ADOPTION OF POLLUTION PREVENTION TECHNOLOGIES: THE ROLE OF ENVIRONMENTAL, TECHNOLOGY, AND MANAGEMENT POLICIES ON ENVIRONMENTAL INNOVATION*

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Abstract

Recent environmental regulations are recognizing the firm's dual objective of environmental compliance and market competitiveness. State level pollution prevention legislations in the United States have incorporated a mix of environmental policies, demand-and supply-side technology polices, and management policies to promote the adoption of pollution prevention technologies which allow firms to reduce environmental liability, improve product quality, and enhance efficiency. This study uses fixed effects Poisson models to determine whether the adoption of different types of pollution prevention practices are promoted by environmental, technology and management policies using facility level data of US firms from 1991 to 2001 derived from the USEPA Toxic Releases Inventory. Results show that the two environmental policies analyzed have opposite effects. While numerical goals promote pollution prevention, reporting requirements inhibit them. The two demand-side technology policies analyzed also have opposite effects. Public recognition or awards promote adoption of pollution prevention technologies, particularly those which are involved with process and material modifications which could be indicated on product labels and enhance market reputation. Regulatory relief, on the other hand, inhibits the adoption of pollution prevention technologies. Supply-side technology policies also have different impacts for different types of pollution prevention activities. More flexible types of financial assistance such as tax rebates and grants promote process modifications, but more specific ones such as technical assistance inhibit process modifications, possibly due to firm-specific nature of such types of technologies, which are not amenable to cookie-cutter solutions. Despite being selective with the adoption of pollution prevention activities in response to state level environmental, technology and management policies, firms have stronger and more robust positive responses to actual or threat of enforcement actions associated with federal environmental statutes. Informal regulations from local communities also matter.

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Adoption of Pollution Prevention Technologies: The Role of Environmental, Technology, and Management Policies on Innovation

1. Introduction

The attitude of firms regarding environmental innovations and environmental technology adoption has shifted from being a costly and reactive response to environmental regulation to one of strategic importance. Due to growing public and consumer awareness for environmentally-responsible manufacturing and environmentally benign products, coupled with increasing stringency of environmental regulations, firms are adopting environmental technologies do not only reduce wastes but which also improve product quality, enhance competitiveness with rivals, and lower production costs. This has a resulted in a shift from end-of-pipe abatement technologies to pollution prevention technologies. By reducing or eliminating wastes before they are even generated, pollution prevention can lower environmental liability by complying with multiple environmental statutes, and lower costs of waste disposal and treatment by addressing pollution at source. In addition, pollution prevention technologies can enhance efficiency by improving the manufacturing process, by using less or alternative raw materials, or by redeveloping procedures to produce more benign products. When such products are more attractive to consumers, pollution prevention can also improve overall public reputation with consumers and other stakeholder (Florida and Davison, 2001).

The evolution of environmental regulations from command and control to market-based incentives, and then finally to voluntary programs, business-led initiatives and information disclosure mechanisms is parallel to the shift in firms' attitude toward environmental innovations which is due to the recognition of strategic, and not just compliance motives for environmental innovations and technology adoption (Lyon and Maxwell, 1999). In the United States, promotion of pollution prevention approaches, which is also referred to in the literature as cleaner production, was prescribed under the National Pollution Prevention Act in 1990 which mandates that "pollution should be prevented or reduced at source whenever possible." Since 1991, the US Environmental Protection Agency (USEPA) has mandated the reporting of 8 broad categories of pollution prevention activities to the US Toxic Releases Inventory (TRI) for 581 individually listed chemicals and 30 chemical categories of all facilities belonging to SIC codes 20-39, emitting at least 10,000 pounds of a listed chemical, and employing 10 or more full-time staff. The adoption of pollution prevention activities remains voluntary and is being promoted by the USEPA through various voluntary environmental programs each providing a mix of incentives and assistance. Thirty-six states have also adopted pollution prevention legislations, each providing a mix of environmental targets and monitoring, technology subsidies, and management-based regulations.

This study analyzes how state regulations promote the adoption of specific types of environmental innovations or technologies, specifically pollution prevention activities. The emphasis is on the comparing the effectiveness of environmental, technology, and management policies embodied in state pollution prevention legislations to determine what types of environmental technologies are adopted more compared to others by which types of firms, and under what policy regimes. Are technologies which provide market benefits through better products adopted more than those that are solely focused on the internal operations of the firm?

Are regulations which provide technology policies through greater public recognition, which promise reduced regulatory scrutiny, or which provide direct and indirect financial assistance more effective than direct monitoring and emission limits in promoting the adoption of environmental technologies? Do regulations that mandate the adoption of management tools promote pollution prevention? These are the key questions that are addressed in this paper.

The pollution prevention activities analyzed include Operating Practices which consists of changes in operating practices and materials and inventory control; Cleaning Practices which include spill and leak prevention, cleaning and degreasing, and surface preparation and finishing practices; Process and Equipment Modifications; Raw Material Modifications; and Product Modifications. Environmental policy to motivate firms to internalize the social costs of their pollution includes environmental standards and reporting requirements. Technology policy aimed at promoting more environmental technologies include supply-side inducements such as technical assistance, and financial assistance in the form of direct grants, tax rebates, and fee refunds, and demand-side inducements that include regulatory relief or expedited permitting and awards or recognitions for good performers. Management policy refers to mandatory planning for pollution prevention or management-based regulations.

The use of multiple instruments or policies in promoting environmental technology adoption or innovation has been widely investigated in the literature. Carraro and Soubeyran (1993) and Carraro and Siniscalco (1994) demonstrated that environmental regulations that incorporate both environmental policies and industrial/technology policies may be more efficient than traditional environmental policies. Because a private firm's decision to adopt environmental technologies is subject to two market failures: the imperfect appropriability of the benefits of own innovations, and negative externalities from its pollution, environmental regulations must include both environmental policies and technology policies (Katsoulacos and Xepapadeas, 1996, Jaffe et al 2004), and that the latter must include both demand-pull incentives that increase public and regulatory demand for cleaner technologies, and supply-push incentives including subsidies, tax credits and information provision about new technologies (Jaffe et al 2004). Boyd (1998) further adds that regulations must also provide an environmental management tool, environmental-cost accounting information to promote innovation, not just compliance. The importance of management is further emphasized by DeCanio et al (1998, 2000) who found that econometric models which ignore organizational structure and management practices do not perform well in explaining the adoption of energy efficiency upgrades or of diffusion of profitable innovations because they suspect that organizational structures defines information flow and nature of communication within different units of a firm which is essential for technology adoption, innovation and diffusion.

Despite the recommendations for a mix of policies in environmental regulations, existing analytic work which have compared the effectiveness and efficiency of regulatory instruments in promoting innovation have focused on contrasting market-based versus command and control regulations (Milliman and Prince, 1989; Jung et al 1996), using varying assumption on the nature of permit market (Parry 1998; Keohane 1999, Denicolo 1999), costs of innovation, benefit functions and number of polluting firms (Fischer 1998), or type of market competition (Montero 2000). Empirical comparisons of various instruments are also rare because there are few regulations that incorporate a mix of environmental, technology, management policies, making comparisons of relative effectiveness challenging. Except for

Frondel et al (2007) and Arimura et al (2007) who compared innovation behavior of facilities in OECD countries, in response to various types of policies, most of the empirical work that have attempted to link regulatory instruments with innovation have separately investigated the impact of environmental, technology and management policies on various measures of environmental innovations.

The studies that deal with establishing a link between specific environmental policies and adoption of specific types of environmental technologies have covered different measures of regulations and various measures of environmental innovation. Both Lanjuow and Mody (1996) and Brunnermeir and Cohen (2003) used environmental abatement expenditures as a measure of regulatory stringency and both found positive significant effects on patents. Jaffe and Palmer (1997) used environmental compliance expenditures as a measure of regulation and found that while R&D expenditures increase with compliance costs, patents do not. Cleff and Rennings (1999) further differentiated between process and product environmental innovations and demonstrated that process innovations respond more to "formal" regulations, while product innovations respond to "soft regulation" which operates through market strategic motives.

