J Regul Econ
DOI 10.1007/s11149-011-9163-2

ORIGINAL ARTICLE

Do environmental audits improve long-term compliance? Evidence from manufacturing facilities in Michigan

Mary F. Evans · Lirong Liu · Sarah L. Stafford

Abstract Using a unique facility-level dataset from Michigan, we examine the effect of environmental auditing on manufacturing facilities' long-term compliance with U.S. hazardous waste regulations. We also investigate the factors that affect facilities' decisions to conduct environmental audits and whether auditing in turn affects the probability of regulatory inspections. We account for the potential endogeneity of our audit measure and the censoring of our compliance measure using a censored trivariate probit, which we estimate using simulated maximum likelihood. We find that larger facilities and those subject to more stringent regulations are more likely to audit; facilities with poor compliance records are less likely to audit. However, we find no significant long-run impact of auditing on the probability of a regulatory inspection or compliance among these Michigan manufacturing facilities.

Keywords Environmental auditing · Hazardous waste · Compliance · Enforcement

JEL Classification Q53 · Q58 · L51

M. F. Evans
The Robert Day School of Economics and Finance, Claremont McKenna College,
500 E. Ninth Street, Claremont, CA 91711, USA
e-mail: mevans@cmc.edu

L. Liu
Department of Economics and International Business, Sam Houston State University,
Huntsville, TX 77341, USA
e-mail: lxl004@shsu.edu

S. L. Stafford (✉)
Department of Economics, College of William and Mary, P.O. Box 8795, Williamsburg,
VA 23187, USA
e-mail: slstaf@wm.edu

Published online: 30 September 2011

1 Introduction

Since the mid 1980s the U.S. Environmental Protection Agency (EPA) has encouraged regulated entities to conduct environmental audits as a way of improving environmental performance.[1] An environmental audit is "... a systematic, documented, periodic and objective review by regulated entities of facility operations and practices related to meeting environmental requirements."[2] In particular, EPA has identified audits as a means of increasing compliance with environmental regulations. Over the past two decades EPA has formally incorporated environmental auditing in its compliance and enforcement strategy. In 1995 EPA adopted an agency-wide Audit Policy that encourages regulated entities to audit by reducing the penalties associated with any violations discovered during the course of an audit.[3] EPA expanded the Audit Policy in 2008 to provide additional incentives for regulated entities to undertake environmental audits when they acquire facilities subject to environmental regulations.[4] In 1997 EPA began to formally include increased environmental auditing in its strategic plan for increasing environmental compliance (U.S. EPA 1997).

EPA's endorsement of environmental auditing as a policy tool appears to have its roots in survey and anecdotal evidence from the 1990s on the impact of auditing on environmental performance. According to a 1995 report by the U.S. General Accounting Office (GAO) on environmental auditing, "private and public organizations that have effective environmental auditing have reported … improved compliance, reduced exposure to civil and criminal liability, cost savings from operating efficiencies and avoided cleanups, and reduced environmental hazards."[5] Respondents to a survey conducted jointly by EPA and the U.S. Chemical Manufacturer's Association similarly concluded that environmental auditing could have a significant positive impact on environmental performance (U.S. EPA 1999). However, there is little systematic empirical evidence that environmental auditing significantly increases environmental performance, particularly compliance with environmental regulations.

Empirical analyses have demonstrated that a related voluntary initiative, the adoption of an environmental management system (EMS), can have a positive effect on compliance with environmental regulations (Dasgupta et al. 2000; Potoski and Prakash 2005; Sam 2010). Since EMSs often include environmental auditing as one component

---

[1] "Interim Guidance on Environmental Auditing Policy Statement," 50 FR 46504 (November 8, 1985).

[2] 50 FR 46504, Section II.A. The academic literature on environmental regulation and compliance (as well as that on compliance more generally) sometimes uses the term audit more generally to mean any periodic inspection or review of an entity's compliance status. To distinguish reviews initiated by regulators from those initiated by regulated entities and to be consistent with EPA's terminology, we use the term "audit" to refer to reviews voluntarily undertaken by the regulated entity and "inspection" to refer to reviews initiated by regulators (and thus involuntary from the perspective of the regulated party).

[3] The Audit Policy was formalized in "Incentives for Self-Policing: Discovery, Disclosure, Correction, and Prevention of Violations—Final Policy Statement," 60 FR 66706 (December 22, 1995) and minor revisions to the policy were issued under "Incentives for Self-Policing: Discovery, Disclosure, Correction, and Prevention of Violations—Final Policy Statement," 65 FR 19618 (April 11, 2000).

