EFFECTIVENESS OF STATE POLLUTION PREVENTION PROGRAMS AND POLICIES

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States are using regulatory-, information-, and management-based policies to encourage the adoption of pollution prevention (P2) and reduce pollution. Using a sample of facilities of S&P 500 firms which report to the Toxic Releases Inventory from 1991 to 2001, this study employs dynamic panel data models to examine the effectiveness of state legislations and policies in increasing P2 and reducing toxic releases. I find that toxic waste legislations are effective in reducing toxic releases and in promoting P2, but the effect of policy instruments differ. Facilities in states with reporting requirement and mandatory planning adopt more P2 even in states that do not emphasize toxic waste reduction. The effectiveness of reporting is stronger among facilities with good environmental performance, while the potency of mandatory planning is greater among facilities with past P2 experience. In contrast, numerical goals reduce toxic pollution levels only among those which have been subjected to high levels of enforcement action. These suggest that reporting requirement and mandatory planning may be promoting the P2 practices which can improve public image and which benefit from enhanced technical know-how, but they are not causing meaningful pollution reductions, implying that the existing policies must be complemented by other approaches to achieve higher reductions in toxic pollution levels. (*JEL* Q55, O38, H23)

I. INTRODUCTION

Environmental policies in the United States have evolved from command and control to market-based incentives, and more recently to voluntary programs and information disclosure mechanisms. The evolution largely stems from the growing recognition that firms respond to environmental policies not only to improve compliance, but also to lower production costs, improve product quality, and enhance market competitiveness. Thus, prescriptive technology and emission standards are being replaced with a mix of policies that promote techniques such as pollution prevention (P2) technologies which allow firms to go beyond compliance and address strategic objectives.

In the United States, the National Pollution Prevention Act of 1990 mandates that "pollution be prevented or reduced at source whenever feasible." Beginning in 1991, the U.S. Environmental Protection Agency (EPA) began collecting annual data on 43 types of P2 activities undertaken by facilities and in doing so, it expanded the purpose of the Toxic

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ABBREVIATIONS

CAA: Clean Air Act
CWA: Clean Water Act
EPCRA: Emergency Planning and Community Right-to-Know Act
IDEA: Integrated Data for Enforcement Analysis
NPRI: National Pollutant Releases Inventory
P2: Pollution Prevention
PBT: Persistent Bioaccumulative Toxic
RCRA: Resource Conservation and Recovery Act
TLV: Threshold Limit Values
TQEM: Total Quality Environmental Management
TRI: Toxic Releases Inventory
TSCA: Toxic Substances Control Act
USEPA: U.S. Environmental Protection Agency

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Releases Inventory (TRI) under the Emergency Planning and Community Right-to-Know Act (EPCRA) by providing the public detailed information about toxic chemical releases as well as waste management activities to promote informed decision-making by industries, government, and the public. In 1992, the National Advisory Council for Environmental Policy and Technology recommended to the U.S. EPA that P2 programs should emphasize diffusion of P2 technologies through preferential increase in the use of nonregulatory drivers, creation of incentives, and provision of rewards, training, and information (U.S. EPA 1992). In addition, 36 states have also legislated P2 programs, each mandating a mix of regulatory-, information-, and management-based policies. How effective these policy instruments are in promoting P2 and reducing toxic releases is the central issue addressed in this study.

The need for multiple policy instruments to address environmental goals arises because profit-maximizing firms tend to adopt fewer than optimal levels of environmental technologies and emit more than optimal pollution levels. In this study, I focus on three of the reasons for the suboptimal choices, which are the targets of the policy instruments I examine. First is externalities: firms do not internalize the damages of their pollution to the rest of society (Jaffe and Stavins 2005). Second is incomplete information: the reputational benefits from environmental technology adoption and pollution reduction cannot be fully realized because stakeholders that could influence firms' choices are not fully aware of the environmental performance and activities of firms (Tietenberg 1998). Lastly, the costs of environmental technology adoption and abatement may be too high (King and Lennox 2002; Lennox and King 2004). Thus, a mix of policy instruments that compel firms to reduce their pollution levels and externalities, provide environmental-related information to the public, and lower costs of technology adoption and abatement are necessary to promote environmental technology adoption and encourage lower pollution.

Empirical comparison of the relative effectiveness of various policy instruments is limited. Foulon, Lanoie, and Laplante (2002) compare the impact of regulation and public disclosure of information on abatement activity while Frondel, Horbach, and Rennings (2007) compare how standards, taxes, accounting, audits, and reports promote adoption of end-of-pipe versus cleaner production technologies. Arimura, Hibiki, and Johnstone (2007) compare how environmental taxes, accounting, and standards promote environmental R&D. In another study, Arimura, Hibiki, and Katayama (2008) compare the effectiveness of management-oriented ISO 14001 and publication of environmental reports on reducing natural resource use, solid waste, and wastewater effluent levels. None of these studies have analyzed the adoption of P2 activities or level of toxic emissions by U.S. facilities nor have any of them analyzed how facility characteristics influence how they respond to different types of policy instruments. None of these previous studies have employed a dynamic framework that takes into account the history of innovation or history of pollution.

The objectives of this study are (1) to investigate whether state-level P2 legislations increase the adoption of P2 activities and reduce toxic emissions; (2) to examine the extent to which three policy instruments namely, numerical goal, reporting requirement, and mandatory P2 planning, contribute to the achievement of these goals; and (3) to determine whether the potency of these policies is influenced by facility characteristics. To address the above objectives, I employ dynamic estimation strategies that recognize the history of P2 adoption and history of pollution, while controlling for facility-specific unobservables. I use U.S. EPA TRI data on toxic releases and P2 activities of a sample of manufacturing facilities belonging to S&P 500 parent companies from 1991 to 2001.

The results show that adoption of P2 activities is higher among facilities that are located in states that have P2 legislations that emphasize toxic waste reduction. When such states additionally mandate P2 planning or require reporting of achievements and progress, facilities adopt more P2 activities. Furthermore, the potency of planning is greater among facilities that have adopted P2 activities in the past, while the effectiveness of reporting is greater among facilities that have demonstrated good environmental performance in the past, but potentially counterproductive for the extremely dirty ones. However, adoption of P2 activities is not significantly influenced by the existence of numerical targets for pollution reduction. The findings also show that the toxic waste discharges are significantly lower among facilities in states where the P2 programs emphasize toxic wastes. When states prescribe pollution reduction targets, toxic releases are not necessarily lower for all facilities, except among highly noncompliant ones in those states. These results imply that while traditional regulatory instruments such as emission reduction targets can contribute to the ultimate policy goal of toxic release reduction, at least among the extremely noncompliant ones, contemporary approaches such as mandatory planning and information disclosure do not.

Section II provides policy background and generates the hypotheses. Section III discusses the empirical issues and the estimation procedures used. Section IV describes the sample, data, and variable construction. Section V presents and discusses the results, and Section VI summarizes and concludes the paper.

II. BACKGROUND, FRAMEWORK, AND HYPOTHESES

A. State P2 Legislation and Policies

Since 1988, there are 36 states that have legislated P2 programs and common among them is their emphasis on source reduction activities over other means of pollution reduction such as waste disposal and treatment. Further, all of them, except for four, provide technical assistance by establishing an information clearinghouse, on-site consultation, education, training, outreach, research assistance, guidance manuals, waste audits, or referral services to experts through the state's environmental agency, a program within the state department, or through the state university. However, they vary in terms of the nature of waste that they seek to reduce. Fourteen of these legislated programs emphasize the reduction of toxic and hazardous wastes, consistent with the U.S. EPA TRI, while others are subsumed under general waste minimization programs or solid waste reduction programs.

Twelve of the 36 states that currently have P2 legislation also have regulatory policies in the form of numerical goals for pollution levels. The targets are expressed in percentage reduction terms, relative to emission levels on a baseline year, which is usually 1987, the first year of TRI reporting. The numerical target is usually a single pollution reduction goal that needs to be achieved by a given year except for four states where it consists of multiple targets that increase in stringency through time. Despite these pollution reduction mandates, none of the legislations have indicated the specific penalties for noncompliance with the targets. Eighteen states have an information-based policy that mandates reporting of action plans, targets, progress reports, pollution levels, or any combination of these. Of the 18 states with a reporting requirement, 8 clearly require reporting of environmental performance measures. While these reports are to be submitted to the state environmental agency, it is not clear to what extent, if at all, the information is made publicly available. Further, while some states collect toxic information and maintain their own toxic releases inventory databases under the TRI Exchange Network Program, the state P2 programs do not clearly indicate whether or how the reports will fit in with the existing state-level toxic release inventory. Finally, 14 of the 36 states have adopted management-based regulations which require each facility to devise a P2 plan that will help it identify problems, set targets, and develop solutions to its pollution problems through source reduction methods. The development of facility-level plans is accompanied by reporting of progress and achievements. In the 14 states that mandate planning, the management policy is stated clearly as a feature of the state legislation. The policy instruments and the year of implementation are summarized in Table 1.

