windows (-2, +2) and (-5, 5). The sample period is from 1994 to 2016. The independent variable, *Regulated_Plant_Ratio*, is the number of regulated plants located in nonattainment areas divided by the total number of plants; *dummy(Constrained)* (*dummy(Unconstrained)*) is an indicator variable that equals one if the firm-year observation's financial constraint index falls in the top (bottom) one-third, and zero otherwise. Year fixed effects, firm fixed effects, and firm-year controls, including *Cash Flow*, *Leverage*, *Sales Growth*, *ln(Total Assets)*, and *dummy(Lobbying)*, are included in all regressions. Robust t-statistics are clustered at the firm level and presented in parentheses. ***, ** and * denote 1%, 5% and 10% significance, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Tobin's Q	1-Factor CAR (-2, 2)	1-Factor CAR (-5, 5)	3-Factor CAR (-2, 2)	3-Factor CAR (-5, 5)	4-Factor CAR (-2, 2)	4-Factor CAR (-5, 5)
dummy(Constrained) * Regulated_Plant_Ratio	-0.5543**	-0.0330***	-0.0488***	-0.0195*	-0.0293*	-0.0253**	-0.0290**
	(-2.04)	(-2.86)	(-2.93)	(-1.74)	(-1.74)	(-1.98)	(-1.97)
dummy(Constrained)	0.0465	0.0017	0.0024	0.0021	0.0039*	0.0018	0.0037*
	(0.88)	(1.15)	(1.16)	(1.51)	(1.82)	(1.29)	(1.72)
dummy(Unconstrained) * Regulated_Plant_Ratio	0.0230	-0.0205	0.0039	-0.0059	-0.0008	-0.0027	0.0014
	(0.05)	(-1.55)	(0.23)	(-0.40)	(-0.05)	(-0.25)	(0.10)
dummy(Unconstrained)	0.1669*	0.0023	0.0030	0.0026*	0.0032	0.0025	0.0023
	(1.84)	(1.53)	(1.35)	(1.68)	(1.39)	(1.62)	(1.00)
Regulated_Plant_Ratio	-0.4743**	-0.0136*	-0.0227*	-0.0192**	-0.0270**	-0.0221**	-0.0234**
	(-2.12)	(-1.74)	(-1.80)	(-2.32)	(-2.06)	(-2.37)	(-2.23)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Observations	9,901	9,568	9,568	9,568	9,568	9,568	9,568
R-squared	0.70	0.22	0.20	0.20	0.18	0.21	0.18

Table 12: The effects of mandatory pollution abatement regulation on firms' plant closure

This table presents the results of the effects of mandatory pollution abatement regulation on the firms' plant closures. The sample period is from 1994 to 2016. The dependent variables are *ln(Close Plant Num)* and *dummy(Close Plant)* in year t and are defined in Appendix Table A1. The independent variable, *Regulated_Plant_Ratio*, is the number of regulated plants located in nonattainment areas divided by the total number of plants; *dummy(Constrained)* (*dummy(Unconstrained)*) is an indicator variable that equals one if the firm-year observation's financial constraint index falls in the top (bottom) one-third, and zero otherwise. Year fixed effects, firm fixed effects, and firm-year controls including *Cash Flow*, *Leverage*, *Sales Growth*, *ln(Total Assets)*, and *dummy(Lobbying)*, are included in all regressions. Robust t-statistics are clustered at the firm level and presented in parentheses. ***, ** and * denote 1%, 5% and 10% significance, respectively.