[4] The "Interim Approach to Applying the Audit Policy to New Owners" was published in 73 FR 44991 (August 1, 2008).

[5] U.S. GAO (1995, p. 3).

of a comprehensive program, one might expect environmental audits to have a similar result. However, the specific impact of environmental auditing on compliance has received little attention. An independent analysis of environmental auditing is important for at least two reasons. First, given the comprehensive nature and cost of EMS programs, regulated entities that adopt them may be very different from regulated entities that only undertake environmental auditing. Second, the EPA policies identified above focus on environmental auditing, not EMSs, and thus any evaluation of the effectiveness of these policies must isolate the compliance impacts of auditing.

Using a unique dataset from the Michigan Department of Environmental Quality (DEQ), we examine both the factors that encourage facilities to undertake environmental audits and the consequences of auditing for manufacturing facilities' compliance with U.S. hazardous waste regulations under the Resource Conservation and Recovery Act (RCRA). We also explicitly consider the potential impact of environmental auditing on the likelihood of regulatory inspections. While our results help to isolate the characteristics of auditing facilities, we find no significant long-lasting effects of environmental auditing on inspections or on RCRA compliance. The remainder of the paper is organized as follows: Sect. 2 discusses the potential benefits of environmental auditing; Sects. 3 and 4 describe the related literature and our approach to identifying firms that conduct environmental audits; Sects. 5 and 6 present our empirical approach and the data used in the analysis; Sect. 7 describes the regression results; and Sect. 8 concludes the paper with a discussion of our findings.

2 Potential benefits of environmental auditing

An environmental audit can be designed to focus on many different aspects of a regulated entity's environmental performance. For example, an audit could emphasize verifying compliance with environmental requirements, evaluating the effectiveness of EMSs already in place, identifying opportunities for source reduction or waste minimization, or assessing risks from unregulated materials and practices. Similarly, a variety of motives could underlie a facility's decision to conduct an audit. A facility may want to have a better understanding of its current environmental liabilities, find ways to increase overall compliance or environmental performance, or earn a particular environmental certification.

Despite the wide range of reasons for conducting audits, most theoretical models of environmental auditing focus on the informational aspect of auditing (see, for example, Mishra et al. 1997; Pfaff and Sanchirico 2000; Friesen 2006).[6] In general the theoretical models assume that environmental performance or compliance with environmental regulations includes a stochastic element. As a result, regulated entities cannot fully observe their levels of emissions or compliance status *ex ante*. By conducting an environmental audit, a regulated entity learns its true level of environmental performance and, where such performance is below the entity's optimal level,

[6] A number of other theoretical models that explore the decision to self-police also model the audit decision either explicitly or implicitly. In general audits in these models also provide facilities with additional information about the facility's true level of environmental performance or compliance. See Stafford (2008) for a review of the theoretical self-policing literature.

can undertake corrective actions. For example, Pfaff and Sanchirico (2000) propose a theoretical model in which an audit reveals the magnitude and nature of environmental harm associated with the regulated entity's activities. Thus, an audit affords the entity the opportunity to correct any harm and improve its compliance status. According to these models, the regulator has an incentive to encourage auditing because doing so ultimately leads to higher levels of compliance and quicker remediation of environmental damage. Entities that undertake audits may also learn about better ways to achieve their desired levels of environmental performance. Khanna and Widyawati (2011) argue that audits may allow entities to "establish internal protocols to prevent future violations." Thus, audits could have a long-lasting positive effect on compliance.

3 Related literature

Our examination of the factors that motivate regulated entities to conduct environmental audits and the impact of auditing on compliance with environmental regulations is closely linked to the literature on voluntary environmental initiatives (VEIs). VEIs include voluntary programs sponsored by regulatory agencies as well as industry associations, third-party programs, and firm-specific initiatives. Khanna and Brouhle's (2008) review of this literature reports mixed evidence of the impacts of VEIs on environmental performance, both across programs and for individual programs. For example, several studies examine whether participation in EPA's "33/50" program—a voluntary pollution prevention program—affects the level of toxic emissions. Khanna and Damon (1999) find lower toxic releases among publicly traded chemical firms who participated in the 33/50 program while Vidovic and Khanna (2007) find the same program had no statistically significant effect on toxic emissions for a sample of firms drawn from 19 different industrial sectors.