B. Framework and Hypotheses

In this study, my interest is to analyze how polluting entities or facilities respond to legislation and policy instruments aimed at promoting the adoption of environmental technologies and/or abating pollution. Profit maximizing facilities choose the level of technology adoption and the level of pollution depending on the private benefits and private costs of these decisions. A facility will choose to adopt environmental technologies up to a point where its private marginal costs of environmental technology adoption are equal to the private marginal benefits from technology adoption. In choosing the level of pollution, which is a by-product of production activities, a facility will choose to release pollution up to a point where its private marginal benefits, in the form of higher output and revenues, are equal to the private marginal costs of pollution. The technology adoption decision and the choice of pollution level are related to each other since the benefits from technology adoption are the costs from pollution that are avoided if one chooses to undertake pollution-abatement activities. These include lower compliance costs associated with violations of environmental regulations, enhanced market recognition among

TABLE 1
State P2 Program Legislation Dates and Policy Instruments

State	Number of Facilities in the Sample	Year of P2 Legislation	Regulatory Policy: Numerical Goal	Information-Based Policy: Reporting Requirement	Management-Based Regulation: Mandatory Planning
AK	0	1990			
AL	22				
AR	28	1993			
AZ	12	1991	✓ (1993)	✓	✓
CA	57	1989	✓ (1993)	✓	✓ (2007)
CO	7	1992			
CT	19	1991			
DE	6	1990	✓ (1992)		
FL	23	1991			
GA	45	1990		✓	✓ (1993)
HI	1				
IA	23	1989	✓ (1994)		
ID	2				
IL	70	1989		✓ (1992)	
IN	61	1990			
KS	20				
KY	37	1988	✓ (1997)		
LA	23	1992		✓	
MA	20	1989	✓ (1997)	✓ (1991)	✓ (1994)
MD	16				
ME	11	1990	✓ (1994)	✓ (2000)	✓ (2000)
MI	69	1994			
MN	19	1990		✓ (1992)	✓ (1991)
MO	27	1990	✓ (1998)		
MS	21	1990	✓	✓	✓
MT	2	1995			
NC	49				
ND	2				
NE	14	1992			
NH	6	1996			
NJ	28	1991	✓ (1996)	✓	✓
NM	3				
NV	0				
NY	44	1990	✓ (2000)	✓	✓
OH	129	1992		✓	
OK	15	1994			
OR	18	1989		✓	✓
PA	63				
RI	1				
SC	25				
SD	2	1992		✓	
TN	41	1991		✓	✓
TX	85	1991		✓	✓
UT	2				
VA	27	1994			
VT	4	1990		✓ (1992)	✓ (192)
WA	20	1988	✓ (1995)	✓	✓
WI	30	1989			
WV	12	1998			
WY	0				

Source: National Pollution Prevention Roundtable, July 15, 2008.

consumers and the supply chain, and improved reputation with local communities (Arora and Cason 1996, 1999; Brunnermeier and Cohen 2003; Gray and Shadbegian 1998; Hall 2001; Khanna, Harrington, and Deltas 2009). It is through all these benefits and costs that the policy instruments influence the rate of adoption of environmental technologies and the level of pollution chosen by facilities. I explore below the impact of legislated programs and policies on the adoption of environmental technologies, specifically P2 practices, and on toxic emission levels by explaining how each program or policy potentially affects the benefits and costs of P2 adoption and the benefits and costs of pollution. I then generate the hypotheses.

Legislated programs may promote environmental technology adoption and reduce pollution levels in two ways. First, information-sharing and technical assistance provided through the legislated programs enhance technical know-how which can lower the costs of searching, discovering, learning, acquiring, and adapting existing knowledge, enabling a facility to adopt environmental technologies and lower pollution levels (Cohen and Levinthal 1989). In the absence of technical assistance, facilities may find such costs to be too high, causing abatement technologies to be underexploited (King and Lennox 2002; Lennox and King 2004). Second, the legislation may provide a perception of increased visibility of the state regulatory agency which monitors and enforces regulations. To enjoy reduced regulatory scrutiny and avoid future regulatory actions, facilities adopt environmental technologies and reduce their pollution levels to signal environmental stewardship (Brouhle, Griffiths, and Wolverton 2009; Brunnermeier and Cohen 2003; Gray and Shadbegian 1998; Khanna and Damon 1999; Khanna, Harrington, and Deltas 2009; Vidovic and Khanna 2007). Thus,

Hypothesis 1a: Legislated P2 programs for toxic waste reduction will lead to more P2 activities.

Hypothesis 1b: Legislated P2 programs for toxic waste reduction will lead to lower toxic releases.

The degree to which legislated programs can achieve their policy goals depends on the mix of policy instruments that are putting them into practice (Freeman et al. 1992). I analyze the impacts of three specific policies: a regulatory policy in the form of a numerical goal for pollution reduction, a mandatory information disclosure policy in the form of a reporting requirement, and a management-based regulation in the form of mandatory P2 planning. Regulatory policies such as mandated maximum allowable pollution standards are direct controls to limit pollution and compliance with such a policy is promoted by imposing a penalty for exceeding the standard. The lower the allowable level of pollution, *ceteris paribus*, the more motivated a facility will be to undertake abatement activities to reduce violations and liabilities associated with noncompliance. Additionally, the higher the expected penalty for exceeding the standard, *ceteris paribus*, the greater will be the incentive to abate pollution in order to meet the target. Thus, emission reduction targets have the ability to enhance the benefits from environmental technology adoption and increase the costs of pollution that are associated with the anticipated penalties and lawsuits due to violations of environmental regulations (Hart and Ahuja 1996).

Empirical evidence on the effectiveness of a mandatory target is mixed. While Lanoie, Thomas, and Fearnley (1998) find that more stringent facility-specific emission limits lead to lower emissions, neither Jaffe and Stavins (1995) or Stafford (2003) find state-level mandatory building codes to improve energy efficiency or mandatory state programs to improve compliance status of polluting entities, respectively. In contrast, the existing literature has consistently found penalties and enforcement actions on noncompliant facilities to be effective not only in reducing violations but also in lowering emissions (see survey by Gray and Shimshack 2011). Further, state enforcement action has been shown to have significant and distinct effects on environmental compliance from federal enforcement actions (Earnhart 2004a, 2004b). Thus, state-level numerical goals may pose a state-level regulatory threat that will lead to better environmental outcomes:

Hypothesis 2a: Emission reduction targets will lead to more P2 activities.

Hypothesis 2b: Emission reduction targets will lead to lower toxic releases.

Information-based policies that provide regulated entities a means to publicly disclose environmental-related information aimed at improving their reputation with consumers, investors, regulators, and the general public can increase benefits from pollution abatement activities and lower costs associated with high pollution levels. Disclosing information about pollution abatement activities and pollution levels allows a facility to respond to the demands of these stakeholders by providing them various signals: a signal of product quality improvement to its consumers, a signal of lower liabilities, fewer lawsuits, and better overall financial performance to its stockholders, a signal of compliance to enforcement agencies, and a signal of environmental stewardship to communities (see survey by Tietenberg 1998).

The empirical evidence on the efficacy of information disclosure programs in promoting better environmental performance and behavior depends on the nature of information disclosure system, the stakeholder channel through which behavior is affected, and the nature of environmental issue addressed. The information that is required to be reported to the U.S. TRI has been effective not only in reducing emissions directly (Khanna and Damon 1999) but also in shaping future regulatory action (inspection activity) and influencing subsequent stock market returns which then affect pollution levels (Decker 2005; Khanna, Quimio, and Bojílova 1998; Hamilton 1995). The U.S. EPA (2003) also documents how the TRI has been used by local communities to lobby for more stringent regulations and by enforcement agencies for prioritizing facilities for enforcement and monitoring and for creating inspection targeting lists. Bae, Wilcoxen, and Popp (2009) further show that the TRI is more useful in reducing releases and health risks when states undertake further data processing efforts to refine and analyze the data before disseminating it to the public. In Canada, mandatory reporting to the National Pollutant Releases Inventory (NPRI) has been shown to reduce chemical pollution levels among those who perceive a stronger threat of regulation and to a much less extent among those who perceive significant consumer pressure (Antweiler and Harrison 2003; Harrison and Antweiler 2003). A stronger role of information via the consumer channel is observed when there is a direct consumer information provision program as shown by Bennear and Olmstead (2008) who find that water utilities reduce their violations of Safe Drinking Water Act standards if they are mandated to report water contaminant levels to consumers. In the climate change arena where the specific form of regulation is forthcoming but still uncertain, voluntary information disclosure programs are growing but existing studies demonstrate evidence of greenwashing behavior among participants in a number of voluntary programs such as the U.S. DOE 1605, U.S. DOE/EPA Climate Challenge, and the Canadian Voluntary Climate and Challenge Registry (Brouhle and Harrington 2010; Kim and Lyon 2011; Welch, Mazur, and Bretschneider 2000). These are in contrast to the electricity industry's mandatory disclosure of fuel mix information which as Delmas, Montes-Sancho, and Shimshack (2009) find, lead to lower usage of fossil fuels and higher usage of clean fuels. As the reporting requirement in state P2 programs are mandated mostly for pollutants that are regulated under an existing environmental statute, one could expect the following:

Hypothesis 3a: Reporting requirements will increase adoption of P2 activities.

Hypothesis 3b: Reporting requirements will reduce toxic releases.

Management-based regulations require the adoption of environmental management practices for the fulfillment of environmental goals. It may lower the costs of environmental technology adoption and pollution abatement for facilities because environmental management practices enable them to systematically review and identify pollution-reducing opportunities, undertake audits and benchmarking, and monitor environmental performance on very specific segments of their operations (Coglianese and Nash 2006). Further, a management system can facilitate communication among different units and can promote better information flow (DeCanio, Dibble, and Amir-Atefi 2000). Such a "management innovation" has the potential to enhance technological opportunities for facilities and promote adoption of environmental product and process innovations that can reduce pollution (Frondel, Horbach, and Rennings 2007).

A few studies show that voluntary adoption of environmental management systems promotes better environmental behavior and performance. Khanna, Harrington, and Deltas (2009) show that Total Quality Environmental Management (TQEM) promotes P2 adoption, while Anton, Deltas, and Khanna (2004) demonstrate that a more comprehensive environmental management system reduces onsite and offsite releases. Arimura, Hibiki, and Katayama (2008) further find that adoption of management systems that comply with ISO 14001 standards can improve environmental performance even after controlling for the influence of environmental regulations. With regard to mandated management systems, Bennear (2007) finds that mandatory planning can promote P2 adoption and lower toxic releases, but she did not account for the presence of other policy instruments (as in Arimura, Hibiki, and Katayama 2008) which may complement or substitute for planning. Thus,

Hypothesis 4a: Mandatory P2 planning will increase adoption of P2 practices.

Hypothesis 4b: Mandatory P2 planning will lower toxic emissions.

In analyzing how a facility responds to each policy instrument, I recognize that the response may depend on facility characteristics such as facility-specific knowledge, past environmental performance, and exposure to past enforcement actions. Facility-specific knowledge acquired through learning is important because past experience promotes acquisition and exploration of new knowledge, enables a facility to exploit other external sources of information, and hastens the build-up of knowledge stock that enhances a facility's ability to assimilate new information (Cohen and Levinthal 1989; Lennox and King 2004; Mansfield 1968). Thus, highly technical facilities may be more capable of improving their environmental performance and modifying their behavior in response to state policies that require a significant amount of facility-specific technical information. Past environmental performance is important because responsive regulators use past performance and behavior of the facility as a sign of latent noncompliance that would warrant future enforcement action (Decker 2005; Maxwell and Decker 2006; Innes and Sam 2008). Facilities that face greater prospect of regulatory scrutiny may therefore respond more aggressively to state policies to avoid future regulations. Finally, because past enforcement actions have been shown to be credible signals of threat (Innes and Sam 2008; Sam, Khanna, and Innes 2009; Shimshack and Ward 2005), exposure to past enforcement activity such as inspections and penalties may make facilities more vigilant in their response to state policies as well. To deflect further monitoring and enforcement, a facility that has been subjected to more regulatory action may be more motivated to adopt P2 technologies and lower pollution. Thus,

Hypothesis 5a: The extent of adoption of P2 in response to state policies is expected to be significantly influenced by different facility characteristics.