	(1) ln(Close Plant Num)	(2) dummy(Close Plant)
dummy(Constrained) * Regulated_Plant_Ratio	0.0882	0.0463
	(1.46)	(0.93)
dummy(Constrained)	0.0128	-0.0002
	(1.30)	(-0.04)
dummy(Unconstrained) * Regulated_Plant_Ratio	0.0143	-0.0020
	(0.26)	(-0.05)
dummy(Unconstrained)	-0.0003	0.0010
	(-0.03)	(0.15)
Regulated_Plant_Ratio	-0.0251	-0.0051
	(-0.39)	(-0.12)
Cash Flow	-0.0695*	-0.0269
	(-1.77)	(-1.20)
Leverage	-0.0606	-0.0221
	(-1.61)	(-1.02)
Sales Growth	-0.0002	-0.0000
	(-0.52)	(-0.05)
ln(Total Assets)	0.0224*	0.0046
	(1.94)	(0.78)
dummy(Lobbying)	-0.0266	-0.0162*
	(-1.27)	(-1.80)
Constant	-0.0025	0.0658
	(-0.03)	(1.41)
Year FE	Yes	Yes
Firm FE	Yes	Yes
Cluster	Firm	Firm
Observations	10,015	10,015
R-squared	0.66	0.63

Table 13: The effects of mandatory pollution abatement regulation on penalty

This table presents the results of the effects of mandatory pollution abatement regulation on penalties. The sample period is from 1994 to 2016. The dependent variables are *ln(Total Penalty)* and *ln(Penalty Num)* in year t and are defined in Appendix Table A1. The independent variable, *Regulated_Plant_Ratio*, is the number of regulated plants located in nonattainment areas divided by the total number of plants; *dummy(Constrained)* (*dummy(Unconstrained)*) is an indicator variable that equals one if the firm-year observation's financial constraint index falls in the top (bottom) one-third, and zero otherwise. Year fixed effects, firm fixed effects, and firm-year controls, including *Cash Flow*, *Leverage*, *Sales Growth*, *ln(Total Assets)*, and *dummy(Lobbying)*, are included in all regressions. Robust t-statistics are clustered at the firm level and presented in parentheses. ***, ** and * denote 1%, 5% and 10% significance, respectively.

	(1) ln(Total Penalty)	(2) ln(Penalty Num)
dummy(Constrained) * Regulated_Plant_Ratio	0.8649	0.0686
	(1.21)	(0.79)
dummy(Constrained)	0.0631	0.0127
	(0.60)	(1.13)
dummy(Unconstrained) * Regulated_Plant_Ratio	1.5568	0.0037
	(1.51)	(0.04)
dummy(Unconstrained)	0.0803	-0.0019
	(0.73)	(-0.17)
Regulated_Plant_Ratio	-1.1407*	-0.1401**
	(-1.78)	(-2.22)
Cash Flow	0.2951	0.0235
	(0.70)	(0.60)
Leverage	0.1136	0.0071
	(0.27)	(0.18)
Sales Growth	-0.0039	-0.0003
	(-0.73)	(-0.72)
ln(Total Assets)	0.1293	0.0130
	(1.08)	(1.07)
dummy(Lobbying)	-0.0557	0.0003
	(-0.33)	(0.02)
Constant	1.2450	0.1347
	(1.27)	(1.47)
Year FE	Yes	Yes
Firm FE	Yes	Yes
Cluster	Firm	Firm
Observations	10,015	10,015
R-squared	0.48	0.59

Table 14: The effects of regulation on firm-county-level pollution abatement investment

This table presents the results of the effects of mandatory pollution abatement regulation on firm-county-level pollution abatement investment. The sample period is from 1994 to 2016. The dependent variables are *ln(Reduction Operation Num)*, *ln(Reduction Process Num)*, *dummy(Reduction Operation)*, and *dummy(Reduction Process)* in year t and are defined in Appendix Table A1. The independent variable, *Pollution Share*, is calculated as the firm's pollution amount in one county divided by the total pollution amount in that county in year t. County * Year fixed effects, firm fixed effects, and firm-year controls, including *Cash Flow*, *Leverage*, *Sales Growth*, *ln(Total Assets)*, and *dummy(Lobbying)*, are included in all regressions. Robust t-statistics are clustered at the firm level and presented in parentheses. ***, ** and * denote 1%, 5% and 10% significance, respectively.