The more commonly empirically tested technology policies are energy efficiency standards, fuel efficiency standards and technological subsidies, but the studies have so far shown mixed evidence. Jaffe and Stavins (1995) provided a detailed comparison of the effectiveness of technology subsidies (cost of energy efficient technology) and technology standards (state level mandatory and voluntary energy efficiency codes) and one environmental policy in promoting investments on energy efficiency in new house construction and found that adoption of energy efficiency enhancing technologies respond to both technology price and quantity policies and that the energy costs are three times more effective in inducing adoption of energy efficient technologies than energy prices were. Greene (1990) found that development of more fuel efficient automobiles are influenced by gasoline prices (technology subsidy) and CAFÉ standard (technology efficiency standard), but the responsiveness varies across auto manufacturers in US, Japan and Europe, because the countries differ in their regulatory environments. Hassett and Metcalf (1995) further distinguished between different types of technology subsidies (technology adoption costs) and found that upfront costs (installation costs) and operating costs (energy prices) have different impacts on investment behavior. Studies that cover demand-side technology policies are sparse. Newell et al (1999) analyzed the effect of a different type of technology policy (vis-à-vis the effect of energy prices) on the purchase of home appliances. The technology "standard" was defined as a labeling requirement that can increase the value of certain product characteristics by making them more visible to consumers, serving as a demand-side inducement. While they found that technological changes were more autonomous, they did find some weak evidence of change due to energy prices and efficiency standard.

The bulk of the existing empirical studies that analyze the link between firm adoption of management systems have mostly focused on analyzing the determinants of voluntary adoption, with emphasis on their comprehensiveness (Henriques and Sadorsky, 2007; Khanna and Anton, 2002), whether they are certified or not (Henriques and Sadorksy 2007; Nakamura et al 2001), their impact on environmental performance (as in Dasgupta et al, 2000; Anton et al 2004; Johnstone et al 2007) or their simultaneous relationship with environmental performance

(Johnstone et al 2007). While Snyder (2000) and Bennear (2006), found planning and management specified in state environmental legislations to be significant motivators for the adoption of pollution prevention technologies, these studies focused on mandatory management tools only, and did not control for other policies included in the state legislations.

Two recent studies, Arimura et al (2007) and Frondel et. al. (2007), have analyzed a wider variety of environmental, technology and management policy instruments, such as input taxes, pollution taxes performance standards, information, technical assistance, importance of public image, and various management tools, using data for facility-level data for OECD countries. Arimura et al (2007) focused on explaining R&D expenditures, while Frondel et al (2007) compared adoption of end-of-pipe technologies and cleaner production technologies. Frondel et al (2007) found that some policies promote end-of-pipe abatement technologies only, while others promote cleaner production technologies. Arimura et al (2007) also found that environmental R&D respond positively to technology subsidy and specific management tools, but not to traditional environmental taxes and standards.

This study also uses pollution prevention activities as measure of environmental innovation, like Snyder (2000) and Bennear (2006), but incorporates environmental and management policies, like Frondel et al (2007) and Arimura et al (2007). In contrast to Frondel et al (2007) and Arimura et al (2007), this paper analyzes a range of pollution prevention activities that serve various purposes for the firm: from cleaning and operating to process, material and product modifications. Further, the technology policies analyzed here cover both demand-side and supply-side inducements.

The paper proceeds as follows: Section 2 presents the conceptual framework and generates the hypotheses. Section 3 discusses the empirical issues and the empirical estimation procedure used. Section 4 describes the data and data sources. Section 5 discusses the results, while Section 6 concludes.

2. Conceptual Framework

A profit-maximizing firm chooses the privately optimal level of innovation where the private marginal benefit from technology adoption is just equal to the private marginal costs. Costs of adoption include cost of searching, learning, developing, and adopting new or existing technologies. The benefits from technology adoption depend on the type of environmental technology. Technologies that involve raw material substitutions and product redesign bring about gains in the form of higher revenues due to better product quality which can boost sales. Process modifications and procedural changes that enhance efficiency of day-to-day operations and manufacturing confer benefits in the form production costs. Technologies that avoid accidents and risks on the production floor also directly reduce costs associated with environmental incidents that may lead to accidents and lawsuits. All types of technologies above, also reduce overall pollution levels, reducing the probability of environmental violations and liability. Because a firm's decision to adopt a level of each type of technology takes into account only the private benefits that accrue to him, the private level of technology adoption tends to be lower than socially optimal. It does not take into account some technological spillovers from his technologies that could benefit other firms as well. As a result, and because it e also takes into account of only private costs that he incurs, without regard for the effect of its unabated pollution to the rest of society, private pollution levels are higher than socially optimal.

Because firms take into account their private benefits and costs (Katsoulacos and Xepapadeas, 1996; Jaffe and Stavins, 2004) or they fail to seek profit-making opportunities in pollution prevention due to regulatory and technical barriers (Boyd 1998), regulations need to include environmental, technology and management policies. An environmental policy in the form of an emission standard or a reporting requirement can pose as a threat of potential enforcement action to firms which can encourage them to adopt pollution prevention technologies to comply with the standard, report good environmental performance and avoid environmental liability. However, mandated reporting, can makes one's activities and performance more visible to the regulatory agency and the public (as in the USEPA TRI), it can also promote other pollution-mitigating technologies.

Technology policies include both demand-side and supply-side policies. Demand-side policies may be in the form of awards, which can directly enhance the benefits from innovation, while regulatory relief in the firm of expedited permitting, or fewer inspections, reduces the probability of being regulated in the future. Awards or public recognition for participation and/or for good performance can improve a firm's its reputation with the community or consumers. Expedited permitting and preferred regulatory status may be able to attract firms to participate in state level environmental programs to improve their relations with the state environmental agencies. However, like the case of reporting requirement, regulatory relief can be enjoyed for better environmental performance, regardless of how the emissions are reduced. Thus, regulatory relief may promote or inhibit pollution prevention activities.

Supply-side innovation policies include those which directly provide technical assistance or financial transfers to firms to reduce their costs of technology adoption. Technical assistance includes provision of networking opportunities or clearinghouses for pollution prevention technologies and training of environmental staff employees. By providing an information clearinghouse, some state pollution prevention programs facilitate information and technology sharing among firms that may lower their costs of searching, developing or adopting new technologies. Financial assistance includes direct monetary grants and transfers and which can be considered technological subsidies. Direct monetary grants can provide firms the opportunity to undertake costly investments in technologies which they would otherwise not have undertaken on their own due to limited resources or lack of employee expertise to undertake environmental innovations.

Management policies can further reduce the cost of identifying and adopting environmental technologies. They enable firms to more cost-effectively identify pollution-reducing opportunities and respond to regulations that are appropriate to each firm's capacity and needs (Coglianese and Nash 2006) and facilitate communication and learning among different units (DeCanio et al, 1998, 2000).

Aside from technical assistance that firms enjoy through the state pollution prevention legislation, firms may also learn from the adoption of pollution prevention technologies by other firms within the same parent company. These spillovers and technological opportunities form peer firms may enhance a firm's capacity to develop its own pollution prevention technologies (Griliches 1992; Jaffe, 1986) and are controlled for in the analysis. Other firm and industry-specific regulatory and market and community pressure variables, are also hypothesized to significantly influence its adoption of pollution prevention technologies (Arora and Cason, 1996; Videras and Alberini, 2000; DeCanio and Watkins, 1998; Khanna and Damon, 1999; Dasgupta et al, 2000; Brooks and Sethi, 1997).

