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Adoption of Pollution Prevention Techniques: The Role of Management Systems and Regulatory Pressures

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Abstract This paper investigates the extent to which firm level technological change that reduces unregulated emissions is driven by regulatory pressures, and firms' technological and organizational capabilities. Using a treatment effects model with panel data for a sample of S&P 500 firms over the period 1994–1996, we find that organizational change in the form of Total Quality Environmental Management leads firms to adopt pollution prevention practices, after controlling for the effects of various regulatory pressures and firm-specific characteristics. We find that the threat of anticipated regulations and the presence of 'complementary assets' is important for creating the incentives and an internal capacity to undertake incremental adoption of pollution prevention techniques.

Keywords Environmental management · Toxic releases · Total Quality Management

JEL Classification O32 · O38 · Q2

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1 Introduction

Command and control environmental regulations in the US have typically sought to control pollution after it has been generated. The steeply rising costs of these regulations (these costs increased by more than 50% between 1990–2000)[1] and their negative impact on the productivity of regulated firms (see survey in Gray and Shadbegian 1995) have shifted the attention of environmental regulators and firms towards flexible environmental strategies that target the reduction of pollution at source. The US National Pollution Prevention Act of 1990 emphasizes pollution prevention rather than end-of-pipe pollution control as the preferred method of pollution reduction. However, it does not mandate adoption of pollution prevention technologies. Instead, the USEPA has sought to induce voluntary adoption of such technologies through the promotion of environmental management systems that induce firms to take a holistic view of pollution control and reduce waste generation at source (Crow 2000; USEPA 1997, 1998; USGAO 1994). This paper investigates the influence of a firm's environmental management system and other internal and external factors on the extent to which the firm adopts pollution prevention technologies.

An environmental management system typically embodies the concept of Total Quality Management which emphasizes prevention over detection, continuous progress in product quality by minimizing defects, and quality improvement across all aspects of the industrial process. Application of these principles to environmental management, referred to as Total Quality Environmental Management (TQEM),[2] can lead firms to apply the same systems perspective to prevent pollution problems. Under TQEM, pollution is viewed as a quality defect to be continuously reduced through the development of products and processes that minimize waste generation at source. Case studies of leading firms, such as Kodak, Polaroid, Xerox and L'Oreal show how TQEM principles and tools led them to implement techniques that reduce waste and improve the quality and environmental friendliness of their processes and products (Ploch and Wlodarczyk 2000; Breeden et al. 1994; Wever and Vorhauer 1993; McGee and Bhushan 1993; Nash et al. 1992). An in-depth study of firms led the President's Commission on Environmental Quality (1993) to conclude that quality management principles and pollution prevention are complementary concepts; a finding reinforced by subsequent surveys of firms which show that firms that adopted pollution prevention practices were more likely to be those practicing TQEM.[3] However, there has been no systematic empirical determination of a link between TQEM and the adoption of new pollution prevention technologies. Moreover, while TQEM provides a framework that encourages pollution prevention, it does not guarantee that firms will choose to do so. Firms may instead resort to other ways to control pollution such as recycling or reusing waste. Alternatively, firms may adopt TQEM simply to

[1] http://yosemite1.epa.gov/ee/epalib/ord1.nsf/77e34926d19d5664852565a500501ed6/335eadf820105910852565d00067efc6!OpenDocument.

[2] The Global Environmental Management Initiative (GEMI) is recognized as the creator of TQEM which embodies four key principles: customer identification, continuous improvement, doing the job right first time, and a systems approach (http://www.bsdglobal.com/tools/systems_TQEM.asp).

[3] A survey of US manufacturing firms in 1995 by Florida (1996) found that 60% of respondents considered pollution prevention to be very important to corporate performance and two-thirds of them had also adopted TQEM. Of the 40% firms that considered pollution prevention to be only moderately important, only 25% had adopted TQEM. A survey of US manufacturing plants in 1998 found that among the pollution prevention adopters, the percentage of firms practicing TQM was twice that for other plants (Florida and Davison 2001). A survey of Japanese manufacturing firms found that plants adopting a green design were more likely to be involved in TQM than other plants (Florida and Jenkins 1996).

convey a visible signal of an environmentally responsible firm among external stakeholders (Shaw and Epstein 2000).[4]

In addition to the influence of a firm's management system, we also investigate the effects of other factors, such as its technical capabilities and the regulatory pressures it faces, on the extent to which a firm adopts pollution prevention technologies. Adoption of pollution prevention technologies is likely to require technical expertise and related experience. This is based on the premise that even though generic knowledge about ways to prevent pollution already exists, strategies to prevent pollution need to be customized to the particular production processes and products of the adopting firm. External pressure from mandatory regulations could also have an impact on the environmental innovativeness of firms even though these regulations do not directly require firms to adopt pollution prevention technologies. Regulatory pressures can create incentives to adopt such technologies if these technologies have synergistic effects on reducing emissions of regulated pollutants and thereby reducing current or anticipated costs of compliance. Firms may also voluntarily adopt pollution prevention technologies to serve as a signal of environmentally responsibility and reduce regulatory scrutiny and the stringency with which environmental regulations are enforced.

We conduct this analysis using an unbalanced panel of 167 firms from the S&P 500 list which reported to the Toxics Release Inventory (TRI) and responded to the survey on adoption of environmental management practices conducted by the Investor Research Responsibility Center over the period 1994–1996. Our study controls for the heterogeneity among firms in a broad range of characteristics while analyzing the impact of technological capabilities, regulatory pressures and TQEM on the adoption of pollution prevention technologies. We address the potential endogeneity of the TQEM adoption by using an instrumental variable approach. We exploit the panel nature of our dataset to test for and implement two ways to account for intertemporal dependence of a firm's decision to adopt pollution prevention activities, one which allows for first order auto-correlation in the errors and the other that allows for firm-specific random effects.

Previous studies have used conceptual analysis and case studies in management and organizational theory to show that organizational structure of the firm can affect its speed in adopting productivity enhancing innovations and its ability to realize the benefits of technology adoption. In particular, an effective management system with clear policies, organizational structure, tracking and reporting mechanisms and performance measures is needed to induce environmental innovations (DeCanio et al. 2000; Breeden et al. 1994). Several empirical studies find that environmental regulatory pressures led to environmental innovation (Lanjuow and Mody 1996; Jaffe and Palmer 1997; Gray and Shadbegian 1998; Brunnermeir and Cohen 2003; Pickman 1998). These studies use either industry expenditures on R&D or aggregate number of patents as a proxy for innovation and industry pollution abatement costs as a measure of regulatory pressures (with the exception of Gray and Shadbegian (1998) who use plant level data). A related study by Cleff and Rennings (1999) examines the perceived importance of various types of environmental policy instruments on the discrete self-classification of firms as being environmentally innovative and finds that firms perceived voluntary programs (eco-labels and voluntary commitments) to be important in encouraging product and process innovation.

[4] For example, Howard et al. (2000) found that Responsible Care participants were more likely to implement practices visible to external constituencies but they varied a great deal in implementation of practices such as pollution prevention and process safety that were visible only internally. Shaw and Epstein (2000) argue that firms adopt popular management practices, such as Total Quality Management, to gain legitimacy and find that implementation of such practices leads to gains in external reputation regardless of whether there is an improvement in the firm's financial performance.