Hypothesis 5b: The extent of toxic pollution reduction in response to state policies also depends on various facility characteristics.

III. EMPIRICAL FRAMEWORK

The main objective of this study is to establish the link between the legislation of P2 program and policy instruments and two measures of environmental performance of a facility: adoption of environmental technologies and pollution levels using panel data models in a framework with lagged dependent variable. As measure of technology adoption, I use the count of P2 activities adopted by a facility i at time t, and denote it as $P2_{it}$. As measure of pollution, I use the level of toxic releases of facility i at time t, and denote it as R_{it}. The main explanatory variables of interest for both are Leg_{it}, the P2 legislation dummy variable, and Policy_{it}, a vector of three policy dummy variables: numerical goal, reporting requirement, and P2 planning. In each model, I include lagged dependent variables, $P2_{it-1}$ and R_{it-1}, respectively, to account for the history of P2 and history of pollution. I also control for various time-varying facility characteristics, including regulatory pressures specific to the facility, (z_{it}), time- or period-specific dummies (Y_t), and time-invariant characteristics (c_i).

I specify the toxic emissions equation with a lagged dependent variable as follows:

$$(1)\quad R_{it} = \alpha_0 R_{it-1} + \text{Leg}_{it}\beta_{0,R} + \text{Policy}_{it}\beta_{1,R} + z_{it}\gamma_{1,R} + Y_t\gamma_{2,R} + c_{i,R} + \varepsilon_{it,R}$$

where c_i includes a full set of facility dummies, industry dummies, and state dummies, and ε_{it} denotes idiosyncratic errors. If there are time-invariant facility-specific unobservables, pooled estimation of Equation (1) that contains a lagged dependent variable will yield inconsistent estimates (Anderson and Hsiao 1982). To derive consistent estimates, I employ the Anderson and Hsiao two-stage approach as implemented by Jaffe and Stavins (1995). The first stage involves estimating the first differenced version of Equation (1). Because the differenced lagged dependent variable is correlated with the first differenced error terms, I instrumented for the differenced lagged dependent variable using its twice lagged level (R_{it-2}) in the differenced equation. The second stage derives the coefficients of the time-invariant regressors by deriving a "residual" from the differenced first stage regression and regressing (using OLS) the residuals against the time-invariant factors. The "residual" is computed for each facility by multiplying each coefficient estimate from the first step by the facility mean for each variable and subtracting their sum from the facility mean of the dependent variable.

In explaining the count of P2 using its lagged count and other factors, I assume that the count of P2 has a Poisson distribution with the mean specified as

$$\begin{aligned} &E(\mathrm{P2}_{it}|X_{it}, c_i)\\ &\quad = c_{i,P2}\exp[\mathrm{P2}_{i,t-1}\rho + \mathrm{Leg}_{it}\beta_{0,P2}\\ &\qquad + \mathrm{Policy}_{it}, \beta_{1,P2} + z_{it}\gamma_{1,P2} + Y_t\gamma_{2,P2}]. \end{aligned}$$

However, the presence of a lagged dependent variable makes within-estimation yield inconsistent coefficient estimates due to the correlation between the differenced lagged regressor and the error term (Cameron and Trivedi 1998). Thus, rather than employing a fixed effects model, I adopt Wooldridge's (2005) model that assumes a specific distribution for the facility-specific effect but which allows the use of a random effects Poisson model with gamma distribution. I follow Wooldridge's (2005) recommendation for c_i to have a specific conditional distribution as follows:

$$c_i = a_i \exp[\alpha_0 + f(\mathrm{P2}_{i0})\alpha_{01} + z_i\alpha_2],$$

where $f(\mathrm{P2}_{i0})$ is a function of the initial value of P2 on the first year of reporting, $\mathrm{P2}_{i,0}$, the vector, z_i consists of time-invariant facility-specific characteristics, and a_i is assumed to be independent of ($\mathrm{P2}_{i0}$, z_i), and follows a gamma distribution. Wooldridge (2005) shows that after conditioning the a_i out of the density (Wooldridge 2005, 50–51, equations 32–34), if only one lag is included and if the explanatory variables are exogenous, one can estimate the following model using a random effects Poisson model with gamma heterogeneity:

$$\begin{aligned} (2)\quad &E(\mathrm{P2}_{it}|\mathrm{P2}_{it-1}, \mathrm{P2}_{i0}, \mathrm{Leg}_{it}, z_{it}, c_i)\\ &\quad = a_i \exp\Big[g(\mathrm{P2}_{i,t-1})\rho + f(\mathrm{P2}_{i0})\alpha_{01}\\ &\qquad + \mathrm{Leg}_{it}\beta_{0,P2} + \sum_{k=1}^{3}\mathrm{Pol}_{itk}\beta_{1,P2}\\ &\qquad + z_{it}\gamma_{1,P2} + Y_t\gamma_{2,P2} + \alpha_0 + z_i\alpha_2\Big] \end{aligned}$$

where the full set of regressors consists of all time- and facility-specific variables and those that determine the facility-specific effects, c_i, shown above. To satisfy these assumptions, I assume gamma heterogeneity in my random effects model,[1] I use one lag of the dependent variable, and I include the initial P2 count, industry dummies, state dummies, and other time-invariant characteristics to define c_i.[2]

Regarding the exogeneity assumption, particularly of the legislation and policy variables, which can be of concern for estimating both Equations (1) and (2) using the approaches described above, there is reason to suspect that the nature of facilities which determines the count of their P2 activities and their level of emissions could also influence whether the state they are located in legislates a P2 program and implements a particular policy. To check for this possibility, I employ a probit model to explain the legislation of the P2 program and the adoption of each of the policies using various state-level measures of environmental performance as well as political pressure and community pressure variables. These state-level explanatory variables are correlated with facility-specific measures of environmental behavior and performance which I use as dependent variables in Equations (1) and (2). If the state-level explanatory variables are significant in the probit models, there is reason to suspect that state legislation/policies are determined simultaneously with the decision to adopt P2 and the level of toxic releases. The results

1. I compared the log likelihood and BIC of the Poisson models with normal versus gamma heterogeneity and find that the gamma heterogeneity models have higher log-likelihoods and lower BIC than the model that assumes normally distributed heterogeneity.

2. Further, as this is basically now a random effects model, I also checked if the other regressors that include measures of actual past regulatory action or proxy for forthcoming regulations are correlated with the initial count of P2. I find that the correlation between initial count and various measures of regulatory pressures (lagged releases, lagged inspections, and lagged penalties) range only from 0.10 to 0.29. Further, while these measures may be associated with total level of pollution, pollution can be abated using either P2 techniques or end-of-pipe abatement methods, or both. Hence, these variables which are all measured at time $t-1$ can be considered uncorrelated with initial P2 count in 1991.

(not shown) indicate that there is no evidence that state P2 legislation and policies are adopted in response to factors that may also affect P2 adoption and toxic releases.[3]

As a second check, I use prelegislation or prepolicy variables in place of the actual legislation/policy variables in Equations (1) and (2) as in Bennear (2007). These prelegislation/prepolicy variables take on a value of 1 for states which eventually pass the legislation/adopt the policy on the *year immediately preceding* the year of legislation or policy implementation, and 0 otherwise. Statistical significance of these variables would indicate that there are differences in the P2 counts and toxic releases of facilities between states which eventually adopt the legislation/policies on the year *before* the legislation/policies were adopted and those facilities in states which never did. This implies that there may be other time-varying factors that can explain differences in P2 counts and emission levels and that I may be wrongfully attributing the response to the legislation/policy. In Table A1, Models 1-A and 1-B are random effects P2 models, while Models 2-A and 2-B are Anderson-Hsiao models, all of which use the prelegislation/prepolicy variables. All models show that none of the prelegislation/prepolicy variables are significant, implying that the legislation and policy can be treated as exogenous in Equations (1) and (2). Thus the toxic emissions equations are estimated using Anderson-Hsiao models, while count of P2 practices are explained using random effects Poisson models with initial P2 as one of the time-invariant variables that define facility-specific effects.

IV. SAMPLE DESCRIPTION, VARIABLE CONSTRUCTION, AND DATA SOURCES

A. Sample Description

The sample consists of facilities whose parent companies are among the S&P 500 firms reporting to the TRI every year from 1991 to 2001.[4] The TRI mandates the reporting of toxic releases and P2 activities by facilities which belong to specific industries, have at least ten full-time employees, and which manufacture, process, or use any EPCRA Section 313 chemical in quantities greater than the established threshold.[5] The original 11-year sample is an unbalanced panel with 34,121 observations, consisting of 5,094 unique facilities. I effectively start my analysis in 1992 and use 1991 P2 data as a facility-specific effect, a key explanatory variable in my dynamic random effects Poisson model. This drops the 1991 reporters, or 5,101 observations. Because many facilities do not report every year and reporting years are not always adjacent, an additional 3,146 observations do not have 1-year lagged data. For those which have lagged data but which do not report every year, their attrition in any year cannot be clearly attributed to having zero or below threshold toxic releases, nor can below-threshold levels be attributed to the use of P2. Thus, I only include the 1,261 S&P facilities who report every year from 1991 to 2001, for a total of 12,610 observations.[6] Relative to the complete unbalanced set, the facilities in this smaller balanced panel adopt approximately 39% more P2 activities and emit 70% more toxic releases. They also have been subjected to 19% more penalties and 39% more inspections. Thus, I emphasize that the conclusions derived from this analysis apply only to the facilities with similar characteristics: belonging to large parent companies (S&P 500 firms) which report every year from 1991 to 2001 and whose toxic emissions are always at or above the threshold.

B. Dependent Variables

I use two variables to measure the response to the state legislation and policies. The first is the count of all *new* P2 activities or practices adopted by a facility each year for all the

3. The full description and results of the probit model and the variables used are not included in the paper for the interest of brevity. They are available in the online version of the article.