	(1)	(2)	(3)	(4)
	ln(Reduction Operation Num)	ln(Reduction Process Num)	dummy(Reduction Operation)	dummy(Reduction Process)
Pollution Share	0.1243***	0.1349***	0.0642***	0.0772***
	(4.06)	(3.84)	(3.58)	(3.25)
Cash Flow	-0.0879	-0.0091	-0.0248	-0.0233
	(-1.31)	(-0.13)	(-0.50)	(-0.46)
Leverage	0.0172	0.0369	0.0358	0.0465
	(0.31)	(0.71)	(0.81)	(1.06)
Sales Growth	-0.0065	-0.0010	-0.0120	-0.0017
	(-0.29)	(-0.05)	(-0.83)	(-0.10)
ln(Total Assets)	0.0311*	0.0075	0.0310***	0.0108
	(1.77)	(0.47)	(2.66)	(0.98)
dummy(Lobbying)	-0.0117	-0.0081	-0.0072	0.0014
	(-0.76)	(-0.59)	(-0.63)	(0.13)
Constant	-0.1506	-0.0074	-0.1895*	-0.0477
	(-0.97)	(-0.05)	(-1.76)	(-0.46)
County * Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Cluster	Firm	Firm	Firm	Firm
Observations	20,414	20,414	20,414	20,414
R-squared	0.46	0.39	0.42	0.37

Appendix Table A1: Variable Definition

Variable Name	Definition	Source
Firm-year level variable		
Regulated_Plant_Ratio	The number of regulated plants divided by the total number of plants owned by a firm in year t. A plant is regarded as regulated if the plants are located in nonattainment counties and are included in the following programs: Title V Permit, State Implementation Plant (SIP) Source, SIP Source under federal jurisdiction, Prevention of Significant Deterioration (PSD) permit, New Source Review (NSR) permit, or New Source Performance Standards (NSPS) permit.	*EPA, CFR, NETS*
Cash Flow	Cash flow is total earnings before extraordinary items (IBC) plus equity's share of depreciation (DP). Cash flow volatility is the variance of the past five years' cash flow/total assets (AT) ratio.	*Compustat*
Capex	Capital expenditure divided by total book assets (AT).	*Compustat*
Clean Energy Investment	A dummy variable that equals one if a firm has taken significant measures to reduce its impact on climate change and air pollution through use of renewable energy and clean fuels or through energy efficiency and equals zero otherwise.	*MSCI ESG*
Cumulative abnormal return (CAR)	5-day CAR during the window (-2, +2), where day 0 is the publishing date of the nonattainment status of each county. We define abnormal returns by using the difference between actual and projected returns, where we estimate projected returns as follows: (1) regress the daily stock return on the returns on the CRSP value-weighted market portfolio over the 200-day period from the 210th trading day through the 11th trading day before the publishing date of the nonattainment status and collect the estimated coefficients and (2) use the estimated coefficients to compute the projected returns during the 5-day window (-2, +2) or 11-day window (-5, +5). The 3-factor and 4-factor models' factors data are from the website of Kenneth R. French.	*CRSP, Kenneth R. French website*
dummy(Close Plant)	A dummy that equals one if the firm closes at least one plant in year t, and equals zero otherwise.	*NETS*
dummy(Constrained)	A dummy variable that equals one if the firm-year observation's financial constraint index falls in the top one-third and equals zero otherwise. Observations with a financial constraint index in the middle one-third are excluded and values are indicated as missing. The financial constraint index is constructed following Bodnaruk, Loughran and McDonald (2015).	*SEC EDGAR*
dummy(Unconstrained)	A dummy variable that equals one if the firm-year observation's financial constraint index falls in the bottom one-third, and equals zero otherwise. Observations with a financial constraint index in the middle one-third are excluded and values are indicated as missing. The financial constraint index is constructed following Bodnaruk, Loughran and McDonald (2015).	*SEC EDGAR*
dummy(Lobbying)	A dummy that equals one if the firm lobbies on environmental policies in year t and equals zero otherwise.	*OpenSecrets*
Environmental Awareness	The combined frequency of words with the stem "environ-," such as "environment" and "environmental," and the words with the stem "pollut-," such as "polluting" and "pollutant," in a firm-year's 10-K filing.	*SEC EDGAR*
ln(Close Plant Num)	Natural logarithm of one plus the number of plants closed by the firm in year t.	*NETS*