A number of studies consider the factors that influence EMS adoption (see for example, Khanna and Anton 2002; Uchida and Ferraro 2007) or the effect of EMS adoption on overall environmental performance (see, for example, Anton et al. 2004; Sam et al. 2009). While such studies are unable to independently assess the role of environmental auditing relative to other aspects of the EMS, their findings remain pertinent to our analysis. The two most relevant studies, Potoski and Prakash (2005) and Sam (2010), estimate the effect of EMS adoption on compliance with U.S. environmental regulations.[7]

Potoski and Prakash (2005) analyze participation in ISO 14001, a third-party certification program that requires, among other things, adoption of an EMS. While periodic environmental auditing is not required for ISO 14001 certification, "a facility must undertake an initial comprehensive review of its environmental practices and systems" (p. 237). Thus, certified facilities are likely to have conducted at least an initial environmental audit. Using a treatment effects model to control for the endogeneity of ISO 14001 participation, Potoski and Prakash analyze the factors that drive ISO 14001

[7] Dasgupta et al. (2000) examine the effect of EMSs on compliance with environmental regulations in Mexico. However, rather than considering the discrete decision to adopt an EMS, they construct an "adoption score" to measure the extent to which Mexican plants have incorporated EMS practices. The authors do find that the higher the adoption score, the higher the plant's self-reported compliance status.

participation among U.S. facilities and the effects of participation on compliance with Clean Air Act (CAA) regulations. Their results show increased regulatory compliance with the CAA among facilities adopting ISO 14001. However, because the authors do not explicitly model the inspection outcome, it is unclear if the ISO 14001-compliant facilities included in their study actually have improved environmental performance or were merely inspected at a different frequency than the non-compliant facilities. Sam (2010) examines the impacts of various pollution prevention activities, including EMS adoption, on overall environmental compliance using a sample of approximately 1,400 S&P 500 manufacturing facilities. He finds that adoption of an EMS during the early 1990s increases compliance during the study period of 1991 to 2004.[8]

Few studies in the VEI literature focus explicitly on environmental auditing. Stafford (2005) examines the effect of state policies to encourage environmental auditing on overall compliance with hazardous waste regulations and finds a positive effect. In particular, she finds higher compliance among facilities in states that privilege the results of environmental audits or limit the fines associated with violations discovered during environmental audits. Unfortunately, the study does not attempt to identify facilities that undertook audits, and thus offers no insight into the effect of auditing on future enforcement or compliance. To our knowledge, the only study other than ours that directly addresses the effect of environmental auditing on compliance is Khanna and Widyawati (2011), hereafter abbreviated KW.

KW estimate the effect of firm-wide environmental auditing programs on contemporaneous compliance with CAA regulations using a sample of S&P 500 firms that responded to the Investor Research Responsibility Center (IRRC) survey on environmental management practices. Their findings suggest that facilities whose corporate parent company reported an environmental audit are significantly more likely to be in compliance with the CAA. There are several important differences between KW's analysis and the analysis presented in this paper. First, their analysis focuses on the *immediate* impacts of auditing on compliance whereas our primary interest lies in the potential for *long-lasting* effects of auditing. Second, we analyze the decision to audit and the impacts of auditing at the facility-level, rather than the firm-level.[9] Third, KW consider only S&P 500 facilities while our analysis includes all manufacturing facilities regulated under RCRA, both large and small. Finally, KW examine compliance with CAA regulations while our analysis looks at compliance with RCRA regulations.

EPA's policies broadly encourage all regulated facilities to undertake audits. That is, the EPA Audit Policy is not targeted towards specific facilities, for example those in a particular industry or those of a certain size. The same is true of state-level policies that provide incentives for environmental auditing. Given the across-the-board nature of these policies, we believe efforts to assess policy effectiveness require a more complete understanding of the effects of auditing on compliance. Whether auditing has a sustained effect on compliance is important in evaluating the appropriate role

[8] Unlike Potoski and Prakash (2005), because EMS adoption is not the focus of the analysis, the model assumes that the decision to adopt an EMS is exogenous. The results should be interpreted with this in mind.