4. 1991 is the first year of P2 reporting, and many states passed their P2 legislations between 1992 and 1998. Further, even though a number of states passed their P2 legislations in 1991 or earlier, many of the actual policies did not take into effect until the 1992 to 2001 time frame.

5. The USEPA mandates reporting to the TRI for facilities that have at least 25,000 pounds of chemicals that are manufactured or processed or 10,000 pounds otherwise used, except for certain persistent bioaccumulative toxic (PBT) chemicals. The threshold for the PBT chemicals is 100 pounds or less depending on the chemical beginning with the 2000 reporting year.

6. Even if we can attribute the reduction in releases to the adoption of P2 activities, the data on P2 adoption and releases that result from previous adoption will not be observed for the year that a facility has below threshold releases because the facility will not be required to report to the TRI. But it is very likely that facilities that have below threshold (but still positive) releases may still be adopting P2 activities. Thus, any TRI-related data will not be available for these facilities in those years.

chemicals it uses, processes, and manufactures.[7] The U.S. EPA classifies 43 different types of practices a facility may adopt into eight categories: good operating practices, inventory control, process and equipment modifications, spill and leak prevention, cleaning and decreasing, surface preparation and finishing, raw material modifications, and product modifications (U.S. EPA 2007). The first three consist of activities that involve adjustments in operating and production systems that are part of day-to-day activities which are highly customized to a facility's operations and include maintenance scheduling, recordkeeping, changes in production schedule, adoption of recirculation within a process, modification of equipment, layout or piping, and use of a different product catalyst. The next three deal with preventing visible air and water residues in work areas that result from production or cleaning activities which can be accomplished through installation of alarms and automatic shut-off valves, installation of vapor recovery systems, implementation of inspection or monitoring program for potential spill or leak sources. Such activities impact day-to-day exposure to water and air residues that may create hazards for employees. The last two practices include the more technologically sophisticated P2 practices: substitution of raw materials and changes in product specification which are becoming the basis for product differentiation through product labeling and marketing campaigns. Each facility is allowed to report up to four practices that it adopts for each of its chemical. The dependent variable *Total P2* is therefore the sum of all the practices from all these categories adopted for all chemicals every year by each facility from 1992 to 2001. To ensure that the change in P2 adoption over time is not due to differences in the chemicals that were required to be reported, chemicals which have been added or deleted (due to changes in the reporting requirements by the EPA) over the sample period were dropped. The average *Total P2* count is 1.64 practices, with a minimum of zero and a maximum of 84. The distribution is also highly skewed, with 68% of observations having adopted zero P2 count, and 19% having between 1 and 10 counts of P2. The states with the highest mean adoption of *Total P2* among its facilities are MT (7.2) and MN (6.2), while the lowest mean adoption is observed in UT (0.05) and ND (0.45).

The other dependent variable is a measure of toxic pollution level. The TRI requires facilities to report the quantities of onsite toxic releases to air, water, land, and underground injection, as well as offsite disposals, transfers, and treatment, on a chemical-specific basis. The level of a facility's toxic releases, denoted as *Toxic Releases*, is an aggregation of the emissions across all media and all chemicals in each time period, released onsite and offsite. To ensure that the change in toxic releases over time is not due to differences in the chemicals that were required to be reported, I dropped from the aggregation the releases for those chemicals which have been added or deleted over the sample period. The level of toxic releases ranges from 0 to 3,402 million pounds, with a median of 141,245 pounds. As the *Toxic Releases* variable is highly skewed, I use the natural log of this variable (plus one).

C. Explanatory Variables

The main explanatory variables of interest are the P2 legislation decisions and adoption of policy instruments at the state level. The dates of legislation and the specific details on the features regarding policy instruments are obtained and manually coded from the NPPR.[8] The *P2 Legislation* dummy variable takes a value of 1 if the facility is located in a state with a P2 legislation beginning at time t, and 0 before that year. A facility located in a state that has never passed a P2 legislation or has adopted it after 2001 will have a value of 0 for this variable for the entire sample time frame, while a facility located in a state that has passed it before 1991 will have a value of 1 for this variable for the sample time frame. A state is considered to have a P2 program if it legislated an act that is named as such or as long as the state legislation clearly gives highest priority of waste reduction to P2. Because *Total P2* and *Toxic Releases* are collected only for specific toxic substances

7. I verified if facilities do indeed report new P2 activities by examining the annually reported P2 counts for each chemical by each facility belonging to S&P 500 firms which report to TRI and compared it with their reports for the preceding year. I calculated the number of facilities for which the reported P2 counts were nondecreasing for all chemicals. This was the case for only 5.68% of all facilities and represents only 0.67% of the chemical-facility pairs (these facilities have a lower than average chemical count). Therefore, even if there was any misinterpretation of the survey question, it impacted a tiny fraction of the data.

8. National Pollution Prevention Roundtable, http://www.p2.org/inforesources/nppr_leg.html, downloaded on July 15, 2008.

identified under EPCRA Section 313, I further differentiate states by including a *Toxic* dummy variable, to indicate whether the state P2 program is focused on toxic wastes.

Each of the policy instruments is constructed as a dummy variable, where 1 indicates presence of a policy beginning at time t, and 0 before that year. The specific years of implementation are obtained from the NPPR and state environmental bureaus. If the legislations do not specify a year of implementation for a particular policy, it is assumed to be in effect on the same year as the legislation. The *Numerical Goal* variable pertains to whether target(s) exist for emission reductions. The year of adoption of a numerical goal is the year that the first target is expected to be met. I alternatively investigate models that use the actual percentage reduction in pollution levels, which I denote as *Target*. *Reporting Requirement* refers to the mandatory submission of details on the action plans, targets, progress reports, or pollution levels. In this study, a state with any type of reporting, regardless of the required content, is considered to have a *Reporting Requirement*. Finally, *Mandatory Planning* variable refers to the presence of mandatory P2 planning policy. States are considered to have a management policy if it is clearly stated as a mandatory feature of the state legislation in the NPPR. The number of facilities in the sample that are subjected to each policy in each state is indicated in Table 1.

The role of history in technology adoption and history of pollution are captured by the inclusion of the lagged dependent variables as explanatory variables. *Lagged P2* is constructed as the count of new practices adopted in the previous year and is included to account for past experience in technology adoption. *Lagged Toxic Releases* is the volume of all toxic releases of a facility in the previous year and is included to account for time-persistent facility characteristics such as nature of operations and technical constraints that influence pollution levels. I use the natural logs of these variables (plus one).

Facility-specific regulatory pressures and market pressure variables are also included to control for influences of regulatory action (some at the federal level) and other external stakeholders. The first set includes measures of regulatory threat. Because past enforcement actions are found to be credible sources of threat (Innes and Sam 2008; Sam, Khanna, and Innes 2009; Shimshack and Ward 2005), polluters who face a prospect of greater regulatory scrutiny because they have been subjected to high enforcement activity in the past may adopt more P2 and reduce toxic releases more to signal environmental stewardship. I use the number of *Lagged Inspections* and the number of *Lagged Penalties*. The *Lagged Inspections* variable is the number of times a facility was inspected by state and federal environmental agencies to monitor compliance with mandatory regulations in the past year. *Lagged Penalties* refer to the number of times a facility has been cited for and has been penalized for noncompliance with federal environmental statutes, such as the Clean Air Act (CAA), the Clean Water Act (CWA), Toxic Substances Control Act (TSCA), and the Resource Conservation and Recovery Act (RCRA) in the past year. Both are from the EPA Integrated Data for Enforcement Analysis (IDEA). I use both to explain *Total P2* and *Toxic Releases*. Both are highly skewed so I use the natural log of these variables (plus one).

To further explain *Total P2*, I include *Lagged Toxic Releases* as a proxy for the threat of anticipated compliance costs with existing or forthcoming regulations. The reporting of P2 practices under the TRI is mandated specifically for toxic chemicals and many of these chemicals are regulated under different environmental statutes.[9] Further, the total volume of releases captures the extent of pollution of the facility, making it more visible to the regulator (Arora and Cason 1996; Innes and Sam 2008; Khanna and Damon 1999). Thus, the lagged level of releases may proxy for the degree of potential liability associated with violations of these regulations, which can increase P2 adoption.

I use two additional measure of regulatory threat to explain *Toxic Releases*: *Lagged Toxicity-Weighted Releases* and *Nonattainment*. Because the risk impacts of the chemicals reported to the TRI vary, *Lagged Toxicity Weighted Releases* may be able to capture extent of liabilities related to health risks as in Bae, Wilcoxen, and Popp (2009). This variable is a weighted sum of toxic releases which is obtained by multiplying the volume of releases for each chemical with its corresponding toxicity weight from the Threshold Limit Values (TLV) Index and summing up over all chemicals for each facility in each year. TLV is determined by the American Conference of Governmental

9. A matrix that relates the TRI chemicals to different environmental statutes is available from the USEPA website: http://www.epa.gov/tri/trichemicals/reg_requirements/94regmat.pdf.

Industrial Hygienists and is obtained from the World Bank.[10] The nonattainment status of all counties in the United States according to the 1977 CAA Amendments is a designation on every county as being in attainment or nonattainment with national air quality standards for each of six criteria air pollutants: CO, SO2, TSP, O3, NO, and PM. Facilities in areas which are in nonattainment may face a more stringent regulatory environment (List, Mchone, and Millimet 2004). For each county, I derived the sum of the number of pollutants for which it is in nonattainment of environmental standards to create the *Nonattainment* variable. The data is obtained from the U.S. EPA Greenbook.[11] I use the natural log of these variables (plus one).

The second set of explanatory variables include measures of influences from the market and local citizens because polluting entities may also be subjected to pressures from its consumers, supply chain, and its local community to improve environmental behavior and performance. On one hand, polluting entities can benefit from higher consumer sales if they can project a signal that the production process reflects environmentally responsible manufacturing, say through adoption of environmental technologies or lower emission levels. Several studies have shown that those that are in closer contact with consumers are more likely to participate in voluntary environmental programs and adopt more comprehensive environmental management systems (Anton, Deltas, and Khanna 2004; Arora and Cason 1996; Khanna and Damon 1999; Vidovic and Khanna 2007). On the other hand, intermediate good producers are exposed to both suppliers and clients in their supply chain and may be required by their suppliers and clients to comply with certain environmental standards (Hall 2001). They may even be expected by their clients to adopt specific environmental management systems to conform to ISO 14001 standards (Arimura, Darnall, and Katayama 2010). Thus, there is no a priori expectation on whether *Final Good* dummy will have a positive or a negative effect on *Total P2* or *Toxic Releases*. The *Final Good* dummy variable is based from the facility's four-digit SIC code as constructed in Harrington, Khanna, and Deltas (2008). It is equal to 1 if the facility produces a final good, 0 otherwise.