3. Empirical Framework

Due to the count nature of the dependent variable, Poisson models are used to explain the adoption of pollution prevention technology. To account for facility-specific heterogeneity, the following estimating equation is used:

$$E[P2_{it}] = exp\left(\beta_1 L_{it} + \delta P2_{jt} + \vartheta X_{it} + \alpha_{1i} + \varepsilon_{1it}\right) \quad (1)$$

where the dependent variable, $P2_{it}$, is the count of pollution prevention activities of facility i at time t. The variable L_{it} represents the dummy variable that takes the value 1 if the facility i is located in state with pollution prevention legislation at time t, and 0 otherwise. The variable $P2_{jt}$ is the average number of pollution prevention activities undertaken by other facilities $j \neq i$ that belong to the same parent company and represents the extent of spillover from other firms. The vector X_{it} represents other firm and location-specific explanatory variables. The parameter α_{1i} is the time-invariant unobserved firm specific effects and ε_{it} represents the error terms, with mean zero and variance $\sigma^2_{\varepsilon_{1it}}$. If the facility-specific parameter, $\alpha_{1i}$is correlated with other explanatory variables, then a fixed effects model is more appropriate. However, if α_{1i} is assumed to be an iid random variable with mean zero and variance σ^2_{α}, a random effects model is appropriate, and the model will estimate an intercept parameter.[1]

[1] The stock or total cumulated count of pollution prevention activities in the past were dropped from the estimating equation for several reasons. First, they are highly correlated with the current count of pollution prevention activities, and would require dynamic models as in Crepon and Duguet (1997),

Because not all state level pollution prevention legislations are the same, the model above is extended to include the specific policies. In the equation below, M_{it} represents the interaction of the state legislation dummy, L_{it} with a dummy variable for management policy, m_{it}, E_{it} is the interaction with the state legislation with a vector of environmental policy dummies, e_{it}, and T_{it} the interaction with the state legislation with a vector of of both demand-side and supply-side innovation policy variables, t_{it},

$$E[P2_{it}] = exp\left[\beta_1 L_{it} + \beta_2 M_{it} + \beta_3 E_{it} + \beta_4 T_{it} + \delta P2_{jt} + \vartheta X_{it} + \alpha_{1i} + \varepsilon_{1it}\right] \quad (2)$$

Because all pollution prevention legislations that require planning were legislated prior to 1991, when the reporting of pollution prevention activities started, there is no variation in management policy and in some of the environmental and innovation policies that were implemented in conjunction with those planning policies. To avoid dropping theses variables

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Blundell et. al. (1995), and Hill et. al. (1998) who used dynamic count models which are more appropriate for longer panels or for datasets where the series of the dependent variable is longer than the series of explanatory variables (Blundell et. al., 1995; Hill et. al., 1998). This condition is not met for this case, since data on pollution prevention activities were available only starting in 1991, while pollution data and data on other enforcement actions are available since in 1987. Second, the data would imply zero cumulated stock for 1991 which is highly suspect, because firms could have been adopting pollution prevention activities in the past, even if the states with legislated pollution prevention programs prior to 1991 have only been moderately successful. Even if the analysis would use data starting in 1992, the very low cumulative counts of pollution prevention activities in 1992 (which is the 1991 data) is still suspicious the adoption of pollution prevention activities. Thus, cumulative stock of pollution prevention activities is not included in the results. Nonetheless, non-panel data models that include cumulated stock of pollution prevention technologies as explanatory variables were also investigated (results are not shown here) and they yield very similar results in terms of the role of state pollution prevention legislations and the role of management, environmental and technology policies, although the significance and signs of some facility specific measures of enforcement actions were different. However, the cumulated stock was always highly positive and significant. To the extent that these cumulated counts are highly correlated with current counts and can capture inherent tendency or propensity to adopt pollution prevention activities, it its inclusion may capture facility-specific effects as in panel data models (Cameron and Trivedi, 1998), which is the model used in this study. There are several other models with dynamics components but they focus on the role of lagged explanatory variables, such as lagged R&D (Hausman et al 1984l Cincera 1997), or lagged spillovers (Cincera 1997) to explain patents.

of interest in fixed effects models, the time-invariant policies are interacted with the number of years they have been in place.

Since another potential issue is heterogeneity that results from over-dispersion due to the high number of zeroes, double hurdle Poisson (as in Cragg, 1971; Mullahy, 1986) and zero-inflated Poisson (ZIP) models (Lambert, 1992) are also estimated. Both models assume that the binary decision to adopt/not adopt is different from the decision on how many to adopt, if one has already decided to adopt a pollution prevention technology. The hurdle model recognizes that because zero counts may be reported by firms who never adopted pollution prevention technology, or from those who do, but not in the period specified, modeling zero and positive would result in a misspecification (Cameron and Trivedi, 1998). Thus, in hurdle models, the probability of reporting zero and reporting a positive count are distinct and are specified as follows:

$$Pr[P2 = 0] = f_1(0); \qquad Pr[P2 = r] = \frac{1-f_1(0)}{1-f_2(0)} f_2(P2), \quad r > 0$$

where f_1 is the density of the zero counts, $f_2$is the density of the positive counts, and r is a positive count. The appropriateness of the hurdle model relative to the standard Poisson model is tested by comparing the log-likelihood of the standard Poisson model with the sum of the log-likelihood of the probit and the log-likelihood of the truncated Poisson model (Mullahy, 1986).

The ZIP model, on the other hand, models excess zeroes differently and recognizes that excess zeroes may come from mis-recorded observations, where the mis-recording is concentrated on the zero class (Cameron and Trivedi, 1998). In ZIP, the probability of reporting zero and reporting a positive count are also distinct: and they are, respectively:

$$Pr[P2 = 0] = \gamma_i + (1-\gamma_i)e^{-\mu_i}; \qquad Pr[P2 = r] = (1-\gamma_i)\frac{e^{-\mu_i}\mu_i^r}{r!}, \quad r = 1,2 \ldots 0$$

where $\mu_i = E[P2_i]$, γ_i is the proportion of zeroes. While the over-dispersion in the hurdle model is due to excess zeroes, the overdispersion in the ZIP model is due to individual heterogeneity among the positive counts (Cameron and Trivedi, 1998). Because the nature of the suspected overdiserpsion is not known, both the as hurdle and ZIP models are investigated in this study, in addition to standard Poisson, and fixed and random effects Poisson.

4. Data Description and Sources

The sample consists of facilities whose parent companies are among the S&P 500 firms reporting to the US Environmental Protection Agency Toxic Releases Inventory (TRI) from 1991-2001, for a total of 45,584 observations. Those observations with missing data, and those which report zero pollution prevention counts for all the years in the sample are dropped. The final analysis sample consists of 2,464 unique facilities from 1991 to 2001 for a total of 20,456 observations[2].

INSERT TABLE 1 HERE

The counts of new pollution prevention activities, number of *Chemicals* of each facility, number of *Facilities* for each parent company, and the average count of pollution prevention activities adopted by other facilities belonging to the same parent company, denoted as *Spillover P2*, are obtained from the TRI from 1991-2001. The count of pollution prevention activities is a sum of new pollution prevention techniques adopted for a given year which can fall into one of

[2] The number of observations is different when different types of pollution prevention are estimated because some types of P2 may not be adopted, even if total pollution prevention is nonzero.

the 8 broad categories indicated in Table 1. The USEPA list of pollution prevention activities are classified into eight (8) categories: (1) changes in operating practices (2) materials and inventory control (3) spill and leak prevention (4) raw material modifications (5) process modifications (6) cleaning and degreasing (7) surface preparation and finishing practices and (8) product modifications. Each of the 8 categories consists of more detailed practices. As Table 1 shows, the eight categories of pollution prevention practices analyzed in this paper are grouped into five broader categories in terms of the benefits they provide to the firms and according to the overall purpose they serve: whether they emphasis operational efficiency that is internal to the firm, or improvement of products that have repercussions on a firm's relations with external stakeholders. Internal-oriented types of pollution prevention include *Operating Practices* (Types 1 and 2), *Cleaning Practices* (Types 3, 6 and 7) and *Process Modifications* (Type 5), while external-oriented P2s include *Material Modifications* (Type 4), and *Product Modifications* (Type 8)[3].

Operational practices consist of specific scheduling activities and operational procedures. They involve low level of technical expertise but may require more frequent updating or monitoring to be effective. They usually involve activities that are part of day-to-day operations. Cleaning practices involve prevention of spills or avoidance of residues and wastes from work areas. Such types of activities deal with preventing the very visible types of air and water pollution from operations through procedural changes or capital equipment modifications. Adaptations or improvements of these technologies or practices may be less frequent than operating practices. The previous two types involve activities that are very firm-

[3] This classification is used to differentiate between benefits and costs that are internal and external. But as Deltas et al (2006) show, these P2 technologies area composite of various attributes.

specific and may be visible only to employees and managers on the production floor. They are key to a firm's operations but are largely imperceptible to the public.

Modifications of inputs, processing systems or equipment, and products can be considered more technologically sophisticated types of innovations. These changes may not be as frequently undertaken as operational or cleaning types of practices as they may require more involvement from the company's R&D division. But once adopted, it may take longer for another round of modifications to occur. To the extent that such adoption of such technologies are increasingly becoming the basis of product differentiation trough product labeling and advertising and marketing campaigns, they can be considered strategic types of technologies as well.

The levels of *Total* toxic releases, are also obtained from the TRI from 1991-2001. It is the sum of onsite releases to air, water and land including underground injections, and offsite disposal and transfers for other waste management activities. In counting pollution prevention practices and summing up toxic emissions, the chemicals which have been added or deleted (due to changes in the reporting requirements by the USEPA) over the sample period were dropped. This ensures that the changes in pollution prevention activities and toxic releases over time are not due to differences in the chemicals that were required to be reported.