[9] The incentives for auditing and complying with environmental regulations may differ across firm-level and facility-level decision makers (Evans et al. 2008).

for environmental auditing in EPA's enforcement strategy. If auditing has long-lasting impacts on compliance, then encouraging facilities to audit may be a cost-effective way of increasing compliance. However, if auditing only has a short-term effect on compliance, the cost-effectiveness of auditing as a means of increasing compliance is less clear. Similarly, it is important to understand whether the effect of auditing is limited to large firms, such as those included in KW's sample, or whether it also applies to smaller firms. By exploring the long-run implications of environmental auditing among a broad sample of manufacturing facilities, the results of this study will shed light on the extent to which environmental auditing can be an effective part of a public enforcement strategy.

4 Identifying audits

One of the largest challenges to examining the consequences of environmental auditing is identifying those facilities that have conducted environmental audits. EPA's policies do not require regulated entities to indicate the presence of audit programs nor has EPA conducted any survey or analysis on the use of environmental auditing in the regulated community.[10] Fortunately, a number of states, including Michigan, have their own environmental auditing programs. Under the provisions of Michigan's audit policy, which began in 1997, voluntary disclosures qualify for immunity from penalties only if a regulated entity has provided advance notice of the intent to audit. Specifically, the facility must file an "intent-to-audit" notice. The intent-to-audit notice consists of four components: (1) announcement of the planned audit, (2) specification of the facility (or portion of the facility) to be audited, (3) indication of the time frame for the audit, (4) statement of the general scope of the audit. An intent-to-audit notice can notify the DEQ of a planned audit of a part of the facility, of one media (e.g., air quality) within the facility, or of a full-facility multimedia audit (Michigan DEQ 2006). The audit must take place within 6 months of the notice submission to be eligible for immunity.

While it is possible that a facility might conduct an environmental audit without first notifying the DEQ, Michigan's list of facilities that have filed intent-to-audit notices includes both facilities that eventually do disclose environmental violations and facilities that do not. For our analysis, we obtained a list of facilities that filed intent-to-audit notices between 1998 and 2003. The data include the company and facility name, a mailing address, and the date the notice was filed. Using this information, we matched each facility to EPA's Facility Registry System (FRS) to identify the federal facility identification number. Ultimately we were able to identify 257 unique facilities in Michigan that filed 547 intent-to-audit notices between 1998 and 2003.

[10] Facilities that decide to disclose a violation under the Audit Policy must demonstrate that the violation was discovered during the course of an environmental audit to obtain full penalty mitigation. If the discovery is not the result of an audit, up to 75% of the penalty can be mitigated through disclosure. Thus, facilities may disclose violations under the federal Audit Policy even if they have not conducted an environmental audit. Therefore the list of facilities that have voluntarily disclosed violations under the Audit Policy both omits many facilities that have conducted environmental audits and have not disclosed violations and includes facilities that have made disclosures but have not conducted environmental audits.

Table 1 Number of facilities in Michigan regulated under various environmental programs

Regulatory program/media regulated	Database name	Number of facilities	Number that filed intent to audit	Percent that filed intent to audit (%)
Clean Air Act/Air pollution	AIRS/AFS	3,378	137	4.1
National Pesticides and Toxic Substances Program/pesticides and toxic materials	NCDB	2,168	36	1.7
National Pollution Discharge Elimination System/water Pollution	PCS	1,858	33	1.8
Toxics Release Inventory/toxics	TRIS	1,983	134	6.7
Resource Conservation and Recovery Act/hazardous waste: all facilities	RCRAInfo	32,924	223	0.07
Resource Conservation and Recovery Act/hazardous waste: manufacturing facilities only	RCRAInfo	3,395	131	4.0

According to the FRS, there are currently 51,381 entities regulated by EPA in Michigan. Thus less than half of 1% of all FRS facilities in Michigan reported an environmental audit to the DEQ during the period of analysis.[11] However, FRS includes many facilities that have very limited exposure to environmental regulations. To better estimate the true audit rate at "actively" regulated facilities, we identified a number of subgroups of FRS facilities based on EPA's various regulatory programs. Table 1 shows the number of facilities in Michigan regulated under EPA's primary media programs and the number and percentage of facilities in each program that filed intent-to-audit notices. The audit rates for these programs range from a high of 6.7% for facilities that must submit Toxics Release Inventory (TRI) reports to a low of just below 1% for facilities subject to RCRA.

While we believe that facilities in Michigan do have strong incentives to file intent-to-audit notices because a primary benefit of auditing is the potential for penalty mitigation and this benefit is available only to auditing facilities that submit the required intent-to-audit notice, some facilities may have been unaware of the requirement.