Studies of environmental management systems (survey in Khanna 2001) have examined the motivations for adopting an environmental plan (Henriques and Sadorsky 1996), seeking ISO certification (Anderson et al. 1999; Dasgupta et al. 2000; King and Lenox 2001; Nakamura et al. 2001), adopting a more comprehensive environmental management system (Khanna and Anton 2002; Anton et al. 2004) and participating in the Responsible Care Program (King and Lenox 2000).[5] Another related set of studies has examined the implications of such initiatives by firms for their environmental performance, measured by toxic releases (Arimura et al. 2008; Barla 2007; Ziegler and Rennings 2004; King and Lenox 2000; Anton et al. 2004; Dasgupta et al. 2000). These studies find mixed evidence of the effects of changes in environmental management on environmental performance (see review in Khanna and Brouhle forthcoming). Potoski and Prakash (2005), Arimura et al. (2008), Anton et al. (2004), and Dasgupta et al. (2000) find that adoption of environmental management systems enables firms to reduce their environmental impacts while Dahlstrom et al. (2003) and Barla (2007) find evidence to the contrary.

A few studies examine the effect of a management system on the environmental innovation behavior of facilities. Ziegler and Rennings (2004) found that EMS certification does not significantly affect environmental innovation and abatement behavior at German manufacturing facilities. Similarly, Arimura et al. (2007), using R&D expenditures as a proxy for environmental innovation, find that management systems did not lead to more environmental R&D. Frondel et al. (2007) examine whether a facility adopted an end-of-pipe technology or a cleaner production technology and find that management systems motivated adoption of both types of technologies.

This paper makes several contributions to the literature on the determinants of environmental innovations. Unlike the previous literature which has used either aggregate and broad measures of innovation such as industry expenditures and patent counts or has used discrete indicators of technology adoption, we use detailed micro data on a specific type of environmental innovation, namely count of adoption of 43 types of pollution prevention techniques adopted by firms to reduce their toxic releases as reported annually to the USEPA's Toxics Releases Inventory (TRI). These pollution prevention practices range from product and process changes to changes in operating procedures. Moreover, we analyze the effects of organizational structure on environmental innovation using a treatment effects model that allows us to control for the endogeneity of the TQEM adoption decision. We also analyze the impact of various types of environmental regulations, both existing and anticipated, on pollution prevention.

2 Conceptual Framework

We consider profit maximizing firms that are emitting toxic releases which are not directly subject to any penalties or other regulations. Despite the absence of regulation, firms may have several motivations to reduce the releases of these pollutants voluntarily. These motivations could be internal, that is, generated by the firm's management philosophy and technical capacity, or external, that is, arising from the firm's interaction with external stakeholders, including environmental regulators, environmental interest groups and consumer groups. These stakeholders have the potential to take actions that affect the costs of compliance, market share, reputation and image of firms. All of these developments have increased the

[5] Several studies also investigate the motivations for firms to participate in public voluntary programs such as EPA's 33/50 program, Waste Wise and Green Lights (for a survey of those studies see Khanna 2001).

incentives for firms to make proactive efforts to reduce their unregulated toxic releases. In the absence of any mandated technology standards, firms have flexibility in choosing either pollution prevention or end-of-pipe technologies for controlling such releases.

Interest in pollution prevention has grown among firms with the passage of the Pollution Prevention Act and due to increasing costs of end-of-pipe disposal. Underlying the concept of pollution prevention is the premise that pollution is caused by a wasteful use of resources; thus, a reduction in these wastes through changes in production methods that increase production efficiency can lead to input cost-savings, higher productivity, lower costs of pollution control and disposal and lower risk of environmental liabilities relative to using end-of-pipe technologies (Porter and van der Linde 1995; Florida 1996). The adoption of pollution prevention activities could also confer a second benefit to firms seeking to improve their environmental image. While emissions reductions from some unobserved counterfactual level may be sometimes hard to ascertain, pollution prevention activities provide tangible evidence to the public and to regulators that the firm is proactively engaged in abatement using methods not mandated by law. Although, recognition of the net benefits of adopting pollution prevention technologies is likely to have been increasing among all firms, we expect these benefits to differ across heterogeneous firms. Next, we discuss our measure of adoption of pollution prevention techniques.

Our dependent variable is the count of new pollution prevention techniques adopted by a firm during a year. Since pollution prevention is popularly referred to as P2, we call this variable *New P2*. Each facility of a firm is required to report new adoption of any of 43 different activities to prevent pollution for each toxic chemical to TRI in a given year. These activities are broadly categorized into changes in operating practices, materials and inventory control, spill and leak prevention, raw material modifications, equipment and process modifications, rinsing and draining equipment design and maintenance, cleaning and finishing practices, and product modifications. Each facility can report up to four different P2 activities adopted for controlling the level of releases of each chemical.

We use two different methods for aggregating the number of P2 practices across categories of practices, across chemicals, and across facilities belonging to the same parent company. First, we simply aggregate the number of all P2 practices adopted in a year across all chemicals for each facility and then across all facilities belonging to a parent company to obtain *New P2* at the firm-level for that year.[6] Second, we weight each facility's P2 activities (summed over chemicals as under the first method above) by its share in the five-year lagged toxic releases of the parent company and obtain a *Weighted Sum of New P2* at the firm level. Facilities with fewer P2 activities per chemical, fewer numbers of chemicals and a smaller share in lagged toxic releases of the firm would contribute less to this measure of firm level *Weighted Sum of New P2*.

We now discuss the specific factors, first the internal factors, including management system, and external factors, that can explain environmental innovativeness of firms.

2.1 Internal Factors

Profit maximizing firms can be expected to adopt pollution prevention activities according to their ability to identify profitable techniques and their learning costs of adoption. Two internal factors may influence their ability and adoption costs. The first of these is the firm's technological capabilities. These are also referred to as "complementary internal expertise/assets"

[6] It is extremely rare in our sample that a firm reports four P2 activities for a particular chemical. Thus, censoring through top coding is not a concern in our data.

or "absorptive capacity" (Cohen and Levinthal 1994). These capabilities depend on the level of in-house technical sophistication.[7] Several scholars have demonstrated the relationship between the knowledge resources and capabilities/competencies of a firm and its innovativeness (Teece et al. 1997; Cohen and Levinthal 1989, 1994). Cohen and Levinthal (1989) contend that R&D expenditures not only generate new information but also enhance the firm's ability to assimilate and exploit existing information, that is, a firm's 'learning' or 'absorptive' capacity.[8] This suggests that proactive efforts at reducing pollution do not occur in a vacuum. Instead, they are associated with broader and previous efforts of a firm to be innovative.[9]

Surveys of firms suggest that adopters of pollution prevention techniques are more innovative in general, with higher R&D intensity and a history of more frequent new product introductions and product design changes (Florida 1996; Florida and Jenkins 1996). Canon de Francia et al. (2007) find that firms with greater technological knowledge, proxied by the depreciated sum of R&D expenditures in the past, were considered by financial markets to be able to adapt at lower cost to the provisions of the Integrated Pollution Prevention and Control Act in Spain. Thus, we hypothesize that firms that have stronger technical capabilities have greater absorptive capacity for other technological innovations and are more likely to adopt more pollution prevention techniques. We measure a firm's absorptive capacity by its *R&D Intensity*, defined as the ratio of its annual R&D expenditures over its annual sales.