The dates of legislation and policies of state pollution prevention legislations are obtained from the National Pollution Prevention Roundtable[4]. The specific policies that are analyzed in this paper are: (1) *Management* (or Planning), (2) *Environmental* Policies, which include *Numerical Goals* and *Reporting Requirement*; (3) *Supply-Side Technology* Policies such as

[4] National Pollution Prevention Roundtable, http://www.p2.org/inforesources/nppr_leg.html

Technical Assistance, *Grants*, *Free Refunds* and *Tax Breaks*; and (4) *Demand-Side Technology* Policies which include *Regulatory Relief* and *Awards*. These are in table 2. The state level pollution prevention policies are derived as follows. A dummy variable indicates whether the facility is located in a state with any state pollution prevention *Legislation*. To differentiate between those which have mandatory planning requirements, a variable *Management* is also created to signify whether the state has a Management-Based Regulation for pollution prevention. The other policy variables are created as follows: The demand-side policies take a value of 1if the state pollution prevention program provides awards and recognitions, and regulatory relief in the form of preferred treatment, expedited permitting and reduced inspections, respectively, and 0 otherwise. The supply-push technology policies take a value of 1if the legislation provides technical assistance, grants, fee refunds or discounts, and tax rebates, respectively, and 0 otherwise. Finally, the measurement factors for environmental policy component of the legislation are developed as similarly. They take the value of 1 to indicate whether the program prescribes numerical targets and mandate reporting of activities and/or performance, and 0 otherwise.

INSERT TABLE 2 HERE

As Table 2 shows, pollution prevention legislations that mandate planning started in 1988 with Washington, followed by California, Massachusetts and Oregon in 1989. Four states adopted it in the same year as the enactment of the National Pollution Prevention Act in 1990: Maine, Minnesota, Mississippi, and Vermont. The last ones to adopt in 1991 were Arizona, New Jersey New York, Tennessee, and Texas. The design of these pollution prevention legislations varies widely across states, but all of them have a reporting requirement and provide technical assistance to firms in the state. However, eight have numerical goals, only three provide financial assistance to firms, and five provide demand-side incentives. Of the 22 states which have pollution prevention legislations but do not mandate planning, seventeen (17) provide technical assistance, seven provide financial assistance, four set numerical goals. There are fewer states which provide demand-side incentives. Two states provide some regulatory relief through reduce permitting process or preferred treatment, while only Kentucky provides awards and public recognition.

Because firms also face regulatory scrutiny and enforcement actions from federal legislations, not just state pollution prevention legislations, various measures of degree of enforcement of federal regulations are included. The number of *Superfund* sites which a facility has been listed as a potentially responsible party under the provisions of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLIS) is obtained from the CERCLIS database of the USEPA[5]. The number of environmental *Penalties* and the number of *Inspections* for each facility are derived from the USEPA Integrated Data for Enforcement Analysis (IDEA) database of the USEPA.[6] The level of air emissions classified as Hazardous Air Pollutants (HAP) are also obtained from the TRI, using the list of 189 toxic chemicals that are listed in Title III of the 1990 Clean Air Act Amendments which were to be regulated under New

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[5] Because facility indicators from CERCLIS database do not match the facility indicators in the NPRI, we aggregated Superfund sites data to parent company level and matched it with all the facilities of that parent company.

[6] The Inspections variable is defined as the number of times a firm was inspected by state and federal environmental agencies to monitor compliance with mandatory regulations. Penalties refer to the number of times a facility has been cited for and has been penalized 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. Since data on inspections and penalties are available at the sub-facility level, inspections and penalties of all sub-facilities of each facility are added up to get facility level data.

Emissions Standards for HAP starting in 2000.

Because there are other state-specific environmental regulations aside from the pollution prevention legislations which are of main interest in this paper, various location-specific indicators of formal and informal regulations to measure extent of local regulatory scrutiny are also controlled for. A measure of the stringency of the regulatory climate for air pollution in the county where the facility is located is the *Non-attainment* status based on their 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, and nitrogen oxide and particulate matter. 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 each facility and the resulting counts is used as the *Non-attainment* variable (as in List, 2000). The *Non-attainment* status of counties is obtained from the USEPA Greenbook[7]. Other socio-economic and demographic characteristics are also controlled for including measures of environmental activism or community activism (as in Brooks and Sethi, 1997). These include *Percentage White* and *Per Capita Income*, *Percentage with a Bachelor's Degree* which are derived from the 1990 and 2000 Census by the Bureau of Census[8]. Political climate variables such as state-level *House* of Representatives voting record on environmental bills may also reflect the political climate in the county or state, which may then influence environmental-related activities. *House* voting record is obtained from the League of Conservation Voters from

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

[8] Can be found at http://www.census.gov/. The 1991-2001 data is extrapolated using a constant rate of growth of each variable in each area.

1992-2001[9].

The summary of all the variables, their means, standard deviations, and ranges are summarized in Table 3. Slightly less than 80 percent of the sample facilities analyzed in this study are located in states with pollution prevention legislation. These facilities have slightly lower counts of pollution prevention technologies compared to facilities in states without pollution prevention legislation. The range of counts of pollution prevention activities adopted is slightly narrower as well, with the maximum number of 66 compared to 84 among facilities in states with and without pollution prevention legislations, respectively. Further, the facilities in states with pollution prevention programs have almost twice as much total toxic releases, have been inspected 40 percent less but have been subjected to penalties 30 percent more than facilities in states without pollution prevention programs. The average regulatory stringency in the counties of states with pollution prevention legislations are fairly similar, except for nonattainment status and per capita income, which are slightly higher in states with pollution prevention programs.

INSERT TABLE 3 HERE

5. Results

The panel structure and count of the data require various specification tests shown in Table 4. Model I-A and I-B are Poisson model with non-robust and robust standard errors, respectively. Models II-A and II-B are random and fixed effects models. Models III-IV address potential over-dispersion in Poisson models due to many zeroes (without controlling for

[9] See http://www.lcv.org

unobserved heterogeneity). Models III-A and III-B are the probit and zero truncated Poisson models, while Models IV-A and IV-B are the first and second stages of the zero inflated Poisson (ZIP) models.

The significance of the panel-level variance component, at the 1 percent level, as shown by the likelihood ratio test indicates that that the panel estimators are better than the pooled estimators. Further, the Hausman test shows that the fixed effects model is more appropriate than the random effects model. While the dispersion parameter is highly significant in the negative binomial model (not shown), the over-dispersion may be more likely due to having 85% of observations having zero P2 counts. Further, the log likelihood of the standard Poisson is lower than the sum of the log-likelihoods of the probit and the truncated Poisson, indicating that the double hurdle model is more appropriate than the standard Poisson model. The ZIP model also has a higher log-likelihood than the Poisson model. There is no test to compare the ZIP or the double hurdle Poisson with either panel data models. However, both fixed effects and random effects models have higher log-likelihood than the hurdle and ZIP models. Because there are substantial differences in the signs and significance of many variables between the panel data models (Model II) and pooled models (Models I, III, and IV) but there is not much difference in the signs and significance of most variables between standard Poisson and either of the two-stage models (ZIP and double-hurdle) (more discussion below), and because there is also little variation in the signs and significance of most variables between the two stages of ZIP and double-hurdle (except for a few exceptions), accounting for facility-specific heterogeneity rather than over-dispersion seems to be more appropriate. Thus, the fixed effects estimators are used in subsequent analysis (results in Tables 5 to 7).

INSERT TABLE 4 HERE

The differences in signs and significance of coefficients between pooled and panel models are observed for the firm-specific measures of enforcement actions and location-specific proxies of formal and informal regulations. Penalties and past toxic emissions, and per capita income are always positive and significant in the panel data models (both fixed and random), while they are negative significant in the pooled models.[10] These differences between pooled and panel models is not very surprising. There may be unobservable facility-specific characteristics which are highly correlated with the level of environmental liability and regulatory scrutiny that a facility faces, rendering coefficients in pooled models inconsistent relative to coefficients from of fixed effects models. Among the county and state controls that capture location specific measures of regulatory stringency, only percent white and House voting record have consistently positive, and negative significant effects, respectively, across all models. Because the location-specific measures of formal and informal regulations are at a highly disaggregated level (county level) as well. These location-specific variables may also be strongly associated with the facilities' activities in their local communities. This may also explain wide differences between the pooled and panel data models.