Because local communities can exert pressures on polluting entities directly through citizen suits or indirectly by lobbying for more stringent regulations (Earnhart 2004b; USEPA 2003) it is important to control for local pressures that capture willingness to pay for environmental quality. I use median household income, denoted as *Income* obtained from the Bureau of Census. Many studies have shown that several measures for economic attributes are correlated with various environmental outcomes such as pollution, exposure to risk, plant location decisions, and participation in voluntary environmental programs (Arora and Cason 1999; Becker 2004; Brooks and Sethi 1997; Earnhart 2004b; Hamilton 1995; Wolverton 2009). Thus, facilities in areas with higher willingness to pay for environmental quality, measured by *Income*, are expected to have higher *Total P2* and have lower *Toxic Releases*.

In addition to the regulatory and market variables, several experience-related variables are included to help explain *Total P2*. *Lagged Cumulative P2* is defined as the count of all new P2 activities adopted since 1991 up to the immediately preceding year and captures the stock of knowledge from past P2 adoption. *Initial P2* is the count of P2 adopted in 1991, the first year that P2 reporting is mandated in the TRI, and it captures both the adoption on the first year of reporting and the facility-specific effect. Both variables are obtained from the TRI. The adoption of P2 may also be influenced by activities of other facilities in the same corporate family because experience of these related facilities may generate positive spillovers that can also enhance a facility's capacity to develop technologies that are in line with the parent company culture, needs, and priorities (Jaffe 1986). Thus, I include the average adoption of P2 by facilities belonging to the same parent company, which I denote as *Spillover P2*. It is obtained from the TRI. I use the natural log of the two experience variables and the spillover variable (plus one).

To control for the scope over which *Total P2* and *Toxic Releases* are reported while avoiding the potential problem of endogeneity of contemporaneous or 1-year lagged number of chemicals, the *Number of Chemicals* of a facility, averaged over all years is included as

10. The TLV is expressed in milligrams per cubic meter and is based on "time-weighted average concentrations in air that cannot be exceeded without adverse effects for workers in a normal 8-hr work day and a 40-hr work week". The index is available from http://www.worldbank.org/nipr/data/toxint/.

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

an explanatory variable.[12] This data is obtained from the TRI. The value of this variable ranges from 0.67 to 79.5, with a median of 3.47. Finally, because environmental quality improvements may be costly and technically challenging for facilities, I use *R&D Intensity*, the ratio of R&D expenditures to net sales as measure of parent company technical capacity as in Anton, Deltas, and Khanna (2004) and Khanna, Harrington, and Deltas (2009), because facilities that belong to more innovative companies are better able to use, assimilate, and exploit existing information to develop new technologies (Cohen and Levinthal 1989). This data is from Research Insight. Due to the skewness of the distribution of the data for both variables, I use the natural logs (plus one) of *Number of Chemicals* and *RD Intensity*. State, year, and industry dummies are also constructed. The descriptive statistics are in Table 2.

V. RESULTS AND DISCUSSION

The discussion of results is organized as follows. I first summarize the robust results with regard to the other factors that influence *Total P2* and *Toxic Releases*. I then proceed with the summary of results with respect to the hypotheses regarding the legislation and policy variables. The detailed discussion of the findings on how *Total P2* (Models I to V in Table 4) and *Toxic Releases* (Models VI to IX in Table 5) respond to each policy variable follows in separate subsections.

Overall, the empirical results show very robust results with regard to the effect of different regulatory, market and community pressure variables on *Total P2* and *Toxic Releases*. For the case of *Total P2*, Models I to V show that *Total P2* is higher among facilities that have higher *Lagged Inspections*, higher *Lagged Toxic Releases*, those which are intermediate good producers, those located in areas with higher *Income*, those which release a higher *Number of Chemicals*, and those which have greater experience in P2 activities in the past. I also find the experience-related variables to have different impacts. One year *Lagged P2* and *Initial P2* are always positive and significant, indicating that past experience provides facilities the know-how in identifying and implementing new source reduction practices, possibly because of cost-reducing effects or momentum effects (*Lagged P2*). However, *Lagged Cumulative P2* is negative and significant which suggests diminishing opportunities for further adoption of new P2 activities. Thus, despite short-term learning effects (captured by *Lagged P2*), there may be some degree of exhaustion of new opportunities to further reduce releases of chemicals at source. Nonetheless, the combined impact of both variables is positive and statistically significant (at 5% level), lending support to the inclusion of past experience as key explanatory variables. In the *Toxic Releases* models, Models VI to IX show *Toxic Releases* to be lower among facilities that have higher *Lagged Penalties*, have higher *Lagged Toxicity-Weighted Releases*, have lower *Number of Chemicals,* and which are *Final good* producers. I also find strong path dependence in *Toxic Releases* suggesting the importance of persistent facility characteristics that may constrain large reductions in pollution levels every year. One interesting result to contrast between *Total P2* and *Toxic Releases* is the negative and significant sign of the coefficient of the *Final good dummy* in both the *Total P2* and *Toxic Releases* equations, which suggests that it is the pressure from the supply chain that is motivating technology adoption, but it is the pressure from consumers that is motivating pollution reduction. These results can be interpreted as a support for the view that consumers are more concerned with observable measures such as pollution levels but not necessarily with the nature of technologies adopted to achieve these ends.

I now summarize the findings with regard to the hypotheses. I find some evidence to support Hypothesis 1a and 1b. While *Total P2* is only slightly higher in states with P2 legislation that emphasize toxic waste reduction, *Toxic Releases* are significantly lower in states with a state P2 legislation that are geared toward reducing toxic wastes. I do not find evidence to support Hypotheses 2a and 2b: *Total P2* is not significantly higher and *Toxic Releases*

12. The number of chemicals reported consists of chemicals used, manufactured, processed, and disposed of, thus, the opportunities for reporting P2 activities is greater for facilities which emit more chemicals. This indicates that contemporaneous number of chemicals may be endogenous with the P2 practices adopted. Lagged chemicals may also pose some endogeneity issue because having fewer chemicals in the previous year implies fewer opportunities to report P2 in the following year. The number of chemicals in 1991 could be used, but it is highly correlated (0.56) with 1991 P2 count, which is a key explanatory variable in this dynamic Poisson model. Hence, I use average number of chemicals between 1991 and 2001.

TABLE 2
Summary of Variables and Descriptive Statistics: Mean and Standard Deviation (in Parentheses).

Variables	Without State P2 Program	With State P2 Program	All Observations	Total P2 Equation	Toxic Releases Equation
Dependent Variables					
Total P2	1.705	1.621	1.637	X	
	(5.446)	(4.425)	(4.638)		
Toxic Releases	1,700,153	2,572,414	2,405,571		X
	(6,957,141)	(36,200,000)	(32,700,000)		
Explanatory Variables					
P2 Legislation	0.000	1.000	0.809	X	X
	(0.000)	0.000	(0.393)		
Numerical Goal	0.000	0.191	0.155	X	X
	(0.000)	(0.393)	(0.362)		
Reporting Requirement	0.000	0.572	0.462	X	X
	(0.000)	(0.495)	(0.499)		
Mandatory Planning	0.000	0.344	0.278	X	X
	(0.000)	(0.475)	(0.448)		
Toxic dummy	0.000	0.37164	0.3005	X	X
	(0.000)	(0.4832)	(0.4585)		
Target	0.5182	0.9359	0.8560	X	X
	(5.0650)	(6.2803)	(6.0687)		
Initial (1991) P2	2.347	2.637	2.581	X	
	(5.783)	(5.999)	(5.959)		
Lagged P2	1.863	1.766	1.785	X	
	(5.786)	(4.665)	(4.899)		
Cumulative P2	10.276	11.504	11.269	X	
	(29.636)	(27.603)	(28.006)		
Spillover P2	0.882	0.929	0.920	X	
	(1.037)	(1.127)	(1.111)		
Lagged Inspections	5.004	2.980	3.367	X	X
	(11.017)	(8.449)	(9.031)		
Lagged Penalties	0.070	0.087	0.083	X	X
	(0.359)	(0.507)	(0.482)		
Lagged Toxic Releases	1.673044	2.616549	2.436078	X	X
	(6.717)	(36.300)	(32.800)		
Toxicity-Weighted Releases	5,750,387	5,069,449	5,199,697		X
	(64,700,000)	(51,300,000)	(54,100,000)		
Nonattainment	0.4556	0.6797	0.6368		X
	(0.7666)	(0.9934)	(0.9582)		
Final Good dummy	0.274	0.358	0.342	X	X
	(0.446)	(0.479)	(0.474)		
Income	34134.62	37475.91	36836.80	X	X
	(8408.175)	(9177.562)	(9130.221)		
R&D Intensity	0.026	0.030	0.030	X	X
	(0.020)	(0.028)	(0.027)		
Number of Chemicals	4.970	5.541	5.432	X	X
	(4.981)	(6.477)	(6.222)		
Number of observations	2,412	10,198	12,610		

are not significantly lower among all facilities in states which have *Numerical Goals*. I find evidence to support 3a and 4a but not 3b and 4b: *Total P2* is higher among facilities in states with *Reporting Requirement* and *Mandatory Planning*, even among those in states that do not emphasize toxic waste reduction, but *Toxic Releases* are not significantly affected by either policy. Finally, I find evidence for Hypothesis 5a and 5b: some facility characteristics do influence the adoption of *Total P2* and reduction of *Total Releases* in response to policy instruments. The hypotheses and findings are summarized in Table 3.