The second internal factor that could influence the adoption of pollution prevention technologies is the organizational structure of the firm. The managerial literature argues that organizational systems are critical to the innovativeness of firms because they condition firm responses to challenges and ability to realize the full benefits of cost-reducing or productivity enhancing technologies (Teece and Pisano 1994; DeCanio et al. 2000). In particular, TQEM creates an organizational framework that encourages continuous improvement in efficiency and product quality through systematic analysis of processes to identify opportunities for reducing waste in the form of pollution. The TQEM tool-kit of senior management commitment, team-work, empowerment of employees at all levels, and techniques such as process mapping, root cause analysis and environmental accounting can enable the firm to become aware of inefficiencies that were not recognized previously and to find new ways to increase efficiency and reduce the costs of pollution control (Wlodarczyk et al. 2000). This may lead the firm to see the value of developing products and processes that minimize waste from "cradle to grave" rather than focusing only on end-of-pipe pollution control. The conceptual relationship between TQEM and pollution prevention suggests that firms that adopt TQEM are likely to adopt more pollution prevention techniques.

We define *TQEM* as a dummy variable equal to 1 if a firm adopted TQEM in a particular year and zero otherwise. It is important to note here that *TQEM* could be an endogenous variable. For example, (unobserved) managerial preferences could influence the adoption of both *TQEM* and pollution prevention techniques. We discuss this issue and our methods for accounting for it in the next section.

[7] These capabilities or specialized assets are firm-specific. They are acquired over time, are non-substitutable and imperfectly imitable, such as firm-specific human capital, R&D capability and brand loyalty. They can enable firms to adopt new technologies at lower cost (Dierickx and Cool 1989).

[8] Blundell et al. (1995) find that the stock of innovations accumulated in the past was significant in explaining current innovations. Christmann (2000) finds that complementary assets in the form of R&D intensity of the firm determine the competitive advantage that a firm receives from adopting P2 strategies.

[9] More generally, prior research suggests that firms cannot costlessly exploit external knowledge, but must develop their own capacity to do so, through the pursuit of related R&D activities and cumulative learning experience (Cohen and Levinthal 1989, 1994).

2.2 Regulatory Pressures

In addition to internal pressures that influence firms' decision to adopt P2 activities, profit maximizing firms are also influenced by existing and anticipated regulations. Existing regulations, that are primarily in the form of end-of-pipe technology standards, may create disincentives for voluntary adoption of pollution prevention technologies. Theoretical studies by Downing and White (1986) and Milliman and Prince (1989) show that the incentive to innovate is stronger under market-based systems (e.g. emission fees or permits) than under command and control regulations because the gains through lower costs of compliance with innovation are much higher with market based policies. Additionally, by diverting resources towards compliance with technology standards and promoting a reactive approach to compliance, command and control regulations can reduce incentives to be innovative. However, these studies ignore the potential for firms to influence the stringency with which regulations are enforced, to preempt or influence future regulations (as Segerson and Miceli 1998; Lutz et al. 2000) or to indirectly lower costs of compliance through synergistic reductions in related pollutants.

Existing mandatory regulations could lead firms to adopt pollution prevention technologies that might be directly targeted at reducing (unregulated) toxic releases but could indirectly lower the costs of regulatory compliance through at least two different channels. First, efforts to prevent toxic releases could reduce the compliance costs for regulated pollutants (if regulated pollutants and toxic releases are complementary by-products of the production process). Surveys find that firms are proactively adopting P2 and seeking to eliminate harmful emissions to avoid complex, inflexible and costly regulatory processes and legal liabilities (Rondinelli and Berry 2000; Florida and Davison 2001).

Second, frequent inspections and penalties associated with enforcement of mandatory regulations are not only costly for firms but they can also have a negative impact on a firm's reputation; creating incentives for firms to take action to reduce the frequency of enforcements. Several authors have also suggested that regulators are responsive to good faith efforts put forth by firms to reduce releases of pollutants not currently regulated or to limit releases of pollutants beyond what is required by statute or permit (Hemphil 1993/1994; Cothran 1993). Empirical studies show that firms that had lower toxic releases were less likely to be subject to inspections and enforcement actions. Such firms were also subject to fewer delays in obtaining environmental permits (Decker 2003). Maxwell and Decker (2006) develop an analytical model to show that in the presence of "responsive" regulators a firm can have incentives to undertake voluntary environmental investments to reduce the frequency with which it is monitored for compliance with regulations. Innes and Sam (2008) find empirical evidence that participation in USEPA's voluntary 33/50 program led to a significant decline in the frequency with which firms were inspected. We therefore hypothesize that firms that face greater enforcement pressure in the form of more frequent inspections and a larger number of penalties to adopt more *New P2* not only to reduce pollution at source but also to earn goodwill with regulators and possibly reduce the frequency of future inspections and severity of penalties.

Furthermore, future regulations, particularly if targeted at toxic releases, can also impact adoption of pollution prevention technologies. Anticipation of stringent environmental regulations for reducing currently unregulated pollutants could induce technological innovation by firms to reduce pollution at source (Porter and van der Linde 1995).[10] By taking actions to

[10] Several theoretical studies show that the threat of mandatory regulations can induce voluntary environmental activities to preempt or shape future regulations (see survey in Khanna 2001). Empirical analyses show that

control pollution ahead of time through product and process modifications, firms may be able to lower costs of compliance as compared to the costs of retrofitting abatement technologies in the future (Christmann 2000). The anticipation of future stringent environmental regulations may also induce firms to be innovative to gain a competitive advantage by establishing industry standards and creating potential barriers to entry for other competitors (Dean and Brown 1995; Barrett 1992; Chynoweth and Kirschner 1993).

As proxies for the costs of existing regulations, we include the variable, *Inspections*, defined as the number of times a firm was inspected by state and federal environmental agencies to monitor compliance with mandatory regulations.[11] We also include *Civil Penalties* received for noncompliance with environmental statutes, such as the Clean Air Act, the Clean Water Act, Toxic Substances Control Act and the Resource Conservation and Recovery Act.

Additionally, as a measure of the stringency of the existing regulatory climate of the county, we construct a measure based on the non-attainment status of all counties in the US. As per the 1977 Clean Air Act Amendments, every county in the US is designated annually as being in attainment or out of attainment (non-attainment) with national air quality standards in regards to six criteria air pollutants: carbon monoxide, sulfur dioxide, total suspended particulates, ozone, nitrogen oxide and particulate matter. The areas that have been designated as non-attainment regions are then subjected to more stringent controls, with the degree of stringency varying with the severity of pollution (basic, marginal, moderate, serious, two categories of severe and extreme) (Tietenberg 2006). Furthermore, within any of the six criteria air pollutant categories, the county status may range from attainment of the primary standard to non-attainment. Because a county can be out of attainment in several air pollutant categories, and many heavy polluters emit numerous pollutants, we construct a dummy variable for each of the six pollutants for each facility based on its location: for each pollutant a value of 1 is given to facilities located in a non-attainment county for that pollutant and 0 otherwise. Each of the six dummy variables is summed up for all the facilities of each parent company and the resulting counts are then summed up over the six pollutants to derive the *Non-attainment* variable (as in List 2001). Higher values indicate that a larger number of facilities of a parent company are located in counties with non-attainment status for a larger number of pollutants.