Nonetheless, the impact of state pollution prevention legislation, after controlling for these state and county level regulator factors is fairly robust to different specifications and is always significant at the 1 percent level. However, its sign is negative, contrary to expectations. The succeeding results further explain the role of management, environmental and technology

[10] Further, in the double hurdle model, past emissions has opposite effects for the binary and the count decision, while in the ZIP model, lagged HAP emissions has different significant signs for the binary and the count decision.

policies embodied in various state pollution prevention legislations on adoption of pollution prevention activities.

The role of incentives and design features of the different pollution prevention programs as embodied in their management, environmental and technology policies are further analyzed in Table 5. Model V differentiates only between pollution prevention legislations that are purely voluntary, i.e., adoption and reporting are voluntary, and those which mandate pollution prevention planning and reporting by incorporating only the *Management* policy dummy, or the presence of a management based regulation. Because some features of states with and without mandatory planning for pollution prevention are similar, Model VI and VII further differentiate the state pollution prevention legislations according to their environmental and technology policies. In Model VI, aside from the management policy the policies are grouped into three broad categories: (a) *Environmental* policy, (b) *Demand-side Technology* policy, and (c) *Supply-side Technology* policy. Model VII breaks down these policies into their more detailed components.

INSERT TABLE 5 HERE

Table 5 shows that accounting for only differences in the presence of a *Management* policy does not change the results to much, with state pollution prevention legislations still negative and significant. When *Environmental* and *Technology* policies are taken into account, state pollution prevention legislation has a positive effect on adoption of pollution prevention activities, but there are specific program features that surprisingly, seem to inhibit adoption of pollution prevention technologies. More specifically, Model VI shows that when the state pollution prevention legislations offer demand-side technology policies only, the count of pollution prevention activities undertaken will definitely be higher, and the effect is greater the longer the demand-side incentives have been in place. However, *Environmental* policy and *Supply-Side Technology* policy are not. In fact, *Environmental* policy seems do not seem to promote pollution prevention, while *Supply-side technology* policies seem to have a strong negative effect (Model VI). In these detailed models, *Management* policy also seems to inhibit adoption of pollution prevention technologies, which is contrary to expectations and to the results of existing studies on the role of management systems.

Because there are several categories of demand and supply technology policies, and of environmental policy, breaking down these features further show which market stakeholders create a positive demand-pull effect on pollution prevention adoption. Between the two demand-side factors, *Awards* has a stimulating effect, suggesting that improved reputation among consumers, local communities, environmental groups and the public create incentives for pollution prevention pollution prevention, similar to Frondel et al (2007). On the other hand, *Regulatory Relief* seems to inhibit pollution prevention. These results seem to indicate that pollution prevention activities respond more to strategic pressures that involve public trust and recognition, rather than the motivation to reduce compliance costs. As mentioned earlier, it was not clear whether regulatory relief in the form of expedited permitting, or reduced inspections is tied to adoption of pollution prevention activities directly, or indirectly, through emission reduction, which could be achieved by other pollution mitigating activities as well. These alternative methods for pollution mitigation may substitute for the adoption of pollution prevention technologies, hence the negative sign.

Among the supply-side technology policies, *Technical Assistance* and *Grants* are insignificant, while *Fee Refunds* is negative significant. However, *Tax Rebates* is highly positive and significant. It seems that direct assistance that is linked to activities related to the program directly are counterproductive or insignificant at best, while tax rebates, which can be provide direct monetary gain that can be used more broadly for other investment and innovative activities promote pollution prevention.

For the case of environmental policies, only state *Numerical Goals* promote pollution prevention, while those with *Reporting Requirement* either inhibit pollution prevention adoption or have no significant effect. While numerical goals serve as an environmental target for the state environmental agency, it may also provide a way for firms to benchmark and assess their own performance, and as such, may create some motivation for firms to innovate and adopt pollution prevention technologies. On the other hand, while reporting requirements also serves as a monitoring tool, it may provide greater visibility to the regulator of a firm's activities, and may in some cases, may dissuade it from adopting environmental practices lest it be used as a signal for high pollution levels, and hence, a basis for regulation. Further, firms may prefer to adopt end-of-pipe abatement technologies that they perceive may have a more immediate impact on their environmental performance, causing a shift away from pollution prevention technologies.

To further illuminate on the role of environmental and technology policies on pollution prevention adoption, the response of different types of pollution prevention technologies is analyzed and the results are shown as Models VIII A-E in Table 6. Results show that while regulatory relief inhibits total pollution prevention, it has a positive significant impact on the adoption of *Product Modifications*, and no or negative significant effect on other types of pollution prevention activities. The reason for a market-oriented type of pollution prevention to respond positively to regulatory relief is unclear. On the other hand, while awards has a positive effect on the total count of pollution prevention activities, it only promotes *Process* and *Material Modifications* and has a negative effect on *Cleaning Practices*. Because many production processes and raw material changes can be signaled through the final product through various types of product labels and marketing campaigns, the visibility factor of these two types of technologies may be the reason that firms in states that provide public visibility benefits adopt more of them. On the other hand, cleaning types of pollution prevention technologies are adopted less in state pollution prevention programs that provide public recognition. The cleaning types of practices as shown in Table 1, may be construed as a sign of non-environmentally sound manufacturing, high volume of wastes and high levels of production inefficiency. Furthermore, while technical assistance and grants have insignificant impacts on total pollution prevention, they have negative and positive significant impacts, respectively on *Process Modifications*. Environmental policies also have variable impact on different types of pollution prevention activities. Numerical goals promote *Process Modifications*, while reporting requirement promote *Operating Practices*. The other policies either have a negative significant or no significant effect on the number of pollution prevention technologies adopted.

INSERT TABLE 6 HERE

Finally, the federal enforcement actions experienced by firms (inspections, penalties, HAP), past level of emissions, positive significant determinants of adoption of total pollution prevention activities, although some of these factor shave variable impacts on different types of technologies. This result indicates that despite the ineffectiveness of some state level policies, federal regulations work in promoting the adoption of pollution prevention technologies. Non-attainment status however, has a counterproductive impact, which may be due to potential use of end-of-pipe abatement technologies and substitution away from pollution prevention, to comply with these regulations. Informal regulations also seem to play an important role. Facilities in regions with high per capita income, low percentage of population with a Bachelor's degree, high percentage Caucasian, and worse Congressional representative voting record adopt more pollution prevention technologies. Spillovers from other firms are also always positive and highly significant.

6. Discussion and Conclusions

Pollution prevention technologies which can provide win-win opportunities by reducing environmental liability while providing market benefits are increasingly being adopted by firms. Because these technologies also reduce the cost of monitoring and enforcement of media-specific regulations, various levels of government are also trying to further encourage the adoption pollution prevention activities through a combination of various policies. The findings show that state pollution prevention legislations promote pollution prevention activities, provided there is an appropriate mix of management, environmental and technology policies. The impact of state pollution prevention legislations and the policies also vary across types of technologies.

The findings show that management policy inhibits adoption of pollution prevention practices, particularly cleaning practices, process modifications and product modifications, which add fuel to the debate on the role of management systems on innovation, given that existing studies already provide mixed evidence. In analyzing management systems and innovation, a central concern is the wide range of practices (written policy, having an environmental personnel, to internal and external auditing, benchmarking, accounting, reporting, and employee training) which can qualify as environmental management and planning. The management activities undertaken by firms in this sample may also be highly heterogeneous, and may have varying impacts on firms' innovation activities. It may also be the case that some management activities such as internal auditing and employee training require highly specialized and skilled manpower that could have been used for innovative activities. It may be worthwhile for future research to identify which management tools promote, and which inhibit the adoption of pollution prevention technologies.