ln(Penalty Num)	Natural logarithm of one plus the number of federal and state enforcement cases with a penalty record.	*EPA ECHO*
ln(Total Assets)	Natural logarithm of total assets (AT).	*Compustat*
ln(Total Penalty)	Natural logarithm of one plus the dollar amount of penalties. The penalties include both federal and state/local penalties. Federal penalties are the total amount assessed or agreed to for federal enforcement actions. State/local penalties are the dollar penalty amount paid to a state or local enforcement authority.	*EPA ECHO*
Leverage	Total liabilities (LT) divided by total book assets (AT) in year t-1.	*Compustat*
Market Share	A firm's sales divided by the same two-digit SIC industry's total sales in year t.	*Compustat*
Pollution Reduction	A dummy variable that equals one if a firm has notably strong emission reduction and toxic-use reduction programs and equals zero otherwise.	*MSCI ESG*
Profit Margin	(Revenue (REVT) - Cost of Goods Sold (COGS)) divided by REVT.	*Compustat*
R&D	Research and development expense (XRD) divided by total book assets (AT).	*Compustat*
ROA	Net income (NI) divided by total book assets (AT).	*Compustat*
Sales Growth	The sales (SALE) in year t minus the sales in year t - 1 then divided by the sales in year t - 1.	*Compustat*
Tobin's Q	Market value of assets (MKVALT + LT) divided by book value of assets (BKVLPS + LT).	*Compustat*
Firm-county-year level variable		
dummy(Reduction Operation)	A dummy variable that equals one if a firm has good operating practices in the county in year t, and equals zero otherwise.	*EPA TRI P2*
dummy(Reduction Process)	A dummy variable that equals one if a firm has process improvements in the county in year t, and equals zero otherwise.	*EPA TRI P2*
ln(Reduction Operation Num)	Natural logarithm of one plus the total number of good operating practices of a firm's plants in one county. According to P2 guidelines, good operating practices include activities such as improving maintenance or quality control.	*EPA TRI P2*
ln(Reduction Process Num)	Natural logarithm of one plus the total number of process improvements of a firm's plants in one county. According to P2 guidelines, process improvements include activities such as improving chemical reaction conditions or implementing better process controls.	*EPA TRI P2*
Pollution Share	Calculated as the firm's pollution amount in one county divided by the total pollution amount in that county in year t.	*EPA TRI*

Online Appendix

Theoretical Analysis

a. Model Setup

Consider a firm which sales is given by

$$S_t = S_t(p_t, q_t) = S_t(p_t(R_{t-1}), q_t(\theta_t))$$

where $p_t(R_{t-1})$ is the price that depends on the firm investment given before period 0, $R_{t-1} = \bar{R}_{-1}$, and $q_t(\theta_t)$ is the quantity of goods sold that is affected by the firm's pollution level in period 0, θ_0. We assume that consumers value the firm's pollution abatement efforts and investment, which increases the sales by allowing the firm to sell at a higher quantity or a higher price, or $\partial p_t/\partial R_{t-1} > 0$ and $\partial q_t/\partial \theta_t < 0$. We simplify the notation and denote

$$S_t = S_t(\theta_t, R_{t-1})$$

Motivated by the empirical findings in Servaes and Tamayo (2013), who show that customer awareness is an essential factor of firm sales and sales are positively affected by corporate social responsibility, we assume

$$\frac{\partial S_t}{\partial \theta_t} < 0$$

which means that more pollution will reduce sales, and we assume that investment has a positive effect on the next period's sales:

$$\frac{\partial S_t}{\partial R_{t-1}} > 0$$

Therefore, the firm's profits in period 0 can be represented as

$$\pi_0 = S_0(\theta_0, \bar{R}_{-1}) - C_0(E_0, R_0) \, \#(1)$$

where π_0 is the firm's profits in period 0 and S_0 is the firm's sales in period 0, which depends on two variables, the pollution level in period 0, θ_0, and the investment given before period 0, $\bar{R}_{-1}$. C_0 is the firm's cost in period 0, which consists of two components: E_0, the pollution abatement expense and R_0, investment in period 0 that affects the firm's sales in period 1, S_1. Similarly, in period 1, we have