A few states have also initiated mandatory P2 programs since 1988 to encourage source reduction of toxic emissions. These programs impose mandatory reporting requirements for P2 activities adopted, similar to the federal TRI, and provide technical assistance to firms in the state. Eight states have numerical goals for P2 adoption, while one state provides financial assistance to firms.[12] We hypothesize that facilities located in states with mandatory P2 programs are more likely to adopt *New P2* activities. We include a dummy equal to one

Footnote 10 continued
regulatory pressures (Henriques and Sadorsky 1996; Dasgupta et al. 2000), threat of liabilities and high costs of compliance with anticipated regulations for hazardous air pollutants (Anton et al. 2004; Khanna and Anton 2002) did motivate adoption of environmental management practices, but their direct effect on environmental technology adoption has not been examined.

[11] Information about the pollution prevention practices adopted by firms is available to regulators only with a lag of 1 or 2 years. Hence we do not expect current inspections and penalties to be influenced by current pollution prevention decisions.

[12] Mandatory P2 programs started in 1988 with Washington, followed by Massachusetts and Oregon in 1989. Six states adopted them in 1990 (Georgia, Maine, Minnesota, Mississippi, New York, and Vermont) while four adopted them in 1991 (Arizona, New Jersey, Tennessee, and Texas). California adopted them in 2007. All states with Mandatory P2 programs provide technical assistance and have reporting requirements to firms. Arizona, California, Massachusetts, Maine, Mississippi, New Jersey, New York and Washington have set numerical goals for P2 activities, while Minnesota provides financial assistance to firms.

if a facility is located in a state with a mandatory P2 program and zero otherwise. These dummies are then summed over the facilities of a firm to obtain the *Mandatory P2 Policy* variable, which provides a measure of the extent to which a firm is facing regulatory pressure to report/adopt P2 activities.

As a proxy for anticipated costs of compliance, we include the volume of *Hazardous Air Pollutants* (*HAP*) consisting of 189 toxic chemicals listed in Title III of the 1990 Clean Air Act Amendments. These were expected to be regulated under New Emissions Standards for HAP from 2000 onwards. We expect that firms with a larger *HAP* face a greater threat of anticipated regulations and are more likely to adopt pollution prevention technologies to obtain strategic advantage over competitors by reducing HAP emissions ahead of time.

2.3 Other Firm-Specific Characteristics

We also control for other factors that could also influence the adoption rates of pollution prevention practices. In addition to regulatory pressures, market pressures from consumers and environmental organizations could also lead firms to undertake pollution prevention.[13] Several studies have shown that consumer willingness to pay premiums for environmentally friendly products and the desire to relax price competition can lead some firms to produce higher quality environmental products to differentiate themselves from other firms (Arora and Gangopadhyay 1995; Cremer and Thisse 1999; Amacher et al. 2004; Deltas et al. 2008). For example, Starbucks consumers pressured the coffee chain to purchase only from suppliers who grow coffee beans in a bird-friendly-fashion (Greenbiz News 2004). We extend the demand-side pressures to include the demand for innovation by other stakeholders, such as environmental and citizen groups and activists. These groups can express their preferences through boycotts and adverse publicity which can affect the reputation of a firm (Baron and Diermeir 2007).

We proxy consumer pressure by a dummy variable, *Final Good*, which is equal to one for firms that produce final goods and zero for those that produce intermediate goods.[14] We measure pressure by environmental groups through an explanatory variable, *Environmental Activism*, which is defined as the ratio of per capita membership in environmental organizations in a state relative to that in the entire US. We obtain a measure of environmental activism for each parent company by averaging the values for all its facilities located in different states.[15] Higher values of this variable indicate that a firm has its facilities in states with relatively high per capita membership in environmental organizations.

Additionally, we recognize that the costs of adopting pollution prevention practices and the effectiveness of pollution prevention as a strategy for reducing emissions may vary with the scale of toxic releases. If larger toxic polluters face larger (smaller) costs of abatement

[13] Consumer preferences for green products may manifest themselves through movements in demand and relative prices in the product markets. This parallels the argument put forth by Schmookler (1962) and Griliches (1957) that demand-pull can explain innovative activity by firms as they strive to deliver the preferred goods in the market (Dosi 1982).

[14] Empirical evidence does suggest that firms that produce final goods and that were larger toxic polluters in the past were more likely to participate in voluntary environmental programs and adopt EMSs (see survey in Khanna 2001; Anton et al. 2004).

[15] Studies also show that community characteristics can influence the level of public pressures for reducing pollution (Arora and Cason 1999; Hamilton 1999). Pressure from environmental groups, proxied by membership in environmental organizations, was found to influence participation in voluntary programs (Welch et al. 1999; Karamanos 2000) and reduction in intensity of use of certain toxic chemicals (Maxwell et al. 2000). Using this measure of environmental activism, Welch et al. (1999) find that firms headquartered in states with greater environmentalism were more likely to participate in the voluntary Climate Challenge program.

using pollution prevention methods, then one would observe a negative (positive) association between the emissions reported to the TRI and pollution prevention activities. Since current emissions are endogenous, as they are affected by the level of pollution prevention activities, we use lagged *Toxic Releases* (choosing a 5 year lag) to ensure that endogeneity is not an issue even in the presence of serial correlation. While it is also possible that firms emitting releases with a higher toxicity index may be more concerned about regulatory or public scrutiny and potential liabilities and thus, may have greater incentives to adopt P2 techniques, the inclusion of lagged *Toxicity-Weighted Releases* as an explanatory variable in the models do not alter any of our results. Further lagged *Toxicity-Weighted Releases* is never a significant variable in any of our models; hence we chose to exclude it from our models.

We control for the number of pollution reduction opportunities a firm has by including the *Number of Chemicals* emitted as an explanatory variable. This variable is the count of chemicals reported by the firm which is obtained by summing up the chemicals reported by each facility over all facilites of that firm. By including this as an explanatory variable we allow for the possibility that firms that report a larger *Number of Chemicals* may adopt more pollution prevention practices, without imposing a proportional relationship between the *Number of Chemicals* and *New P2*.