In terms of the role of environmental policies in promoting the adoption of environmental innovations, three points deserve mention. First, the environmental policies analyzed here are quite different from those analyzed in existing literature. This study differentiates between facility specific regulations and enforcement actions (such as inspections, penalties,), and state level regulatory policy that sets numerical goals and reporting requirements to all firms in the state, beyond any federal requirements, and regardless of industry. Second, the negative significant effect of reporting requirement begs the question of whether firms are indeed adopting other types of pollution mitigating technologies to be able to achieve a cleaner environmental record. Third, the positive significant effect of numerical goal but the negative significant effect of reporting requirement may also imply that we should be careful about environmental policy design and mixing-and-matching instruments when other policies, in the same way that Gunningham and Grabosky (1998) warn against counterproductive interactions among regulatory instruments. In this case, the issue may lie in the existence of a federal level information disclosure program, the USEPA Toxic Releases Inventory (TRI) which collects data on toxic emissions and pollution prevention activities for all manufacturing firms in the US. While setting numerical targets at the state level, which is absent at the federal level, may be effective at achieving environmental goals, the duplication of reporting requirements may pose as an additional administrative burden to firms, and/or may pose as an additional threat of heightened stringency if the firms fear that the reports will be used to modify regulations, and increase enforcement activity. The above have seems to be true especially for process modifications, the adoption of which is higher for firms in states with numerical goals, but lower in states with a reporting requirement. Reporting process modifications may reveal details about its manufacturing process and the use of inputs, and hence, may be information that firms would rather not make available to the state regulatory agency. On the other hand, operating practices are adopted more by firms in states with reporting requirements, but it is not significantly affected by numerical goals. Operating practices, are more procedural and managerial in nature, and hence, may not be an area that would raise regulatory scrutiny. Testing for whether there is technology substitution or a negative interaction between regulatory instruments would be another interesting subject for future research.

The demand-side technology policies analyzed here also seem to give quite surprising results, and the findings distinguish between the importance of key external stakeholders: community/public/consumers, and the regulatory agency. The positive sign and significance of awards imply that firms care about public image and trust, consumer reputation and goodwill with its community, similar to Frondel et al's (2007) fndings, especially for process and material modifications. The negative significance of regulatory relief, on the other hand is quite surprising as it seems to indicate that not only is the desire for liability cost savings not important, but instead, regulatory relief has a counterproductive effect on pollution prevention activities. However, the analysis here, unlike Frondel et al (2007) focuses on pollution prevention technologies, only and does not contrast its adoption with that of end-of-pipe abatement technologies. It may be the case that compliance can better be achieved by other measures which are more visible to the regulator (say through installation of new equipment) and/or more immediate, as opposed to pollution prevention, which may be process- or input oriented, and as such may involve more time to develop and tailor to a firm's operations. Frondel et al (2007) indeed found that compliance motives matter for the adoption of end-of-pipe abatement but not for cleaner production. In this study, the negative impact of regulatory relief is observed for cleaning practices, process modifications and material modifications, whose impact on emission mitigation could also be achieved through treatment and disposal of wastes which are end-of-pipe techniques. However, it is not clear why product modifications are adopted more by firms in states which provide regulatory relief. It may be the case that such types of innovations are not readily substitutable with end-of-pipe abatement technologies, and hence, the compliance motive does not substitute for other motives for pollution reduction, such as improvement of product quality and greater market returns.

Finally, supply-side factors, in the aggregate, inhibit, rather than promote the adoption of total pollution prevention activities. Further, when distinction is made among various supply-side policies, the findings indicate that the cost-reducing effect of supply side policies depend on the type of pollution prevention technology and the type of assistance given.

Technical assistance seem to inhibit the adoption of technologies that require more firm-specific design and adaptation such as process modifications which may not benefit from cookie-cutter types of assistance from regulators. It requires tailored design and adaptation to a firm's processes and operations. However, process modifications are the only type that benefits from grants, which is a more flexible type of support, as the firm can use grants to fund its own innovations and technology developments. Tax rebates also seem to be a more effective supply-side support as it provides the firms more flexibility in using the funds for their own needs. However, fee refunds and discounts are not only insignificant, they are negative significant for operating and cleaning practices and for product modifications. It is not clear why this type of support which is based on participation inhibits pollution prevention.

While the management, environmental and technology policies have mixed impacts on the adoption of pollution prevention activities, and on different types, the evidence for learning and spillover from peer facilities and enforcement actions for federal environmental statutes (penalties, inspections, HAP emissions) seem to be much stronger and robust to specifications. These results have several implications. First, they suggest that management, environmental and technology policies may be more effective if they promote learning and networking among similar firms. Second, enforcement action for federal environmental statutes that are unique for each facility work better, than state level policies that provide standardized regulations for all firms in a state. Lastly, compared to the voluntary innovations encouraged by state pollution prevention legislations, direct regulation, such as inspections and penalties are more effective in promoting pollution prevention activities.

Finally, in analyzing the role of state level legislations as formal regulations, the findings show that we cannot ignore the role of other local regulations, and informal regulations at the county level. Despite the significance of some state level management, environmental and technology policies, the other factors enumerated above consistently show to be significant factors that determine a firm's pollution prevention decision.

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Table 1. Classifications and Summary Statistics of Different Types of P2.

P2 Categories			Detailed Practices [a/]
Internal	Operating Practices	Type 1 Good Operating Practices	13 Improved maintenance scheduling, record keeping, or procedures
			14 Changed production schedule to minimize equipment and feedstock changeovers
			19 Other changes made in operating practices
		Type 2 Inventory Control	21 Instituted procedures to ensure that materials do not stay in inventory beyond shelf-life
			22 Began to test outdated material — continue to use if still effective
			23 Eliminated shelf-life requirements for stable materials
			24 Instituted better labeling procedures
			25 Instituted clearinghouse to exchange materials that would otherwise be discarded
			29 Other changes made in inventory control
	Cleaning Practices	Type 3 Spill and Leak Prevention	31 Improved storage or stacking procedures
			32 Improved procedures for loading, unloading, transfer operations
			33 Installed overflow alarms or automatic shut-off valves
			35 Installed vapor recovery systems
			36 Implemented inspection or monitoring program of potential spill or leak sources
			39 Other changes made in spill and leak prevention
		Type 6 Cleaning and Decreasing	6 Changed to mechanical stripping/cleaning devices (solvents)
			61 Changed to aqueous cleaners (from solvents or other materials)
			63 Modified containment procedures for cleaning units
			64 Improved draining procedures
			65 Redesigned parts racks to reduce drag out
			66 Modified or installed rinse systems
			67 Improved rinse equipment design
			68 Improved rinse equipment operation
		Type 7 Surface Preparation and Finishing	71 Other cleaning and degreasing modifications made
			72 Modified spray systems or equipment
			73 Substituted coating materials used
			74 Improved application techniques
			75 Changed from spray to other system
			78 Other surface preparation and finishing modifications made
	Process Modifications	Type 5 Process Modifications	51 Instituted re-circulation within a process
			52 Modified equipment, layout, or piping
			53 Used a different process catalyst
			54 Instituted better controls on operating bulk containers to minimize discarding of empty containers
			55 Changed from small volume containers to bulk containers to minimize discarding of empty containers
			58 Other process modifications made
			59 Modified stripping/cleaning equipment
External	Material Modf'ns	Type 4 Raw Material Modifications	41 Increased purity of raw materials
			42 Substituted raw materials
			49 Other raw material modifications made
	Product Modf'ns	Type 8 Product Modifications	81 Changed product specifications
			82 Modified design or composition of product
			83 Modified packaging
			89 Other product modifications made

Source: [a/] USEPA Toxic Releases Inventory

Table 2. State P2 Legislations and Policies

State [a/]	# of S&P 500 Facilities [b/]	Year of Legislation	Mgmt Policy (Mandatory P2 Plan)	Environmental		Technology- Supply				Technology-Demand	
				Num Goal	Report	Fin. Asst	Fee Refund	Tax Rebates	Tech. Asst.	Reg. Relief	Awards
AK *	98	1990		✓		✓			✓		
AL	91										
AR	62	1993		✓					✓		
AZ	553	1990	✓	✓	✓		✓	✓	✓		✓
CA	47	1989	✓	✓	✓				✓		
CO	73	1992				✓			✓		
CT	13	1991				✓			✓		
DE	143	1990		✓				✓	✓		
FL	205	1991							✓		
GA	70	1990	✓		✓				✓		
HI	18										
IA	259	1989		✓					✓		
ID	217										
IL	62	1989			✓				✓	✓(1990)	
IN	110	1990				✓			✓		
KS	85										
KY	106	1988		✓					✓	✓	✓
LA *	55	1992			✓						
MA	25	1989	✓	✓	✓				✓		✓
MD	229										
ME	95	1990	✓	✓	✓				✓		✓
MI	113	1994					✓		✓		
MN	96	1990	✓		✓	✓			✓		✓
MO	4	1990									
MS	225	1990	✓	✓	✓				✓		
MT	8	1995				✓					
NC	37										
ND	21										
NE	128	1992							✓		
NH	16	1996							✓		
NJ	16	1991	✓	✓	✓				✓		
NM	172										
NV	366										
NY	42	1991	✓	✓	✓				✓		
OH	247	1992									
OK	15	1993					✓	✓	✓		
OR	131	1989	✓		✓				✓		
PA	8										
RI	147										
SC	336										
SD	29	1992			✓				✓		
TN	118	1991	✓		✓				✓		
TX	13	1991	✓		✓				✓		
UT	146										
VA	39	1994				✓			✓		
VT	8	1990	✓		✓				✓		✓
WA	98	1988	✓	✓	✓				✓		
WI	91	1989							✓		
WV	62	1998									
WY	553										

Table 3. Descriptive Statistics.