[11] This estimate excludes approximately 280 records on the Michigan list that could not be matched to facilities in the FRS database.

Additionally, there could be facilities that conduct environmental audits but chose not to give advance notice of doing so to the DEQ. Since the inception of EPA's Audit Policy, there have been concerns from the regulated community that environmental audit documents could be used against regulated entities in some way. While EPA has stated in numerous policy documents and guidance that it will only request audit reports in limited situations, it has also categorically refused to grant statutory or regulatory audit privilege.[12] However, this may be less problematic in our sample as Michigan passed legislation in 1996 granting privilege to all environmental auditing documents (Michigan DEQ 2006).

Due to the scarcity of data on environmental auditing, there are no real benchmarks to which we can compare the Michigan auditing rates. Given the specialized nature of their sample (i.e., S&P 500 firms that responded to the IRRC survey), KW's analysis does not provide a good comparison for our sample of all RCRA-regulated manufacturers in Michigan.[13] However, the auditing rates for our sample are in line with estimates of participation in other VEIs. For example, in Potoski and Prakash's (2005) analysis of "major" facilities regulated under the CAA, approximately 4% (151 of 3,709) were ISO14001 certified as of December 2001. In Gamper-Rabindran (2006), approximately 12% of the manufacturing facilities eligible for the 33/50 program participated. King and Lennox's (2000) analysis of the chemical industry's Responsible Care program suggests a participation rate of about 8%.

5 Empirical approach

EPA regulates air, water, toxic materials, and hazardous waste through different programs, each of which are separately enforced. As a result, there is insufficient consistent data across media programs and empirical analyses of compliance and enforcement are generally limited to a particular media program. We examine compliance with EPA's hazardous waste program, RCRA. To further focus the analysis, we restrict our analysis to Michigan manufacturing facilities that are regulated as hazardous waste generators under RCRA.[14] Four percent of such facilities (131 of 3,395 facilities) undertook an environmental audit during the time period of analysis.

According to the theoretical models of environmental auditing cited in Sect. 3, whether a facility decides to conduct an environmental audit may depend on both the facility's underlying compliance behavior and the likelihood of an inspection. Thus, our empirical model must account for this potential endogeneity. One additional esti-

[12] "Incentives for Self-Policing: Discovery, Disclosure, Correction and Prevention of Violations", Final Policy Statement, 65 FR 19617, April 14, 2000, Section I.F.

[13] Only 225 of the S&P 500 firms regularly return the IRRC survey. However, in an analysis of firm participation in voluntary environmental programs using the same data, Videras and Alberini (2000) do not find evidence of a selection bias.

[14] The full sample of all RCRA generators includes service-oriented businesses, government agencies, among other facilities. Because we have access to only a handful of facility-specific characteristics, our ability to control for differences across this large set of heterogeneous facilities is limited. As a result, we restrict the sample to a more homogeneous set of facilities. However, all of our primary results hold when we conduct our analysis for all RCRA generators in Michigan. These results are available from the authors upon request.

mation challenge results from the nature of enforcement under RCRA where compliance is enforced primarily through facility inspections. As compliance status is observed only for inspected facilities, we have data only on compliance for a subset of the facilities in our analysis. In other words, the data on compliance has been "censored" by the regulators' inspection decisions and our empirical model must also control for this censoring of the compliance outcome.

Let a_i^* represent facility i's net benefit from conducting an audit in the current period, p_i^* represent the regulator's net benefit from inspecting the facility in a future period, and q_i^* represent facility i's net benefit from complying with regulations in a future period. Each of these latent variables has a corresponding observable binary variable although the compliance status variable, q_i, is observed only for those facilities that are inspected (i.e., q_i is censored).

Our model consists of the following three-equation system:

$$\text{The audit decision}: \quad a_i = \begin{cases} 1 & \text{if } a_i^* = x'_{ai}\beta_a + \varepsilon_{ai} \geq 0, \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

$$\text{The inspection decision}: \quad p_i = \begin{cases} 1 & \text{if } p_i^* = x'_{pi}\beta_p + a_i\delta_p + \varepsilon_{pi} \geq 0, \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

$$\text{The compliance decision}: \quad q_i = \begin{cases} 1 & \text{if } q_i^* = x'_{qi}\beta_q + a_i\delta_q + \varepsilon_{ai} \geq 0 \text{ and } p_i{=}1, \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