We also include the *Newness of Assets* of a firm, its *Market Share of Sales* and its *Sales* as explanatory variables. *Newness of Assets*, measured by the ratio of total assets to gross assets (as in Khanna and Damon 1999; Cohen et al. 1995), indicates how depreciated a company's assets are and is thus a proxy for the cost of replacement of equipment. Total assets are current assets plus net property, plant and equipment plus other non-current asserts. Gross assets are total assets plus accumulated depreciation on property plant and equipment. Higher values of this variable indicate newer assets. The newer the equipment, the more costly it would be to replace it, which may be a barrier to innovative activities to prevent pollution. Newer equipment may also be more efficient and less polluting; reducing the need for making the modifications needed to prevent pollution. We expect that firms with older assets may, thus, be more likely to adopt more *New P2*.[16]

We include the *Market Share* of a firm in terms of industry sales as an explanatory variable to control for any effects of industry leadership on the incentives for innovation. There is a considerably large theoretical and empirical literature analyzing these effects and yielding ambiguous predictions (see survey by Cohen and Levin 1989). Some have supported the Schumpeterian argument that monopolists or market leaders can more easily appropriate the returns from innovative activity. Others argue that insulation from competitive pressures breeds bureaucratic inertia and discourages innovation.[17] Market share can also be a proxy for a firm's innovativeness and technical capabilities as innovative and technically capable firms tend to dominate their markets. Finally, we include the *Sales* of a firm as a measure of firm size. Larger firms may have more resources to adopt pollution prevention practices. They are also likely to be more visible and thus targets of social pressure by stakeholders

[16] Studies find that firms with older assets were more likely to participate in voluntary environmental programs (Khanna and Damon 1999) and adopt a more comprehensive environmental management system (Khanna and Anton 2002).

[17] In the context of quality provision, Spence (1975) shows that this depends on the relationship between the marginal value of quality and the average value of quality to the firm while Donnenfeld and White (1988) show that it depends on the differences in the absolute and marginal willingness to pay for quality.

because they may be held to higher standards. Such firms may also be more vulnerable to adverse effects of a tarnished reputation.[18]

3 Empirical Model

Our empirical model consists of a *New P2* adoption Eq. 1 which relates the number of *New P2* techniques Y_{it}, adopted by the ith firm at time t to a vector of observed exogenous variables and other firm-specific characteristics, X_{it}, the *TQEM* adoption decision, T_{it}, and unobserved factors, ε_{1it}.

$$Y_{it} = \alpha X_{it} + \beta T_{it} + \varepsilon_{1it} \tag{1}$$

Since the New P2 variable ranges from 0 to 284 in our sample (Table 1), it is reasonable to treat it as a continuous variable, and we thus use standard least squares treatment effects methods (Wooldridge 2002) to estimate the models. Contemporaneous values of explanatory variables X_{it} are used to explain *New P2* in Eq. 1, except for five-year lagged values of toxic releases and *HAP*, because emissions might be jointly determined with the *New P2* adoption decisions; unobserved factors influencing *New P2* adoption are likely to influence current emissions. However, our results are robust to using current emissions as a regressor with past emissions as an instrument. Since the distributions of *HAP* and *Toxic Releases* are highly skewed to the right and to allow for diminishing marginal effects these variables on *New P2*, we include the square roots of these variables as explanatory variables. We also estimated models using (untransformed) levels of these variables and found that the signs and statistical significance of these and other explanatory variables were unaffected. We handle unobserved firm heterogeneity using two distinct models that make different assumptions about the error specification. First, we estimate a pooled model and allow serial correlation among error terms with a form $\varepsilon_{1it} = \rho_1 \varepsilon_{1it-1} + u_{it}$ where $E(u_{it}) = 0$, $E(u_{it}^2) = \sigma_u^2$ and $Cov(u_{it}, u_{is}) = 0$ if $t \neq s$ using the Prais and Winsten (1954) algorithm. This model assumes that unobserved heterogeneity evolves slowly over time and thus has imperfect persistence.[19] Second, we estimate the models using a random effects specification to account for the possibility that unobserved heterogeneity is time invariant, and thus can be captured by unobservable time invariant firm-specific effects.

The coefficient of *TQEM* represents the average treatment effect of *TQEM* adoption on *New P2* adoption levels. We recognize that the *TQEM* adoption decision, T_{it}, may be endogenous because the unobserved variables that influence *TQEM* may be correlated with the unobserved variables that influence *New P2* equation. For example, one such unobserved variable could be the 'green' preferences of the current management which would affect both the decision to undertake *TQEM* and undertake more *New P2* even after conditioning for observed variables. The bias on β in (1) could be positive if *TQEM* is more likely to be adopted by such firms. However, the bias could be negative if firms with an inherently low scope for pollution prevention activities do not find the adoption cost of *TQEM* worthwhile. A test for the endogeneity of *TQEM* (Wooldridge 2002) rejects the null hypothesis that it is an exogenous variable at the 1% significance level. To deal with this endogeneity problem, we instrument for *TQEM* using the 5 year lagged values of the following variables: square

[18] Larger firms have been found to be more likely to participate in the chemical industry's Responsible Care Program (King and Lenox 2000), Green Lights, Waste Wise, and 33/50 programs (Videras and Alberini 2000) and in Climate Challenge (Karamanos 2000).

[19] A fixed effects model could not be estimated because we have several regressors that are time-invariant.

root of toxic releases, square root of R&D intensity, square root of sales, and number of facilities. We find these four variables to be statistically predictors of TQEM adoption (see Harrington et al. 2008). Lagged toxic releases reported to the *TRI* is a measure of the scale of the environmental problem, while lagged sales are a measure of the economies of scale and firm size which could then influence the firm's ability to bear the fixed costs of adoption. R&D intensity is a proxy for the technical capacity of firms, while number of facilities of a firm could influence the firm's costs of coordinating a common management system within the corporation and the gains from implementing a uniform approach towards environmental management.

4 Data Description

The sample consists of S&P 500 firms which responded to the Investor Research Responsibility Center (IRRC) survey on corporate environmental management practices adopted by them and whose facilities reported to the TRI at least once over the period 1994–1996 or 1989–1991 (since we are using five-year lagged values of toxic releases as explanatory variables). The IRRC data provide information about the adoption of TQEM by parent companies over the period 1994–1996. Focusing on the early to mid 1990s allows us to examine adoption of TQEM after the concept was introduced but before it became almost universally adopted. The TRI contains facility-level information on releases of chemical-specific toxic pollutants and on the pollution prevention activities adopted by firms since 1991. It also provides data on *HAP*. To match the TRI dataset with the IRRC, we construct unique parent company identifiers for each facility in the TRI database, and then aggregate all chemical and facility level data to obtain parent company level data.[20] We dropped the chemicals which had been added or deleted over the period 1989–1996 due to changes in the reporting requirements by the USEPA. This ensures that the change in toxic releases in our sample over time is not due to differences in the chemicals that were required to be reported. Of the S&P 500 firms, only 254 firms reported to the TRI at least once during the period 1989–1996. Of these firms, an unbalanced panel of 184 firms responded to the survey by the IRRC in at least one of the three years. Restricting our sample to the firms for which complete data for estimating Eqs. 1–2 were available resulted in 463 observations belonging to 174 firms for estimating Eq. 1 and 422 observations belonging to 167 firms for estimating Eq. 2. Summary statistics for the variables used here are presented in Table 1.