$$\pi_1 = S_1(\theta_1, R_0) - C_1(E_1, R_1)\#(2)$$

where π_1 is the firm's profits in period 1, S_1 is the firm's sales in period 1, θ_1 is the firm's pollution level in period 1, and R_0 is the investment given in period 0. C_1 is the firm's cost in period 1, E_1 is the pollution abatement expense in period 1, and R_1 is the firm's investment in period 1. The key variable linking the two periods is R_0, the input and cost in period 0 which creates more sales in period 1. In addition, the pollution level θ_t is negatively related to pollution abatement spending E_t, which means $\frac{\partial \theta_t}{\partial E_t} < 0$. Furthermore, costs C_t increase with R_t and E_t, i.e., $\frac{\partial C_t}{\partial E_t} > 0$ and $\frac{\partial C_t}{\partial R_t} > 0$. To derive explicit solutions, we assume the following functional forms:

$$\theta_0 = \frac{1}{E_0}$$

$$\theta_1 = \frac{1}{E_0 + E_1}$$

$$C_t = R_t^2 + E_t^2$$

$$S_t = \bar{S} + \frac{R_{t-1}}{\theta_t}$$

where $\bar{S}$ is the constant part of total sales that is independent of the influence of investment and pollution. Therefore, the sum of discounted profit (or market value) of the firm is given by

$$V = \pi_0 + \frac{\pi_1}{1 + r_1}$$
$$= \bar{S} + \bar{R}_{-1}E_0 - E_0^2 - R_0^2 + \frac{1}{1+r}(\bar{S} + R_0(E_0 + E_1) - E_1^2 - R_1^2)\ \#(3)$$

where r is the interest rate.

b. Maximization of Firm Value Under No Regulation

We first analyze the case where the firm maximizes the present value of the profits. The set of first-order conditions (FOCs) for the maximization of Equation (3) is given as follows:

$$\frac{\partial V}{\partial E_0} = \bar{R}_{-1} - 2E_0 + \frac{R_0}{1+r} = 0 \Leftrightarrow E_0 = \frac{R_0}{2(1+r)} + \frac{\bar{R}_{-1}}{2} \#(4)$$

$$\frac{\partial V}{\partial E_1} = \frac{R_0 - 2E_1}{1+r} = 0 \Leftrightarrow E_1 = \frac{R_0}{2} \#(5)$$

$$\frac{\partial V}{\partial R_0} = -2R_0 + \frac{E_0 + E_1}{1+r} = 0 \Leftrightarrow R_0 = \frac{E_0 + E_1}{2(1+r)} \#(6)$$

$$\frac{\partial V}{\partial R_1} = -2R_1 = 0 \#(7)$$

Equation (7) implies that the firm sets $R_1^* = 0$. This model only has two periods, which means the firm does not need to consider its sales thereafter, so choosing $R_1^* = 0$ minimizes its cost in period 1 and maximizes profit. Solving the first-order conditions, we have

$$E_0^* = \frac{(4r^2 + 7r + 3)}{2(4r^2 + 7r + 2)} \bar{R}_{-1}$$

$$E_1^* = \frac{1+r}{2(4r^2 + 7r + 2)} \bar{R}_{-1}$$

$$R_0^* = \frac{1+r}{4r^2 + 7r + 2} \bar{R}_{-1}$$

The investments that maximize the value of the firm or its present value of profits are $(E_0^*, E_1^*, R_0^*, R_1^*)$. It is clear that the optimal spending on E_0^*, E_1^* and R_0^* decreases with the interest rate. For the remainder of the analysis, we let $r = 0$. Therefore, we have as the unconstrained solutions