TABLE 3
Summary of Hypotheses and Evidence

Hypotheses	Evidence to Support Hypotheses
Hypothesis 1a: Legislated P2 programs for toxic waste reduction will lead to more P2 activities.	✓
Hypothesis 1b: Legislated P2 programs for toxic waste reduction will lead to lower toxic releases.	✓
Hypothesis 2a: Emission reduction targets will lead to more P2 activities.	×
Hypothesis 2b: Emission reduction targets will lead to lower toxic releases.	×
Hypothesis 3a: Reporting requirements will increase adoption of P2 activities.	✓
Hypothesis 3b: Reporting requirements will reduce toxic releases.	×
Hypothesis 4a: Mandatory P2 planning will increase adoption of P2 practices.	✓
Hypothesis 4b: Mandatory P2 planning will lower toxic emissions.	×
Hypothesis 5a: The extent of adoption of P2 in response to state policies is expected to be significantly influenced by different facility characteristics	✓
Hypothesis 5b: The extent of toxic pollution reduction in response to state policies also depends on various facility characteristics.	✓

A. Effect of P2 Policies on the Adoption of P2 Practices

The results of the models that explain how policy instruments affect *Total P2* are in Table 4. All models (except for Model V) are estimated using random effects Poisson and include the lagged dependent variable, state dummies, year dummies, initial (1991) P2 counts, industry dummies, and time-varying covariates to control for past experience in P2, fixed differences between states, national trends that affect all facilities, facility-specific characteristics, fixed differences between industries, and time-varying characteristics affecting P2 at each time period, respectively. In Table 4, Model I is the base model and includes the *P2 Legislation* dummy and *Toxic* dummy. Model II is Model I with all policy dummy variables included. Model III uses *Target* instead of *Numerical Goal* dummy. Model IV-A and IV-B include interaction terms. Model V has the same specification as Model II but is estimated using Poisson with all facility dummies in place of the *Initial P2* and is presented for comparison purposes. It yields similar coefficients.

All models in Table 4 show some limited evidence for Hypothesis 1a, no support for 2a, but broad support for Hypothesis 3a and 4a. The nonsignificant coefficient of *P2 Legislation* in all models indicates that any *P2 Legislation* is not sufficient to yield higher adoption rates for *Total P2*. However, the *Toxic* dummy variable is significant at 10% which suggests that when the effect of *P2 Legislation* is assessed for facilities in states that emphasize toxic pollution reduction, the effect on *Total P2* variable is positive and significant indicating that *P2 Legislation* is effective in promoting P2 activities only in these states. This is not surprising because the data on P2 activities used in this study are obtained from the TRI and are the ones adopted specifically for toxic chemicals. Hence, P2 activities adopted by facilities in states whose legislation and technical assistance emphasize reduction of other types of wastes would not be reflected in this dataset, which may explain the lack of significance of the *P2 Legislation* variable by itself, but a significant effect when the focus of the legislation is accounted for.

The coefficients of *Reporting Requirement* and *Mandatory Planning* are positive and significant, consistent with Bennear (2007) and Khanna, Harrington, and Deltas (2009), while that of *Numerical Goal* is not significant. These findings suggest that the P2 adoption decision of facilities positively responds to policies which may improve their reputation with external stakeholders (*Reporting Requirement*) and which allow them to reduce their costs of technology adoption (through *Mandatory Planning*) but not to those that can pose threat of regulatory action. The signs of the policy coefficients are similar whether included singly or jointly, though the magnitudes and levels of significance are higher if the policy instrument variables are included in the model one at a time (results not shown). This is especially true for *Reporting Requirement* which has a coefficient of 0.62 and significant at 1% when included as the only policy instrument in the model. Nonetheless, *Reporting Requirement* and *Mandatory Planning* are individually significant even when other policy variables are included in Model II, indicating that they have distinct effects and

TABLE 4

Determinants of *Total P2*, Poisson Random Effects (RE) and Fixed Effects (FE)

	Poisson RE					Poisson FE[a]
Variables	**I**	**II**	**III**	**IV-A[b]**	**IV-B[b]**	**V**
P2 Legislation	0.03249	0.03715	0.03933	0.03708	0.07579	0.0347*
	(0.0515)	(0.0518)	(0.0516)	(0.0518)	(0.0523)	(0.0521)
Toxic dummy	0.23036*	0.23023*	0.22833*	0.19268	0.23158*	0.2055
	(0.1351)	(0.1351)	(0.1351)	(0.1361)	(0.1350)	(0.1353)
Numerical Goal		−0.02541		−0.02731	−0.04252	−0.0169
		(0.0397)		(0.0397)	(0.0397)	(0.0398)
Reporting Requirement		0.40922*	0.4010*	0.4599**	0.4325**	0.5127**
		(0.2192)	(0.2194)	(0.2204)	(0.2183)	(0.2186)
Mandatory Planning		0.2122**	0.2113**	0.2111**	−0.0625	0.1921**
		(0.0937)	(0.0935)	(0.0937)	(0.1065)	(0.0938)
Target			−0.00161			
			(0.0015)			
Reporting Requirement × Lagged Toxic Releases				−0.1110**		
				(0.0450)		
Mandatory Planning × Cumulative P2					0.0972***	
					(0.0182)	
Lagged P2	0.8410***	0.8408***	0.8411***	0.8400***	0.8427***	0.9079***
	(0.0170)	(0.0170)	(0.0170)	(0.0170)	(0.0170)	(0.0176)
Cumulative P2	−0.5203***	−0.5219***	−0.5227***	−0.5227***	−0.5567***	−0.731***
	(0.0259)	(0.0259)	(0.0259)	(0.0259)	(0.0266)	(0.0257)
1991 P2	0.7083***	0.7101***	0.7106***	0.7097***	0.7171***	
	(0.0532)	(0.0532)	(0.0532)	(0.0532)	(0.0533)	
Spillover P2	0.2772***	0.2794***	0.2812***	0.2823***	0.2824***	0.276***
	(0.0338)	(0.0339)	(0.0338)	(0.0339)	(0.0339)	(0.0349)
Lagged Inspections	0.0422***	0.0416***	0.0411***	0.0411***	0.0444***	0.0426***
	(0.0110)	(0.0110)	(0.0110)	(0.0110)	(0.0110)	(0.0111)
Lagged Penalties	0.0160	0.0180	0.0170	0.0208	0.0166	0.0167
	(0.0297)	(0.0297)	(0.0297)	(0.0297)	(0.0296)	(0.0298)
Lagged Toxic Releases	0.0919***	0.0919***	0.0918***	0.1657***	0.0927***	0.0887***
	(0.0219)	(0.0219)	(0.0219)	(0.0371)	(0.0220)	(0.0229)
Final Good dummy	−0.2941***	−0.2946***	−0.2946***	−0.2976***	−0.2949***	−2.1567
	(0.1049)	(0.1050)	(0.1050)	(0.1051)	(0.1054)	(2.0794)
Income	0.000014***	0.000015***	0.000015***	0.000015***	0.000013***	0.000018***
	(0.0000047)	(0.0000047)	(0.0000047)	(0.0000047)	(0.0000047)	(0.00000637)
RD Intensity	0.5469	0.3778	0.4376	0.4293	0.5270	0.6041
	(0.8093)	(0.8133)	(0.8150)	(0.8137)	(0.8136)	(0.8943)
Number of Chemicals	0.5997***	0.6013***	0.6013***	0.5943***	0.5953***	3.9990***
	(0.0825)	(0.0825)	(0.0825)	(0.0824)	(0.0829)	(1.2629)
Constant	−2.9408***	−2.9434***	−2.9448***	−2.9523***	−2.8627***	−6.375***
	(0.6503)	(0.6507)	(0.6509)	(0.6512)	(0.6531)	(1.8794)
Facility dummies	—	—	—	—	—	5351.45***
SIC dummies	43.80***	43.89***	43.84***	43.73***	43.06***	143.98***
State dummies	68.64**	75.84***	75.54***	75.66***	76.25***	770.70***
Year dummies	68.88***	65.81***	65.70***	66.01***	69.66***	163.39***
LR (a)	3913.46***	3915.72***	3919.11***	3915.11***	3944.32***	—
No. of observations	12,610	12,610	12,610	12,610	12,610	8,810
No. of groups	1,261	1,261	1,261	1,261	1,261	881

[a]There are 8810 for Models III because those facilities which have zero P2 counts in all the years get dropped from a Poisson model with facility dummies.

[b]Models with other interaction terms between *Reporting Requirement* and *Final Good dummy, Numerical Goal and Lagged Inspections or Lagged Penalties* and *Reporting Requirement and Lagged Inspections or Lagged Penalties* are not shown for the interest of brevity but in all these models, the interaction terms are not statistically significant while the rest of the coefficients variables are similar to those in Model II. A complete set of these results are available upon request.

Standard errors in parentheses: *significant at 10%, **significant at 5%, ***significant at 1%.

reinforce each other's influence on P2 adoption, similar to findings by Arimura, Hibiki, and Katayama (2008). Additionally, these policies increase *Total P2* adoption even in states that do not emphasize toxic waste reduction (and they remain significant even if *Toxic* dummy is dropped from all models in Table 4), implying that the effectiveness of such policies is not constrained by the emphasis of the state's P2 legislation.

To demonstrate the magnitude of the effect of *Reporting Requirement*, *Mandatory Planning*, or both, I compute for the ratio of the conditional mean of P2 counts between states with and without each policy, which is a function of the relevant coefficients.[13] The magnitude of the coefficients of *Reporting Requirement* and *Mandatory Planning* are very consistent across the models and are approximately 0.41 and 0.21, respectively. Thus, facilities in states with reporting requirement have 1.5 times as much P2 counts as those in states which do not require reporting, while facilities in states with mandatory planning have 1.2 times as much P2 counts as those in states without mandatory planning. For those facilities in states with both *Reporting Requirement* and *Mandatory Planning*, their count of P2 practices is 1.86 times that of facilities in states with neither. (These three ratios are statistically different from one at the 1%, 5%, and 5% levels, respectively). If one takes into account that being in states whose P2 programs emphasize toxic waste reduction leads to even higher *Total P2*, the coefficients from the models suggest that facilities in states with a toxic waste reduction focus and which impose a *Reporting Requirement*, *Mandatory Planning*, or both will respectively have 1.97, 1.61, and 2.43 times as much P2 counts as those in states without them. (These ratios are statistically different from one at 1%.)

I further investigated the role of *Numerical Goal* in Model III where I alternatively use the level of pollution reduction, *Target*, in place of the *Numerical Goal* dummy and I obtain results similar to those in Models I and II, indicating that even differences in stringencies of targets do not affect adoption of *Total P2*. In fact, *Numerical Goal* also remains insignificant when its interactions with *Lagged Inspections* and *Lagged Penalties* are included, and the interactions are also insignificant (results not shown). The results suggest that regardless of how much regulatory action or enforcement activity that a facility has been subjected to in the past, *Numerical Goal* is an ineffective policy tool in promoting P2. These results hold if the *Toxic* dummy is dropped from all models in Table 4.