Variables	All Observations			With P2 Legislation			Without P2 Legislation		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
P2 Legislation Dummy	0.77	0.42	(0,1)	1.00	0.00	(1,1)	0.00	0.00	(0,0)
Total Pollution Prevention	2.06	4.64	(0,84)	2.01	4.39	(0,66)	2.21	5.41	(0,84)
Operating Practices	0.68	2.22	(0,52)	0.67	2.13	(0,40)	0.74	2.51	(0,52)
Cleaning Practices	0.58	1.95	(0,31)	0.58	1.97	(0,31)	0.59	1.88	(0,28)
Procedural Modifications	0.47	1.62	(0,31)	0.44	1.52	(0,31)	0.55	1.94	(0,28)
Material Modifications	0.22	0.80	(0,21)	0.22	0.78	(0,21)	0.22	0.88	(0,17)
Product Modifications	0.11	0.68	(0,28)	0.11	0.60	(0,12)	0.12	0.88	(0,28)
Average P2 Count of Peer Facilities	1.00	1.15	(0,10.5)	1.00	1.17	(0,10.5)	0.99	1.10	(0,9.73)
Toxic Releases (Million Lbs)	2.13	26.38	(0,3402.82)	1.84	11.08	(0,65.75)	3.12	51.23	(0,3402.82)
Onsite Releases (Million Lbs)	1.82	26.31	(0,3402.82)	1.51	10.88	(0,649.97)	2.87	51.20	(0,3402.82)
Offsite Releases (Million Lbs)	0.30	1.33	(0,39.91)	0.32	1.42	(0,39.915)	0.25	0.96	(0,20.37)
Toxicity-Weighted Releases (Million Lbs)	3.84	40.05	(0,2348.6)	3.84	40.38	(0,2348.6)	3.83	38.92	(0,2007.97)
Number of Chemicals	4.97	6.11	(1,85)	4.97	6.14	(1,85)	4.93	6.04	(1,72)
Number of Facilities	35.78	30.13	(1,133)	35.72	29.95	(1,133)	36.01	30.70	(1,133)
Inspections	3.09	8.36	(0,389)	2.69	7.94	(0,389)	4.46	9.53	(0,152)
Penalties	0.09	0.47	(0,27)	0.09	0.49	(0,27)	0.07	0.38	(0,11)
Lagged HAP Releases (Million Lbs)	0.12	0.40	(0,19.79)	0.11	0.42	(0,19.79)	0.13	0.35	(0,5.91)
Nonattainment Status	0.73	1.05	(0,5)	0.80	1.10	(0,5)	0.50	0.81	(0,4)
House Voting Record	0.46	0.20	(0,1)	0.47	0.20	(0,1)	0.42	0.20	(0,1)
Per capita Income (Thousand $)	17.59	4.35	(5.68,39.84)	18.06	4.35	(5.68,39.84)	16.00	3.96	(7.27,33.58)
Percent with Bachelor's Degree	0.09	0.03	(0.017,0.21)	0.09	0.03	(0.017,0.21)	0.08	0.03	(0.023,0.21)
Percent White	0.81	0.15	(0.20,0.99)	0.81	0.15	(0.20,0.99)	0.80	0.16	(0.25,0.99)
Number of Observations	20,456			15,770			4,686		

Table 4. Different Specifications for the Pollution Prevention Equation.

Variables	Pooled Poisson		Panel Poisson		Double Hurdle Poisson		Zero-Inflated Poisson	
	I-A Non-robust	I-B Robust	II-A Random Effects	II-B Fixed Effects	III-A Probit	III-B Zero Trunc.	IV-A 1st Stage	IV-B 2nd Stage
State P2 Legislation	-0.03615***	-0.03615	-0.07522***	-0.11372***	0.03206	-0.06146***	-0.0474**	-0.06022***
	(0.0118)	(0.0727)	(0.0245)	(0.0278)	(0.0221)	(0.0124)	(0.0240)	(0.0124)
Spillover P2	0.42519***	0.42519***	0.53982***	0.54253***	0.30271***	0.21530***	-0.2922***	0.21290***
	(0.0105)	(0.0667)	(0.0206)	(0.0223)	(0.0227)	(0.0110)	(0.0246)	(0.0110)
Inspections	0.01301**	0.01301	0.009	0.01922**	0.03833***	-0.02399***	-0.0494***	-0.02414***
	(0.0052)	(0.0308)	(0.0075)	(0.0078)	(0.0108)	(0.0054)	(0.0117)	(0.0054)
Penalties	-0.19113***	-0.19113**	0.06392***	0.07493***	0.03405	-0.17976***	-0.0778*	-0.17846***
	(0.0193)	(0.0816)	(0.0223)	(0.0224)	(0.0438)	(0.0200)	(0.0471)	(0.0199)
Past Toxic Releases	0.00344	0.00344	0.05601***	0.06370***	0.05150***	-0.07651***	-0.0803***	-0.07587***
	(0.0067)	(0.0440)	(0.0123)	(0.0129)	(0.0165)	(0.0070)	(0.0174)	(0.0070)
Past HAP Releases	0.09878***	0.09878	0.21893***	0.25757***	0.18114***	0.08380***	-0.1927***	0.08924***
	(0.0188)	(0.1470)	(0.0392)	(0.0407)	(0.0584)	(0.0195)	(0.0598)	(0.0194)
Number of Chemicals	0.84861***	0.84861***	0.86253***	0.89895***	0.05989***	0.87992***	0.0917***	0.87506***
	(0.0086)	(0.0555)	(0.0209)	(0.0258)	(0.0170)	(0.0094)	(0.0188)	(0.0093)
Non-attainment status	0.23385***	0.23385***	0.033	-0.06330*	0.02141	0.19653***	0.0141	0.19310***
	(0.0112)	(0.0735)	(0.0260)	(0.0333)	(0.0212)	(0.0116)	(0.0229)	(0.0115)
House Voting Record	-0.01742	-0.01742	-0.20456***	-0.23671***	0.07967	-0.07019**	-0.1047	-0.07570***
	(0.0266)	(0.1459)	(0.0411)	(0.0439)	(0.0502)	(0.0281)	(0.0549)	(0.0280)
Per Capita Income	-0.04514***	-0.04514***	0.00004	0.03172**	-0.00901*	-0.04239***	0.00021	-0.04107***
	(0.0031)	(0.0156)	(0.0089)	(0.0141)	(0.0052)	(0.0033)	(0.0058)	(0.0033)
Percent Bachelor's Degree	5.67447***	5.67447***	2.34669**	-6.62560**	1.71220***	4.46782***	-0.9849	4.33942***
	(0.3135)	(1.7593)	(1.1028)	(2.7060)	(0.5644)	(0.3328)	(0.6168)	(0.3314)
Percent White	0.39901***	0.39901*	0.35234***	5.47187***	-0.00022	0.25642***	0.0431	0.23759***
	(0.0355)	(0.2300)	(0.1326)	(0.4693)	(0.0639)	(0.0374)	(0.0691)	(0.0370)
Year Trend	-0.03976***	-0.03976***	-0.06677***	-0.05132***	-0.06918***	0.01849***	0.0784***	0.01768***
	(0.0026)	(0.0124)	(0.0056)	(0.0085)	(0.0045)	(0.0027)	(0.0049)	(0.0026)
Constant	-0.79412***	-0.79412***	-0.86963***		0.19246***	-0.27605***	-0.5324***	-0.25013***
	(0.0404)	(0.2874)	(0.1360)		(0.0723)	(0.0419)	(0.0795)	(0.0416)
Log-Likelihood	-54314.984	-54314.984	-36462.579	-27681.286	-13454.813	-26861.593	-40333.94	
LR Test			36000***					
Hausman Test				200.76***				
Number of Observations	20,456	20,456	20,456	20,456	20,456	9,564	20,456	9,564
Number of Groups			2,464	2,464				

Standard errors in parentheses, *** is significant at the 1%, ** is significant at the 5%, * is significant at the 10% levels.