The TRI instructs firms to report the new P2 activities adopted by them in that year. However, it is possible that some firms might be reporting all (cumulative) P2 activities adopted by them instead of only the incremental ones. To check if this was the case we examined the annually reported P2 counts by each facility belonging to S&P 500 firms and reporting to TRI for each chemical for the period 1992–1996 and compared it with their reports for the previous period (1991–1995). We then derived the change in the reported *New P2* count for a total of 74,780 instances at the chemical-facility level. If firms were inadvertently reporting all P2 activities adopted instead of *New P2* activities, we would expect that the annual count

[20] To match the facilities with their parent companies, a combination of the Dun and Bradstreet number, facility name, location, and SIC code were used (these additional identifiers were used for some facilities when the Dun and Bradstreet number was missing). The ticker symbol, which identifies the parent companies in the Research Insight database, was used to match the IRRC data with financial data from Research Insight. Since some parent company names had changed over our study period, Market Insight, a database tool linked with Research Insight was used to trace the parent company's history. The historical information included mergers, acquisitions, changes in names, SIC codes and ticker symbols.

Table 1 Descriptive statistics (1994–1996)

Variable	Mean	SD	Minimum	Maximum
TQEM	0.68	0.47	0.00	1.00
New P2	23.40	37.13	0.00	284.00
Weighted sum of New P2	2.49	4.16	0.00	28.93
R&D intensity	0.03	0.04	0.00	0.24
Final good	0.56	0.50	0.00	1.00
Environmental activism	0.90	0.28	0.26	2.43
Lagged toxic releases (millions of pounds)	14.87	42.34	0.00	382.88
Current toxic releases (millions of pounds)	31.88	69.85	0.00	519.18
Lagged HAP (million of pounds)	3.05	6.86	0.00	57.97
Penalties	1.49	3.43	0.00	33.00
Inspections	50.66	82.79	0.00	491.00
Non-attainment	12.24	16.87	0.00	96.00
Mandatory P2 policy	1.69	2.87	0.00	18.00
Market share of sales	0.26	0.22	0.00	0.98
Net sales ($ billion)	12.96	22.40	0.18	165.37
Newness of assets	0.75	0.10	0.46	0.93
Number of chemicals	80.69	113.86	1.00	625.00
Number of facilities	17.64	20.73	1.00	111.00

Summary statistics are presented for $N = 422$

of P2 reported would be increasing or stay constant over time for all years. Our investigation focused at the facility level on the premise that any misinterpretation of the instructions in the TRI would be at the facility rather than chemical level. In particular, we have calculated the number of facilities for which the reported P2 counts were non-decreasing for all chemicals. We found that this was the case for only 236 facilities (5.68% of all S&P facilities reporting to TRI) and represents only 0.67% of the chemical-facility pairs (because these facilities have a much lower than average number of chemicals).[21] Therefore, even if there was any misinterpretation of the survey question, it impacted at most a small fraction of the data. An equally likely possibility is that the P2 count was indeed non-decreasing for all the chemicals and time periods for these facilities. We thus feel confident that *New P2* does measure incremental adoption of pollution prevention activities by a firm that year.

The number of environmental *Civil Penalties* and the number of *Inspections* are derived from USEPA's Integrated Data for Enforcement Analysis (IDEA) database. Since these data are reported at the sub-facility level, inspections and penalties of all sub-facilities of each parent company are added up to get parent company level data.

The S&P 500 Compustat database, now known as Research Insight, is the source of parent-company level financial data on net sales, total assets, gross assets and R&D expenditures. *Market share* data are obtained from Ward's Business Directory using parent company names. The *Final Good* dummy is constructed based on the firm's four-digit SIC code (as

[21] In terms of total sample, this translates to 502 out of 74,780 chemical-facility pairs. Additionally, these 236 facilities belong to 113 different parent companies. Hence, we can rule out systemic and large scale misinterpretation of TRI instructions at the parent company level. Even if it occurred at the facility level, the number of facilities and the number of P2 activities affected by it is negligible.

described in Harrington et al. 2008). The primary SIC code of a parent company is that reported in the Research Insight database. If that was missing, then we use the SIC code in Ward's Business Directory to construct the *Final Good* dummy.

The *Non-attainment* status of counties is obtained from the USEPA Greenbook.[22] These data are matched with the TRI using the location information of each facility. The data on *Environmental Activism* are obtained at the state level for 1993 from Wikle (1995).[23] Data on state P2 policies are obtained from the National Pollution Prevention Roundtable.[24]

5 Results

We estimate several different models to examine the determinants of *New P2* adoption. We first examine the results of models that include only the exogenous explanatory variables and firm-specific characteristics and exclude *TQEM*. Models I-A and I-B (Table 2) explain adoption of *New P2*, assuming AR1 error structure and random effects, respectively. Model II uses *Weighted P2* as dependent variable. The coefficients of all variables will also include any indirect effects the associated factors will have through their influence on *TQEM* adoption. We report the estimates of the autocorrelation parameter for the AR1 model, as well as the point estimate of the variance of the random effect component as a fraction of overall variance for the random effects models. The AR1 models strongly support the validity of assuming an AR1 error process against the alternative of an *i.i.d.* error distribution. The high share of the overall variance attributed to the random effects component underlines the importance of controlling for unobserved heterogeneity. We then estimate and report the results of the full structural system which includes the *TQEM* variable, appropriately instrumented, in Table 3.

Results from the linear regressions for *New P2* (Models I-A and I-B) consistently support our hypotheses that current and anticipated regulatory pressures, as proxied by *Penalties, Inspections, HAP and Non-Attainment* have a statistically significant positive impact on *New P2* adoption, with the exception of *Inspections* and *Penalties* which have a statistically insignificant coefficient in Model I-B. Among these proxies for regulatory pressures, only *HAP* has a statistically significant impact on the *Weighted P2* measure of adoption of pollution prevention techniques (Model II). Recall that *Weighted P2* differs from *New P2* in that it attaches a higher weight to P2 adoption by facilities with a higher share of toxic emissions within the firm. Therefore, it is possible that existing regulatory pressures primarily impact the P2 activities of those facilities that have a smaller share of the firm's toxic releases. Anticipated *HAP* regulations, however, do motivate a higher level of *Weighted P2* adoption in addition to a higher level of *New P2* adoption. This indicates that regulations targeted at toxic releases were more effective in motivating P2 adoption by the pollution intensive facilities within firms as compared to command and control regulations aimed at other pollutants. Interestingly, we find that a Mandatory P2 policy has a statistically insignificant impact on *New P2* adoption in models I-A and I-B and only a weakly significant but negative impact in Model II.

We find some support for our hypothesized impact of internal firm capabilities on pollution prevention adoption; Model I-A and Model II show that *R&D Intensity* has a positive

[22] Can be found at http://www.epa.gov/oar/oaqps/greenbk/anay.html.

[23] It is based on data on membership in 10 environmental organizations, namely African Wildlife Foundation, American Birding Association, The Nature Conservancy, World Wildlife Fund, Zero Population Growth, American Rivers, Bat Conservation International, Natural Resources Defense Council, Rainforest Action Network, and Sea Shepherd Conservation Society.

[24] http://www.p2.org/inforesources/nppr_leg.html.