I further investigate whether the response to *Reporting Requirement* and *Mandatory Planning* depend on facility characteristics in Models IV-A and IV-B by including interaction terms. In Model IV-A, the interaction between *Reporting Requirement* and *Lagged Toxic Releases* is significant, while none of the other policy variables or any other explanatory variables experience a change in sign, magnitude and significance. Specifically, the sign of the interaction term is negative, which implies that facilities that respond more positively to *Reporting Requirement* by adopting more P2 are those which have been able to demonstrate good environmental performance in the past (those with low *Lagged Toxic Releases*). This suggests that the mandatory information disclosure program promotes better environmental behavior among those which have good news to report, but not for those whose toxic releases are too high. Using the coefficients in Model IV-A, the level of toxic releases needs to be extremely high, 3,402 million pounds, (99th percentile) before reporting will have a negative impact on the P2 count.[14] Hence, for most of the facilities in the study, P2 counts are higher when reporting is mandated in the state P2 program, but extremely dirty ones are "penalized" by the policy. Note further that the sample used in this analysis has relatively higher toxic releases than those in the original unbalanced sample of all TRI reporters. Thus, even among these relatively high emitters, the results show that a policy that mandates reporting will still promote P2 adoption among most facilities. These results suggest that the response to a reporting requirement may be driven by the desire to reduce potential enforcement action in the future, which is consistent with the findings of Maxwell and

13. The ratio is computed as $\frac{E(P2_{it}|P2_{it-1}, P2_{i0}, 2_{it}, c_i, Leg_{it}=1, Policy_{it}=1)}{E(P2_{it}|P2_{it-1}, P2_{i0}, 2_{it}, c_i, Leg_{it}=1, Policy_{it}=0)} = \exp[\beta_{Policy}]$.

14. In models with an interaction, the ratio can be computed for facilities in states with and without reporting requirement for various values of the *Lagged Releases*, that is, $\exp[\beta_{\text{Report}} + \gamma_{\text{Report–Lagged Releases}}(\text{Lagged Releases} * \text{Report})_{it}]$. The ratio is significantly lower than unity (at the 11%) when the natural log of lagged releases is at least 8.13 (lagged releases is at least 3,402 million pounds).

Decker (2006) and Decker (2005) who show that disclosure of information can be used to lower the probability of being inspected and that those which have reported lower toxic releases per unit of output receive fewer inspections. In an alternative model where *Reporting Requirement* is interacted with *Final good dummy*, the interaction term is not significant but the rest of the coefficients are unchanged (results not shown).

Model IV-B further investigates how a facility responds to *Mandatory Planning* given its characteristics. It includes an interaction term between *Mandatory Planning* and *Lagged Cumulative P2*. In this model, *Mandatory Planning* becomes negative but insignificant (it used to be positive and significant in the model without the interaction term), but the interaction term is positive and significant. This implies that for facilities that have not adopted any P2 in the past (36% of the sample), mandatory planning will not result in significantly higher (or lower) count of P2 activities. But for those facilities which have adopted at least one P2 practice in the past and are in states with *Mandatory Planning*, they adopt significantly more P2 practices than those in states without such a policy. How much mandatory planning can promote P2 is shown by the ratio of the conditional mean of P2 counts of facilities in states with planning to the conditional mean of those in states without planning for various values of *Lagged Cumulative P2*. The ratio is significantly greater than one at the 5% level of significance for facilities with at least 30 counts of *Lagged Cumulative P2* practices in the past (within the 90th percentile).[15] These findings lend support to Bennear (2006) who asserts that the management-based regulations will be successful when the regulated facility enjoys low costs to pollution reduction. Since the literature shows how past experience lowers cost of adoption, the findings in this study imply that a high enough accumulation of P2-specific experience lowers a facility's costs of exploiting other sources of knowledge and integrating new knowledge generated through P2 planning, which in turn lowers the costs of finding new P2 opportunities.

15. If an interaction with *Lagged Cumulative P2* is included, the ratio can be computed for facilities in states with and without mandatory planning for various values of the *Lagged Cumulative P2*, that is, $\exp[\beta_{\text{Planning}} + \gamma_{\text{Planning–Lagged Cumulative P2}}(\text{Lagged Cumulative P2*Planning})_{it}]$. The ratio is significantly higher than unity when the natural log of cumulative P2 is 3.43 or when count is at least 30 practices.

B. Effect of P2 Policies on Toxic Releases

The results of the models explaining *Toxic Releases* are in Table 5. All models are estimated using the Anderson and Hsiao (1982) two-step approach and include the lagged dependent variable, state dummies, year dummies, industry dummies, and time-varying covariates to control for the past history of pollution, fixed differences between states, national trends that affect all facilities, fixed differences between industries, and the time-varying characteristics affecting toxic releases at each time period, respectively. Model VI is the base model that includes *P2 Legislation* and *Toxic* dummy. Model VII includes all the policy instruments, while Model VIII uses *Target* in place of *Numerical Goal*. Model IX-A and IX-B include interaction terms. All models in Table 5 show that P2 legislations are effective in reducing *Toxic Releases* in states whose legislated programs emphasize toxic waste reduction, consistent with Hypothesis 1b. Similar to Earnhart (2009), the findings here suggest that state agencies are able to provide an additional threat to facilities that are distinct from the threat associated with federal legislations.

However, I do not find evidence to support Hypotheses 2b, 3b, and 4b: none of the policy instruments I investigate are able to encourage further toxic pollution reduction. In conjunction with the significant effect of the legislation, these results are consistent with findings by Thornton, Gunningham, and Kagan (2005) who find that promulgation of laws and uncertainty surrounding their enforcement may be more salient than actual sanctions. Except for *Numerical Goal*, the coefficients of the policy variables are slightly larger when the policy variables are included one at a time but their coefficients remain insignificant in those models (results now shown). In Model VI, I use the actual level pollution reduction *Target* in place of the *Numerical Goal* dummy, and I find that states with more stringent targets do not have lower toxic pollution either. Despite the unexpected findings, the results regarding the insignificant effect of *Numerical Goal* or *Target* is consistent with findings of Jaffe and Stavins (1995) and Stafford (2003) who find mandated state-level codes to be ineffective in inducing energy efficiency and compliance, respectively. The nonsignificant effect of *Mandatory Planning* however, is in contrast with the findings of Bennear (2006) and Arimura, Hibiki, and Katayama (2008). *Reporting Requirement*

TABLE 5
Determinants of *Toxic Releases*, Anderson–Hsiao Estimators

Variables	VI	VII	VIII	IX-A[a]	IX-B[a]
P2 Legislation	0.02712	0.02744	0.02757	0.02734	0.02829
	(0.0265)	(0.0265)	(0.0265)	(0.0265)	(0.0265)
Toxic dummy	−0.31253***	−0.31258***	−0.31241***	−0.31268***	−0.31384***
	(0.0903)	(0.0903)	(0.0902)	(0.0903)	(0.0902)
Numerical Goal		−0.00266		−0.00731	0.00457
		(0.0188)		(0.0202)	(0.0190)
Reporting Requirement		0.05883	0.05881	0.05776	0.06935
		(0.1011)	(0.1011)	(0.1012)	(0.1011)
Mandatory Planning		0.02036	0.0205	0.02061	0.02068
		(0.0389)	(0.0389)	(0.0389)	(0.0389)
Target			0.00019		
			(0.0003)		
Numerical Goal × Lagged Inspections				0.00607	
				(0.0094)	
Numerical Goal × Lagged Penalties					−0.08169***
					(0.0298)
Lagged Inspections	−0.00207	−0.00215	−0.00211	−0.00294	−0.00214
	(0.0034)	(0.0034)	(0.0034)	(0.0036)	(0.0034)
Lagged Penalties	−0.02332*	−0.02351*	−0.02363*	−0.02364*	−0.00632
	(0.0127)	(0.0127)	(0.0127)	(0.0127)	(0.0141)
Lagged *Toxic Releases*	1.01843***	1.01841***	1.01793***	1.01910***	1.01629***
	(0.1285)	(0.1286)	(0.1285)	(0.1287)	(0.1283)
Lagged Toxicity-Weighted Releases	−0.40768***	−0.40777***	−0.40760***	−0.40810***	−0.40690***
	(0.0464)	(0.0464)	(0.0464)	(0.0464)	(0.0463)
Nonattainment	0.02741*	0.02783*	0.02774*	0.02787*	0.02810*
	(0.0161)	(0.0161)	(0.0161)	(0.0161)	(0.0161)
Final Good dummy[b]	−0.17499***	−0.17517***	−0.17512***	−0.17530***	−0.17320***
	(0.0165)	(0.0165)	(0.0165)	(0.0165)	(0.0164)
Income	0.00000193	0.00000211	0.00000207	0.00000214	0.00000214
	(0.00000830)	(0.00000830)	(0.00000830)	(0.00000830)	(0.00000829)
RD Intensity	0.2425	0.24278	0.23518	0.2445	0.22624
	(0.3908)	(0.3909)	(0.3908)	(0.3910)	(0.3903)
Number of Chemicals[b]	0.83050***	0.83063***	0.83066***	0.83095***	0.82113***
	(0.0112)	(0.0112)	(0.0112)	(0.0112)	(0.0111)
Constant	−0.0027	−0.00306	−0.0031	−0.00309	−0.00317
	(0.0110)	(0.0110)	(0.0110)	(0.0110)	(0.0110)
SIC dummies[b]	88.35***	88.42***	88.40***	88.44***	88.30***
State dummies[b]	21.62***	21.51***	21.49***	21.52***	21.76***
Year dummies	22.51***	22.30***	22.20***	22.30***	21.93***
No. of observations[c]	11,349	11,349	11,349	11,349	11,349
No. of groups	1,261	1,261	1,261	1,261	1,261

[a]Models with other interaction terms between *Reporting requirement* or *P2 Legislation and Lagged Inspections or Lagged Penalties* are not shown for the interest of brevity but in all these models, the interaction terms are not statistically significant while the rest of the coefficients variables are similar to those in Model VII. A complete set of these results are available upon request.

[b]These are the variables that are estimated in the second stage of the Anderson–Hsiao two-step framework.

[c]There are 10,088 observations in Models VI–IX because the Anderson–Hsiao models require 2-year lagged levels as instrument for the first differenced 1-year lagged dependent variable.