Table 5. The Role of Management, Environmental and Technology Policies, Fixed Effects

	Variables	V	VI	VII-A	VII-B
State P2 Legislation		-0.11516*** (0.0283)	0.13807*** (0.0495)	0.12032** (0.0497)	0.10954** (0.0482)
Management Policy *Yrs		-0.00113 (0.0040)	-0.00735* (0.0044)	-0.01008** (0.0044)	-0.01457*** (0.0047)
Technology Policies	**Demand-Side*Yrs**		0.02051*** (0.0065)	0.01837*** (0.0065)	
	Regulatory Relief*Yrs				-0.03199** (0.0125)
	Awards*Yrs				0.02587*** (0.0072)
	Supply-Side*Yrs		-0.37329*** (0.0584)	-0.42987*** (0.0591)	
	Technical Assistance				-0.04386 (0.0889)
	Financial Assistance				-0.11236 (0.0940)
	Refunds/Discounts				-0.66394*** (0.0953)
	Tax Rebates				0.35507*** (0.1066)
Environmental Policies	**Environmental Policy**		0.07939 (0.0525)		
	Numerical Goal			0.57352*** (0.0948)	0.22664** (0.1153)
	Reporting Reqt*Yrs			-0.03106*** (0.0066)	-0.00966 (0.0111)
Spillover P2		0.54243*** (0.0223)	0.54022*** (0.0223)	0.53113*** (0.0224)	0.52171*** (0.0226)
Firm-Specific Controls	Inspections	0.01903** (0.0078)	0.02088*** (0.0078)	0.01898** (0.0078)	0.01953** (0.0078)
	Penalties	0.07500*** (0.0224)	0.07333*** (0.0224)	0.06573*** (0.0224)	0.05914*** (0.0224)
	Past Toxic Releases	0.06390*** (0.0130)	0.05948*** (0.0130)	0.06009*** (0.0130)	0.06441*** (0.0130)
	Past HAP Releases	0.25796*** (0.0407)	0.24615*** (0.0408)	0.24184*** (0.0408)	0.23618*** (0.0411)
	Number of Chemicals	0.89938*** (0.0259)	0.90434*** (0.0260)	0.90902*** (0.0260)	0.91483*** (0.0260)
County and State Controls	Non-attainment status	-0.06329* (0.0333)	-0.06417* (0.0333)	-0.05425 (0.0334)	-0.06685** (0.0335)
	House Voting Record	-0.23507*** (0.0443)	-0.17107*** (0.0451)	-0.18515*** (0.0451)	-0.15475*** (0.0448)
	Per Capita Income	0.03201** (0.0141)	0.02402* (0.0142)	0.02988** (0.0142)	0.03919*** (0.0143)
	Percent Bachelor's Degree	-6.67079** (2.7108)	-7.15790*** (2.7241)	-6.49697** (2.7218)	-8.44127*** (2.7317)
	Percent White	5.44825*** (0.4768)	5.05390*** (0.4806)	4.94719*** (0.4800)	5.00786*** (0.4832)
Year Trend		-0.05121*** (0.0085)	-0.04669*** (0.0086)	-0.04975*** (0.0086)	-0.05177*** (0.0086)
Number of Observations		20,456	20,456	20,456	20,456
Number of Groups		2,464	2,464	2,464	2,464

Standard errors in parentheses, *** is significant at the 1%, ** is significant at the 5%, * is significant at the 10% levels.

Table 6. Impact of Management, Environmental and Technology Policies on Types of Pollution Prevention Practices, Fixed Effects

	Variables	VIII-A Operating	VIII-B Cleaning	VIII-C Process Mod	VIII-D Material Mod	VIII-E Product Mod
State P2 Legislation		-0.16716**	0.24580***	0.24510**	0.07138	0.62546***
		(0.0832)	(0.0915)	(0.1024)	(0.1519)	(0.2229)
Management Policy *Yrs		0.01137	-0.01628*	-0.05490***	-0.02735*	0.02488
		(0.0082)	(0.0086)	(0.0100)	(0.0164)	(0.0230)
Technology Policies	Regulatory Relief*Yrs	-0.01829	-0.07737***	-0.07523***	-0.07442*	0.13476***
		(0.0208)	(0.0285)	(0.0255)	(0.0403)	(0.0488)
	Awards*Yrs	0.01042	-0.03662**	0.08654***	0.09585***	-0.00865
		(0.0123)	(0.0159)	(0.0154)	(0.0228)	(0.0319)
	Technical Assistance	0.18812	0.20868	-0.84755***	-0.52404	-0.13932
		(0.1486)	(0.1694)	(0.1981)	(0.3783)	(0.3605)
	Grants	-0.15261	-0.55275***	0.47033**	0.60372	0.36304
		(0.1565)	(0.1769)	(0.2125)	(0.3837)	(0.5282)
	Fee Refunds/ Fee Discounts	-0.87039***	-0.74189***	0.17187	0.19805	-1.70457***
		(0.1596)	(0.1934)	(0.2105)	(0.3847)	(0.3323)
	Tax Rebates	0.34439**	0.25734	1.11068***	-0.29293	0.89977***
		(0.1633)	(0.2412)	(0.3561)	(0.3897)	(0.3252)
Envtal Policies	Numerical Goal	0.33581	-0.11167	0.71660***	0.58776	-0.54539
		(0.2052)	(0.2136)	(0.2405)	(0.4483)	(0.5027)
	Reporting Reqt*Yrs	0.06614***	-0.05331**	-0.03306	0.01516	-0.28625***
		(0.0189)	(0.0241)	(0.0231)	(0.0344)	(0.0461)
Spillover P2		0.67163***	0.52200***	0.31100***	0.60435***	0.28865***
		(0.0394)	(0.0417)	(0.0509)	(0.0689)	(0.1075)
Firm-Specific Controls	Inspections	0.0208	-0.01536	0.05114***	0.04685**	-0.01231
		(0.0136)	(0.0151)	(0.0164)	(0.0233)	(0.0375)
	Penalties	0.13260***	0.07011*	0.03249	-0.04901	-0.09594
		(0.0437)	(0.0392)	(0.0422)	(0.0851)	(0.1126)
	Past Toxic Releases	0.06745**	0.17493***	-0.00901	0.08501*	-0.02792
		(0.0262)	(0.0232)	(0.0227)	(0.0454)	(0.0699)
	Past HAP Releases	0.37660***	0.29740***	0.18856**	-0.27992**	0.12933
		(0.0756)	(0.0832)	(0.0845)	(0.1308)	(0.1432)
	Number of Chemicals	0.84122***	0.94030***	0.88644***	0.99123***	1.26770***
		(0.0444)	(0.0490)	(0.0589)	(0.0760)	(0.1244)
County and State Controls	Non-attainment status	-0.13805**	0.08495	-0.12182*	-0.25974***	0.09302
		(0.0584)	(0.0677)	(0.0663)	(0.0999)	(0.1533)
	House Voting Record	-0.20616***	-0.10117	-0.20000**	-0.37733***	0.27522
		(0.0796)	(0.0873)	(0.0927)	(0.1359)	(0.1777)
	Per Capita Income	0.18134***	-0.12489***	0.06626**	-0.06278	-0.0275
		(0.0243)	(0.0296)	(0.0299)	(0.0438)	(0.0603)
	Percent Bachelor's Degree	-46.60604***	30.59119***	-18.27660***	13.77325*	6.00826
		(4.6695)	(5.9686)	(5.9061)	(7.7486)	(10.6633)
	Percent White	7.53428***	8.99943***	-0.39985	1.44983	4.08996**
		(0.9267)	(0.9597)	(0.8650)	(1.8915)	(1.9252)
Year Trend		-0.05903***	-0.0001	-0.09517***	-0.03875	-0.01173
		(0.0148)	(0.0179)	(0.0181)	(0.0265)	(0.0370)
Number of Observations		12,201	12,105	11,200	8,876	4,198
Number of Groups		1,432	1,446	1,247	993	458

Standard errors in parentheses, *** is significant at the 1%, ** is significant at the 5%, * is significant at the 10% levels.