$$E_0^* = \frac{3}{4} \bar{R}_{-1}$$

$$E_1^* = \frac{1}{4} \bar{R}_{-1}$$

$$R_0^* = \frac{1}{2} \bar{R}_{-1}$$

The corresponding pollution levels are $\theta_0^* = \frac{4}{3\bar{R}_{-1}}$ and $\theta_1^* = \frac{1}{\bar{R}_{-1}}$, respectively. The profit in period 0 is

$$\pi_0^* = \bar{S} - \frac{1}{16}\bar{R}_{-1}^2$$

The profit in period 1 is

$$\pi_1^* = \bar{S} + \frac{7}{16}\bar{R}_{-1}^2$$

The value of the firm (for $r = 0$) is

$$V^* = \pi_0^* + \pi_1^* = 2\bar{S} + \frac{3}{8}\bar{R}_{-1}^2$$

One implication of this model is that, even without a compulsory pollution abatement requirement, firms would voluntarily make such an effort for profit maximization, reflected by $E_0^* > 0$ and $E_1^* > 0$.

c. Maximization of Firm Value Under Mandatory Pollution Abatement

Now we consider the situation where the regulator imposes a mandatory pollution abatement requirement on the firm. For each allowed maximum level of pollution of $\bar{\theta}_0$, there exists a corresponding $\bar{E}_0$. For simplicity, we assume that the government directly requires the firm to invest at least $\bar{E}_0$ on pollution-abatement equipment in period 0. The firm chooses (R_0, E_0, E_1) to maximize the firm value $V = \pi_0 + \pi_1$ subject to the constraint $E_0 \geq \bar{E}_0$. There are two cases. If $E_0^* \geq \bar{E}_0$, then regulation does not change the optimal behavior of the firm. Regulation is not binding. But if $E_0^* < \bar{E}_0$ and regulation is binding, then it is optimal for the firm to choose $E_0 = \bar{E}_0$, i.e., the minimum deviation from the unconstrained optimum. So the firm chooses R_0 and E_1 to maximize the firm value:

$$V^{reg} = \pi_0 + \pi_1 = \bar{S} + \bar{R}_{-1}E_0 - E_0^2 - R_0^2 + \bar{S} + R_0(E_0 + E_1) - E_1^2 - R_1^2$$

$$= 2\bar{S} + \bar{R}_{-1}\bar{E}_0 - \bar{E}_0^2 - R_0^2 + R_0(\bar{E}_0 + E_1) - E_1^2 \ \#(8)$$

The FOCs are

$$\frac{\partial V^{reg}}{\partial E_1} = R_0 - 2E_1 = 0 \Leftrightarrow E_1 = \frac{R_0}{2} \ \#(9)$$

$$\frac{\partial V^{reg}}{\partial R_0} = -2R_0 + E_1 + \bar{E}_0 = 0 \Leftrightarrow R_0 = \frac{\bar{E}_0 + E_1}{2} \ \#(10)$$

The solution to the equation system (9) and (10) gives the value-maximizing pollution abatement effort and investment under regulation and is as follows,

$$E_1^{reg} = \frac{1}{3}\bar{E}_0 > E_1^*$$

$$R_0^{reg} = \frac{2}{3}\bar{E}_0 > R_0^*$$

Interestingly, with the mandatory pollution abatement requirement, both E_1 and R_0 are larger compared to the situation without regulation. Note that we are in case $E_0^* < \bar{E}_0$. Since $E_0^* = \frac{3}{4}\bar{R}_{-1}$, therefore, $E_1^{reg} = \frac{1}{3}\bar{E}_0 > \frac{1}{3} \times \frac{3}{4}\bar{R}_{-1} = \frac{1}{4}\bar{R}_{-1}$. Similarly, $R_0^{reg} = \frac{2}{3}\bar{E}_0 > \frac{2}{3} \times \frac{3}{4}\bar{R}_{-1} = \frac{1}{2}\bar{R}_{-1} = R_0^*$. E_1 increases by $\frac{1}{3}\bar{E}_0 - \frac{1}{4}\bar{R}_{-1}$ and R_0 increases by $\frac{2}{3}\bar{E}_0 - \frac{1}{2}\bar{R}_{-1}$.