Standard errors in parentheses: *significant at 10%, **significant at 5%, ***significant at 1%.

is not significant either, which is contrary to findings of many studies that show mandatory information disclosure mechanisms yield significant pollution reductions. However, if viewed in conjunction with the findings of Bae, Wilcoxen, and Popp (2009), my results may suggest that state agencies need to further process and disseminate the reported information better to make them more relevant to the public and local communities before these external stakeholders can effectively use the information to influence the environmental performance of facilities.

I investigate the lack of significance of the policy instruments to determine whether there are specific types of facilities that would reduce their toxic emissions in response to the policies by constructing several interaction terms between *Lagged Inspections* or *Lagged Penalties* and *Numerical Goal*, *Reporting Requirement, Mandatory Planning*, or *P2 Legislation* dummies and included each interaction term one by one in the model. I show in Models IX-A and IX-B two of these models which include interaction terms between *Numerical Goal* and *Lagged Inspections* (Models IX-A) and *Lagged Penalties* (IX-B). I find that among all interaction terms investigated, only the interaction between *Numerical Goal* variable with *Lagged Penalties* is negative and significant (in Model IX-B) while the rest of the coefficients remain unchanged, providing some evidence for Hypothesis 5b. While the coefficient of *Lagged Penalties* is slightly lower and loses significance in Model IX-B, the elasticity of *Toxic Releases* with respect to *Lagged Penalties* is now stronger (but still very modest), at −0.09, compared to elasticity in Models VI-VIII, at only −0.02. The findings also show that state pollution reduction targets are effective in reducing emissions only among highly noncompliant facilities, that is, those which have already been subjected to more enforcement action in the past. Specifically, toxic emissions are significantly lower among those facilities located in states with a *Numerical Goal* if they have been subjected to at least eight penalties (75th percentile) in the previous year.[16] This is consistent with Earnhart (2009) who find that the potency of deterrence instruments is greater among polluting entities that are facing more regulatory scrutiny.

VI. SUMMARY AND CONCLUSIONS

Regulations for pollution reduction have increasingly emphasized P2 over end-of-pipe abatement through legislation of P2 programs offering a combination of numerical goals, reporting requirements, and management policies. The findings of this study show a significant effect of the toxic waste reduction legislation in reducing toxic emissions, and to a less extent in promoting P2 adoption, which indicates that the potential for enforcement action and provision of technical assistance through the state legislation may be providing additional regulatory threat while also reducing the costs of undertaking pollution abatement. However, the policy instruments play very different roles in further influencing P2 adoption and the level of toxic releases. Specifically, the results show that facilities in states with reporting requirement and mandatory planning adopt significantly more P2 practices, even in states that do not emphasize toxic waste reduction, while numerical goals prescribed under the state P2 programs do not yield significantly higher P2 counts. On the other hand, numerical goals yield significantly lower toxic pollution levels but only among those which have been subjected to greater enforcement action in the past. Thus, while policy instruments enhance the effect of toxic waste legislation in increasing P2 adoption, they are largely ineffectual in further reducing pollution levels. Overall, these results are consistent with the survey findings of Koehler (2007) who finds significant demonstration of efforts (through participation in voluntary environmental programs) in response to various measures of regulatory threat and other external pressures, but no meaningful or long-term environmental performance improvements.

Several insights can be gleaned from these findings. First, the significance of reporting requirement and mandatory planning for P2 adoption suggest some consistency with the growing emphasis on management- and information-based instruments to promote P2 activities. It also lends some support to the findings of Lent and Wells (1994) who find that the trend and pattern of firm investment in environmental management shows a shift in investment priorities from remediation and regulatory compliance toward investments that will reduce pollution and increase competitive advantage. As management- and information-based policies are more flexible and allow firms to respond to market factors, it is not very surprising that they are the types of approaches that may promote strategic and beyond-compliance types of activities such as P2.

Second, that reporting increases P2 adoption but does not reduce toxic releases shows a very limited role for information disclosure as a policy tool, at least at the state level, contrary to numerous positive findings about the TRI. The disclosure of environmental-related plans

16. This is the number of penalties that would make the marginal effect of *Numerical Goal* dummy statistically negative in Model IX-B.

and actions to the state regulatory agency seem to create incentives to adopt P2 practices that would enable facilities to sufficiently signal environmental stewardship through their technology adoption behavior possibly to deflect regulatory action and other pressures, but without making any meaningful pollution reduction. By improving the quality of information that is made publicly available, say through better data processing and dissemination as Bae, Wilcoxen, and Popp (2009) find is necessary for TRI data, the state agencies may be able to create incentives for facilities to undertake P2 activities that do not only improve reputation through their demonstration of efforts but also activities that can actually reduce toxic releases. Nonetheless, the findings emphasize the power of good news: how information disclosure promotes P2 among those who have demonstrated good behavior in the past and that information disclosure may be potentially detrimental to extremely dirty facilities.

Third, the significant impact of a management policy in promoting P2 adoption contributes to both economic literature and policy regarding the role that environmental management systems play in promoting adoption of environmentally responsible practices especially in the context of the EPA's specific emphasis on management based tools to promote P2. A key contribution of this study is the observed complementarity between planning and past experience, implying that P2 planning as a policy tool cannot entirely operate in a vacuum; it is a more potent instrument among facilities that have accumulated enough P2-specific expertise in the past. Thus, despite the recent popularity of employing management-based regulations, it would be foolish to abandon other policy tools that can promote even modest adoption of P2 practices to allow facilities to build experience and know-how that will allow them take advantage of the benefits of P2 planning. The findings also reveal that not only are management based regulations effective in promoting P2, the impact of management systems is distinct from and reinforces the effect of other policies such as reporting requirement, which is consistent with findings of Foulon, Lanoie, and Laplante (2002) and Arimura, Hibiki, and Katayama (2008). However, while the findings suggest that P2 planning is able to lower the cost of P2 adoption, they also imply that P2 planning is not able to facilitate adoption of other abatement techniques that lead to significant reduction in toxic releases. Reduction of toxic releases may be more responsive to other abatement activities (say, end-of-pipe techniques) that are not promoted by P2 planning. Because P2 planning may be effective in promoting specific means of pollution reduction, but not in achieving the ultimate goal of lowering pollution levels, it may need to be complemented by other policy instruments.

Finally, any discussion of the role of policy instruments in inducing environmentally responsible behavior is incomplete without providing the dynamic context to the analysis. Thus, despite the finding that they only promote investment in environmental technologies without bringing about consequential environmental improvements and that the coefficients of the policy instruments are small compared to the very large and statistically strong coefficients of history of P2 adoption and history toxic releases, the impact of the policy instruments would be larger if we consider how the effect of past behavior perpetuates further out into the future. Thus, even with modest short-term impacts on P2 and toxic releases, this study shows that reporting requirement and mandatory planning can promote P2 in the long term because the effect of accumulated knowledge and expertise is strong. For the case of toxic releases, strong path dependence in the level of releases suggests it may still be worthwhile to pursue numerical targets, even though it is only effective among highly noncompliant facilities because this policy significantly reduces levels of releases, which can then reduce future growth rate of pollution among violators.

APPENDIX

TABLE A1
Robustness Check Using Prelegislation and Prepolicy Variables

	Dependent Variable: *Total P2* Poisson Random Effects		Dependent Variable: *Toxic Releases*[a] Anderson–Hsiao Two-Step Model	
Variables	**1-A**	**1-B**	**2-A**	**2-B**
Pre-P2 Legislation	−0.00167	−0.00365	0.0272	0.02716
	(0.0611)	(0.0611)	(0.0187)	(0.0188)
Pre-Numerical Goal		0.04835		−0.0253
		(0.0467)		(0.0337)
Pre-Reporting Requirement		0.07751		0.01006
		(0.3053)		(0.0141)
Pre-Mandatory Planning		−0.16798		0.00606
		(0.1038)		(0.0742)
Lagged P2	0.84059***	0.83996***		
	(0.0170)	(0.0170)		
Cumulative P2	−0.52117***	−0.51990***		
	(0.0259)	(0.0259)		
1991 P2	0.70909***	0.70843***		
	(0.0532)	(0.0532)		
Spillover P2	0.28803***	0.29033***		
	(0.0332)	(0.0333)		
Lagged Inspections	0.04097***	0.04016***	−0.00214	−0.0022
	(0.0110)	(0.0110)	(0.0034)	(0.0034)
Lagged Penalties	0.01604	0.01753	−0.02433*	−0.02434*
	(0.0297)	(0.0297)	(0.0127)	(0.0128)
Lagged Toxic Releases	0.09665***	0.09748***	1.01852***	1.02020***
	(0.0218)	(0.0218)	(0.1286)	(0.1288)
Lagged Toxicity-Weighted Releases			−0.40747***	−0.40812***
			(0.0464)	(0.0465)
Nonattainment			0.02472	0.02521
			(0.0161)	(0.0161)
Final Good dummy[b]	−0.29342***	−0.29331***	−0.17511***	−0.17531***
	(0.1049)	(0.1049)	(0.0165)	(0.0165)
Income	0.000014***	0.000014***	0.00000216	0.00000224
	(0.00000467)	(0.00000467)	(0.00000820)	(0.00000831)
RD Intensity	0.59635	0.52452	0.24588	0.24503
	(0.8092)	(0.8100)	(0.3910)	(0.3913)
Number of Chemicals[b]	0.59583***	0.59531***	0.83104***	0.83130***
	(0.0825)	(0.0825)	(0.0112)	(0.0112)
Constant	−2.94637***	−2.94605***	−0.00301	−0.00314
	(0.6505)	(0.6502)	(0.0110)	(0.0110)
SIC dummies[b]	43.62***	43.64***	88.42***	88.43***
State dummies[b]	66.68***	66.72***	18.65***	18.69***
Year dummies	74.79***	73.16***	23.61***	23.46***
LR (α)	3915.45***	3910.73***	—	—
No. of observations	12,610	12,610	11,349	11,349
No. of groups	1,261	1,261	1,261	1,261

[a]There are 10,088 observations in Models 2-A and 2-B because the Anderson–Hsiao models require 2-year lagged levels as instrument for the 1-year lagged differenced dependent variable.

[b]These are the variables that are estimated in the second stage of the Anderson–Hsiao two-step framework.

Standard errors in parentheses.

+Significant at 15%, *significant at 10%, **significant at 5%, ***significant at 1%.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Probit Models for State P2 Legislation/Policy Adoption.

Table S1. Descriptive Statistics of Variables for Probit Models

Table S2. Probit Model Results: P2 Legislation and Policy Adoption