Table 2 Determinants of the adoption of pollution prevention techniques

Explanatory variables	Model I-A New P2: OLS with AR1	Model I-B New P2: random effects	Model II weighted P2: random effects
Constant	11.463 (9.736)	12.678 (12.096)	3.538* (2.127)
Innovative capabilities			
R&D Intensity	54.352* (28.357)	41.197 (33.722)	10.5997* (5.930)
Regulatory pressures			
Square root HAP	4.743*** (1.519)	6.887*** (1.763)	1.172*** (0.312)
Penalties	0.639* (0.361)	0.271 (0.298)	−0.00031 (0.054)
Inspections	0.035* (0.021)	0.004 (0.018)	0.0024 (0.003)
Non-attainment	0.386*** (0.093)	0.443*** (0.085)	0.011 (0.015)
Mandatory P2 Policy	−0.199 (0.551)	0.175 (0.703)	−0.231* (0.124)
Other firm characteristics			
Final good	1.668 (2.335)	0.712 (3.432)	0.665 (0.598)
Environmental activism	2.672 (3.518)	1.831 (4.639)	1.783** (0.819)
Square root toxic releases	−0.882** (0.428)	−0.734** (0.331)	−0.035 (0.060)
Market share	16.968*** (5.069)	8.028^{+} (5.514)	0.513 (0.984)
Net sales	−0.072 (0.072)	−0.095 (0.092)	0.017 (0.016)
Newness of assets	−24.271** (12.139)	−23.641^{+} (15.2001)	−5.722** (2.675)
Number of chemicals	0.170*** (0.027)	0.153*** (0.029)	−0.004 (0.005)
Year	−0.928 (0.967)	−0.274 (0.772)	−0.174 (0.141)
ρ	0.609*** (0.039)	0.796	0.777

$N = 422$. Values in parentheses are standard errors
* Significant at 10%; ** Significant at 5%; *** Significant at 1%; $^{+}$ Significant at 15% level
The ρ for the AR1 model refers to the autocorrelation parameter, while for the random effects model, it refers to variance of the random effects component as a fraction of overall variance

and statistically significant impact on *New P2*. We also find that other firm characteristics matter. *Lagged Toxic Releases* and *Newness of Assets* both have a negative significant impact on *New P2*, while *Market share* and *Number of chemicals* have significant positive effects.

In Table 3, we present the results of models that include the impact of *TQEM* adoption on P2 activity. Model III estimates a random effects model that disregards the endogeneity of the *TQEM* adoption decision. The model that ignores the panel structure but assumes an AR1 structure of the error terms yields similar results as Model III and is not shown. Model IV-A and IV-B examine the impact of *TQEM* on *New P2* using the significant determinants of *TQEM* adoption identified in Table 2 as instruments for *TQEM*. Model IV-A assumes an AR1 error structure, while Model IV-B is a random effects model. Model V is similar to Model IV-B, but uses *Weighted P2* as dependent variable.

Model III which is estimated without correcting for the endogeneity of *TQEM* shows that the effect of *TQEM* on *New P2* is negative, small and statistically insignificant. The other models, Models IV-A and IV-B, however, consistently support our hypothesis that *TQEM* has a positive and statistically significant impact on *New P2*. The coefficient of *TQEM* in the models that instrument for *TQEM* is much larger than in Model III, indicating the presence of a negative selection bias in its estimation, i.e., that *TQEM* adopters are firms with lower than average *unobserved* propensity to adopt pollution prevention activities.

Table 3 Impact of TQEM on pollution prevention adoption

Variables	Model III New P2: random effects TQEM exogenous	Model IV-A New P2: 2SLS AR1	Model IV-B New P2: 2SLS random effects	Model V weighted P2: 2SLS random effects
Constant	−13.264 (11.984)	−0.032 (11.193)	−7.447 (17.231)	0.258 (3.176)
Internal managerial and innovative capabilities				
TQEM	−0.182 (2.207)	13.617** (6.649)	22.508* (11.962)	3.429^{+}(2.251)
R&D intensity	38.993 (33.229)	37.911 (29.361)	10.368 (41.059)	5.027 (7.520)
Regulatory pressures				
Square root HAP	6.921*** (1.742)	4.429** (1.521)	6.001*** (2.023)	1.011*** (0.361)
Penalties	0.318 (0.283)	0.719** (0.363)	0.402 (0.341)	0.018 (0.059)
Inspections	0.001 (0.018)	0.035* (0.021)	0.002 (0.021)	0.001 (0.004)
Non-attainment	0.440*** (0.083)	0.393*** (0.093)	0.386*** (0.099)	0.002 (0.018)
Mandatory P2 policy	0.134 (0.692)	0.029 (0.559)	0.477 (0.801)	−0.192** (0.145)
Other firm characteristics				
Final good	0.784 (3.349)	1.332 (2.333)	1.171 (3.855)	0.509 (0.711)
Environmental activism	1.561 (4.473)	3.496 (3.535)	4.264 (5.337)	2.171** (0.968)
Square root toxic releases	−0.744** (0.322)	−1.182*** (0.454)	−1.857** (0.376)	0.060 (0.064)
Market share	8.236^{+}(5.437)	12.767** (5.436)	3.013 (6.722)	−0.308 (1.194)
Net sales	−0.095 (0.091)	−0.096 (0.073)	−0.142 (0.106)	0.008 (0.019)
Newness of assets	−24.038^{+} (14.800)	−20.881* (12.287)	−11.379* (18.185)	−3.420 (3.306)
Number of chemicals	0.154*** (0.029)	0.168*** (0.027)	0.160*** (0.033)	−0.001 (0.006)
Year	−0.190 (0.757)	−0.454 (0.996)	−0.823 (0.912)	−0.272* (0.159)
ρ	0.796	0.592*** (0.039)	0.795	0.826

$N = 422$. Values in parentheses are standard errors
* Significant at 10%; ** Significant at 5%; *** Significant at 1%; $^{+}$ Significant at 15%
The ρ for the AR1 model refers to the autocorrelation parameter, while for the random effects model, it refers to variance of the random effects component as a fraction of overall variance

The magnitude of the *TQEM* coefficient in the base models (IV-A and IV-B) suggests that the average effect of *TQEM* adoption on the annual count of *New P2* practices is equal to approximately 18 practices (based on an average of the coefficient of TQEM in models IV-A and IV-B). In our sample, the average annual count of pollution prevention practices by adopters of *TQEM* is equal to 27. This suggests that if these firms had not adopted *TQEM*, their average annual count would be only about nine. The non-adopters of *TQEM* average about 16 *New P2* practices per year in our sample. The fact that adopters would have introduced fewer pollution prevention practices per year in the absence of *TQEM* is consistent with our finding that there is negative selection into the adoption of *TQEM* (though this simple difference in means is partially due to differences in observable firm characteristics). In comparing the results of Table 3 with those of Table 2, the most important observation is that with the inclusion of *TQEM* as a variable, the magnitude of the coefficient of *R&D Intensity* and its statistical significance diminishes in all models. This suggests that *R&D intensity* has an indirect effect on the adoption of *New P2* through the adoption of *TQEM* and after accounting for that, its direct effect is smaller. On the other hand, the effects of variables proxying for regulatory pressure, particularly *HAP* and *Non-attainment*, appear to be primarily direct effects on *New P2*. This is consistent with the results obtained by Harrington et al. (2008) which show that *R&D* intensity has a significant influence on *TQEM* adoption while regulatory pressures do not. We do not find any robust evidence about the significance of *Penalties* and *Inspections* as they are only significant in the AR1 models. However, their coefficients are always positive. We also find that *TQEM* has a statistically significant (at 15% only) and positive effect on *Weighted P2* (Model V), while the effects of other variables remain as discussed above. These results suggest that *TQEM* leads even the more pollution intensive facilities within firms to adopt more pollution prevention activities. Further, *Weighted P2* is lower among firms in states with a *Mandatory P2* program, which is also the case in Table 2, Model II.