The rationale behind the increasing R_0 is as follows. Regulation implies more E_0 which increases the marginal benefit of investment, R_0, on sales in period 1. Note, a higher E_0 also reduces pollution in period 1 (i.e., θ_1 goes down) which leads to higher sales in period 1, ceteris paribus. While the marginal cost of investment is the same as under no regulation, the marginal benefit increases and, therefore, the firm invests more. Formally, Equation (10) shows that R_0 increases with E_0.

Although not immediately obvious, the reason why the firm voluntarily spends more on pollution abatement in period 1 (E_1) is also intuitive. A higher E_0 leads to a higher R_0, which increases the marginal benefit of E_1 on sales in period 1. Since the marginal cost of E_1 is the same with or without regulation, but the marginal benefit increases, the firm invests more in E_1. See Equation (9). The profit in period 0 is

$$\pi_0^{reg} = \bar{S} + \bar{R}_{-1}\bar{E}_0 - \frac{13}{9}\bar{E}_0^2 < \bar{S} - \frac{1}{16}\bar{R}_{-1}^2 = \pi_0^*$$

and it is smaller than without regulation. The profit in period 1 is

$$\pi_1^{reg} = \bar{S} + \frac{7}{9}\bar{E}_0^2 > \bar{S} + \frac{7}{16}\bar{R}_{-1}^2 = \pi_1^*$$

because $\bar{E}_0 > E_0^* = \frac{3}{4}\bar{R}_{-1}$. The value of the firm under regulation is

$$V^{reg} = 2\bar{S} + \bar{R}_{-1}\bar{E}_0 - \frac{2}{3}\bar{E}_0^2 < 2\bar{S} + \frac{3}{8}\bar{R}_{-1}^2 = V^*$$

The firm value drops under mandatory the pollution abatement requirement. This is intuitive since V^* is the unconstrained optimum. Any $E_0 \neq E_0^*$ reduces market value. We summarize our findings as a proposition.

Proposition 1: *A mandatory extra pollution abatement effort leads to (i) more investment in period 0; (ii) less profit in period 0; (iii) more voluntary pollution abatement spending in period 1; (iv) more profit in period 1; and (v) lower value of the firm.*

d. Mandatory Pollution Abatement and Financial Constraint

We assume that the maximum amount of spending the firm can finance in period 0 and 1 is K_0 and K_1, respectively. To facilitate comparison, we assume the firm can finance its first best investment under no regulation, i.e., $K_0 = R_0^* + E_0^* = \frac{5}{4}\bar{R}_{-1}$ and $K_1 = E_1^* = \frac{1}{4}\bar{R}_{-1}$.[17] If $\bar{E}_0 > E_0^*$, then the firm has to reduce its investment in period 0 at least by the amount $\Delta = \bar{E}_0 - E_0^*$. So the value of the firm is

$$V^{fincon} = \pi_0 + \pi_1 = 2\bar{S} + \bar{R}_{-1}\bar{E}_0 - \bar{E}_0^2 - R_0^2 + R_0(\bar{E}_0 + E_1) - E_1^2 \ \#(8')$$

as in Equation (8) but with the additional constraint that

$$R_0 + \bar{E}_0 \leq \frac{5}{4}\bar{R}_{-1}$$

$$E_1 \leq \frac{1}{4}\bar{R}_{-1}$$

Note, a financially unconstrained firm chooses $R_0^{reg} = \frac{2}{3}\bar{E}_0$. Since $\bar{E}_0 > E_0^* = \frac{3}{4}\bar{R}_{-1}$,

$$R_0^{reg} + \bar{E}_0 > \frac{5}{4}\bar{R}_{-1}$$

It is optimal for a financially constrained firm to choose the smallest deviation from R_0^{reg}, i.e.

$$R_0^{fincon} = R_0^{reg} - \Delta = \frac{2}{3}\bar{E}_0 - \Delta = \frac{2}{3}\bar{E}_0 - (\bar{E}_0 - E_0^*) = E_0^* - \frac{1}{3}\bar{E}_0 = \frac{3}{4}\bar{R}_{-1} - \frac{1}{3}\bar{E}_0.$$

[17] The qualitative results in this section hold for any K_0, K_1>0.

Under binding regulation ($\bar{E}_0 > E_0^* = 3/4$), we have the following comparative results of regulation and financial constraint for investment

$$R_0^{fincon} < \frac{1}{2} = R_0^*.$$

From the FOC of Equation (3), $dV^{fincon}/dE_1 = 0$, the optimal pollution abatement spending in period 1 is

$$E_1^{fincon} = \frac{1}{2} R_0^{fincon}.$$

Since $R_0^{fincon} < 1/2$, we have

$$E_1^{fincon} < \frac{1}{4} E_1^*.$$

The profit of the financially constrained firm in period 0 is

$$\pi_0^{fincon} = \bar{S} + \bar{E}_0 - \bar{E}_0^2 - (\frac{3}{4} - \frac{1}{3}\bar{E}_0)^2$$

Note, $5/4 = K_0 \geq \bar{E}_0 > E_0^* = 3/4$. Depending on $\bar{E}_0$, the profit in period 0 can be either larger or smaller than π_0^*=$\bar{S} - 1/16$. Comparing the formulas of π_0^{fincon} and π_0^* and solving out the quadratic equation of $\bar{E}_0$, we obtain the conditions:

$$\pi_0^{fincon} > \pi_0^* \text{ , if } 0.6 < \bar{E}_0 < 0.75$$

$$\pi_0^{fincon} < \pi_0^*\text{, if } \bar{E}_0 > 0.75 \text{ or } \bar{E}_0 < 0.6$$

However, since regulation is binding ($\bar{E}_0 > E_0^* = 0.75$), the model predicts that

$$\pi_0^{fincon} < \pi_0^*.$$

Note, $\pi_0^{fincon} > \pi_0^{reg}$ since the financially constrained firm invests less in period 0 than a financially unconstrained firm while both firms choose $E_0 = \bar{E}_0$.

The profit of the financially constrained firm in period 1 is

$$\pi_1^{fincon} = \bar{S} + (\frac{3}{4} - \frac{1}{3}\bar{E}_0)\left(\bar{E}_0 + \frac{3}{8} - \frac{1}{6}\bar{E}_0\right) - \left(\frac{3}{8} - \frac{1}{6}\bar{E}_0\right)^2$$

Since $\bar{E}_0 > E_0^* = \frac{3}{4}$, we have

$$\pi_1^{fincon} < \pi_1^*.$$

For the value of the firm, we have

$$V^{fincon} < V^{reg}.$$

The value of the firm is $V^{fincon} < V^{reg}$, since V^{reg} is the financially unconstrained maximum given regulation. We summarize these results as the second proposition.

Proposition 2: *When the firm is financially constrained, a mandatory extra pollution abatement effort leads to (i) less investment in period 0; (ii) less profit in period 0; (iii) less pollution abatement effort in period 1; (iv) less profit in period 1; and (v) lower value of the firm.*

The implications of mandatory pollution abatement for current profit and market value are the same for both types of firms. Profits in period 0 as well as market value decline. But our model also makes a prediction about the magnitude. From the above analysis, we have the following results.

Corollary 1: *When there is mandatory extra pollution abatement spending, profits in period 0 for financially constrained firms drop less than for unconstrained firms.*

Corollary 2: *When there is mandatory extra pollution abatement spending, the market value of financially constrained firms drops more than unconstrained firms.*

The following table summarizes the set of testable hypotheses.

	Variable	Unconstrained Firms (Proposition 1)	Constrained Firms (Proposition 2)
Pollution abatement effort in period 0	E_0	$+$	$+$
Pollution abatement effort in period 1	E_1	$+$	$-$
Investment in period 0	R_0	$+$	$-$
Profit in period 0	π_0	$--$	$-$
Profit in period 1	π_1	$+$	$-$
Firm value	V	$-$	$--$