Among the other firm characteristics, *Toxic Releases*, *Newness of Assets*, and *Number of Chemicals*, have a statistically significant effect on *P2* adoption. The effect of *Number of Chemicals* was as expected; the more opportunities a firm has to adopt pollution prevention technologies the more such technologies it will adopt. The negative sign of *Newness of Assets* is also as expected. Firms with newer assets may find it more costly to adopt pollution prevention technologies, or may already have highly efficient and less polluting technologies which reduce their need to adopt more prevent pollution. We find a fairly robust negative and statistically significant sign for *Toxic Releases* suggesting that firms that were relatively small toxic polluters had lower costs of abatement of toxic releases using pollution prevention technologies. The effects of other firm characteristics, such as *Market share* is not robustly significant across all the models.[25] The effects of other external pressures from environmental groups, communities or consumers on adoption of pollution prevention techniques, as proxied by *Environmental Activism* and *Final Good*, are also not statistically significant except for Model V where *Environmental Activism* is positive significant. The effects of firm characteristics and the magnitudes of their coefficients are very similar in models that include *TQEM* and those that exclude *TQEM* as a variable.

To further test the robustness of our results and the appropriateness of the instrumental variable approach, we explain *P2* adoption separately for 1994, 1995 and 1996 in Table 4. Model VI (like Models III–V) uses lagged values of the square root of toxic releases, square root of R&D intensity, square root of sales and number of facilities as instruments.

We find that *TQEM* is a positive determinant of *New P2* in in each of the years, although the effect is statistically significant only in 1995 and 1996. This is despite the fact that the number of observations in each year, and particularly in 1994, is much smaller than for the entire sample. Our results for the other explanatory variables are also robust, in that none of these variables changes signs in a statistically significant way.

6 Conclusions

The objective of this paper is to study the factors that influence the voluntary adoption of technologies that reduce toxic pollution at source in a sample of S&P 500 firms. Particular attention is devoted to examining the impact of a firm's management system and of external regulatory pressures on the adoption of pollution prevention technologies. In addition, we investigate the role played by internal capabilities in influencing incremental adoption of

[25] We find low correlation between Toxic Releases and other firm characteristics, suggesting that the lack of significance in these characteristics is not due to co-linearity.

Table 4 Impact of TQEM on pollution prevention adoption in 1994, 1995 and 1996

Explanatory variables	Model VI dependent variable: New P2 2SLS with cross-section data		
	1994	1995	1996
Constant	−12.713 (28.077)	−27.756 (25.785)	2.257 (14.742)
Internal managerial and innovative capabilities			
TQEM	18.224 (14.082)	45.420** (18.445)	20.155** (9.038)
R&D intensity	17.836 (71.367)	−3.119 (66.386)	38.411 (41.230)
Regulatory pressures			
Square root HAP	0.802 (4.357)	−0.550 (4.985)	3.679 (2.559)
Penalties	−0.636 (1.275)	0.959 (0.972)	0.667 (0.573)
Inspections	0.320*** (0.077)	−0.011 (0.059)	0.060* (0.031)
Non-attainment	0.455*** (0.174)	0.478** (0.212)	0.625*** (0.208)
Mandatory P2 policy	−0.303 (1.093)	1.289 (1.398)	0.760 (0.842)
Other firm characteristics			
Final good	−4.541 (5.204)	0.419 (5.668)	1.228 (3.620)
Environmental activism	8.401 (8.830)	11.442 (8.979)	−1.649 (5.966)
Square root toxic releases	0.868 (3.249)	2.255 (3.415)	−1.562* (0.803)
Market share	12.685 (11.949)	−6.719 (13.149)	13.657* (8.076)
Net sales	0.098 (0.142)	−0.0077 (0.155)	−0.178 (0.113)
Newness of assets	−12.204 (29.121)	−15.355 (28.566)	−21.235 (18.286)
Number of chemicals	0.042 (0.067)	0.134** (0.064)	0.126*** (0.040)
No of Obs	128	146	148

Values in parentheses are standard errors
* Significant at 10%; ** Significant at 5%; *** Significant at 1%

these technologies. More generally, our study makes a contribution to the broader literature that studies the determinants of environmental innovation by firms.

Our main econometric findings are as follows. First, regulatory pressure from current and anticipated regulations plays an important role in motivating voluntary environmental innovation. In contrast, other firm-specific characteristics are found to have an insignificant effect on firm behavior, except for the consistently significant and negative significant impact of *Newness of Assets*. Pressure from existing regulations, particularly those associated with *HAP* and criteria air pollutants in *Non attainment* areas, is found to be strongly associated with adoption of more P2 practices by a firm but only some of these regulatory pressures have an impact on the adoption of P2 practices by the most polluting facilities of these firms. Second, adoption of *TQEM* does indeed motivate the adoption of more pollution prevention technologies. Thus, managerial innovations, such as adoption of *TQEM*, lead firms to be innovative in their approaches towards environmental management. Third, technological capability is an important determinant of a firm's adoption of pollution prevention technologies. Fourth, firms with a relatively higher volume of toxic releases face higher costs of abatement using pollution prevention technologies.

These results indicate that firms' adoption of *TQEM* is not simply a 'greenwash'. Such firms are indeed changing their operations to make them more environmentally friendly. While our study cannot shed light on whether strategies to induce voluntary adoption of pollution prevention techniques are sufficient (or more effective than mandatory approaches requiring pollution prevention) for achieving the goals of the Pollution Prevention Act, it does show that efforts to encourage voluntary changes in a firm's management system while maintaining a strong regulatory framework and a credible threat of mandatory regulations can be effective in moving firms towards those goals.

This analysis has several policy implications. It shows the extent to which policy makers can rely on environmental management systems to induce voluntary pollution prevention. It also shows the role that regulations can play in motivating innovative methods for pollution control. By distinguishing between different types of regulatory pressures, this analysis shows that regulatory pressures targeted towards hazardous toxic releases and criteria air pollutants are more effective than others in inducing the pollution intensive firms and facilities within firms to adopt pollution prevention practices. The results obtained here also highlight the importance of providing technical assistance to firms that may not have the capacity to undertake innovative pollution prevention activities. Lastly, by identifying the types of firms less likely to be self-motivated to voluntarily adopt pollution prevention practices, this analysis has implications for the design and targeting of policy initiatives that seek to encourage greater pollution prevention.

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