In Eq. 1, x_{ai} denotes a vector of facility-specific covariates that impact facility i's decision to conduct an audit and β_a is the corresponding parameter vector to be estimated. In Eq. 2, x_{pi} represents a vector of covariates that affect the regulator's net benefit of inspecting facility i with β_p the associated vector of parameters. x_{qi} and β_q are likewise defined for Eq. 3, the compliance equation. The parameters δ_p and δ_q measure the impact of the potentially endogenous binary audit variable on the inspection and compliance outcomes respectively. We assume the error terms in the above equations follow a trivariate normal distribution:

$$\begin{bmatrix} \varepsilon_{ai} \\ \varepsilon_{pi} \\ \varepsilon_{qi} \end{bmatrix} \sim N(0, \Sigma) \text{ with } \Sigma = \begin{bmatrix} 1 & \sigma_{ap} & \sigma_{aq} \\ \sigma_{ap} & 1 & \sigma_{pq} \\ \sigma_{aq} & \sigma_{pq} & 1 \end{bmatrix} \tag{4}$$

where Σ denotes the variance covariance matrix. Note that for identification, we have restricted the variances of ε_{ai}, ε_{pi} and ε_{qi} to be one. Identification of this model also requires at least one variable in x_{ai} that is not expected to influence q_i or p_i.

We estimate the model using full information maximum likelihood techniques. First, we derive the relevant joint probabilities used to form the contributions to the log likelihood function. When $p_i = 0$, q_i is unobserved. Therefore,

$$\begin{aligned} \Pr(a_i = 0, p_i = 0) &= \Pr\left(\varepsilon_{ai} < -x'_{ai}\beta_a, \varepsilon_{pi} < -x'_{pi}\beta_p\right) \\ &= \Phi_2\left(-x'_{ai}\beta_a, -x'_{pi}\beta_p, \rho_{ap}\right) \end{aligned} \tag{5}$$

and

$$\Pr\left(a_i=1,p_i=0\right)=\Pr\left(\varepsilon_{ai}<x'_{ai}\beta_a,\varepsilon_{pi}<-x'_{pi}\beta_p-\delta_p\right)$$
$$=\Phi_2\left(x'_{ai}\beta_a,-x'_{pi}\beta_p-\delta_p,\rho_{ap}\right) \quad (6)$$

where $\Phi_2(\cdot)$ denotes the bivariate standard normal cumulative distribution function (CDF) and ρ_{ap} represents the correlation between ε_{ai} and ε_{pi}.

If a facility is inspected and compliance is observed (i.e., $p_i=1$), the contributions to the likelihood function contain trivariate normal integrals. Thus,

$$\Pr\left(a_i=0,p_i=1,q_i=0\right)=\Pr\left(\varepsilon_{ai}<-x'_{ai}\beta_a,\varepsilon_{pi}<x'_{pi}\beta_p,\varepsilon_{qi}<-x'_{qi}\beta_q\right)$$
$$=\Phi_3\left(-x'_{ai}\beta_a,x'_{pi}\beta_p,-x'_{qi}\beta_q,-\rho_{ap},\rho_{aq},-\rho_{pq}\right), \quad (7)$$
$$\Pr\left(a_i=0,p_i=1,q_i=1\right)=\Pr\left(\varepsilon_{ai}<-x'_{ai}\beta_a,\varepsilon_{pi}<x'_{pi}\beta_p,\varepsilon_{qi}<x'_{qi}\beta_q\right)$$
$$=\Phi_3\left(-x'_{ai}\beta_a,x'_{pi}\beta_p,x'_{qi}\beta_q,-\rho_{ap},-\rho_{aq},\rho_{pq}\right), \quad (8)$$
$$\Pr\left(a_i=1,p_i=1,q_i=0\right)$$
$$=\Pr\left(\varepsilon_{ai}<x'_{ai}\beta_a,\varepsilon_{pi}<x'_{pi}\beta_p+\delta_p,\varepsilon_{qi}<-x'_{qi}\beta_q-\delta_q\right)$$
$$=\Phi_3\left(x'_{ai}\beta_a,x'_{pi}\beta_p+\delta_p,-x'_{qi}\beta_q-\delta_q,\rho_{ap},-\rho_{aq},-\rho_{pq}\right), \quad (9)$$

and

$$\Pr\left(a_i=1,p_i=1,q_i=1\right)$$
$$=\Pr\left(\varepsilon_{ai}<x'_{ai}\beta_a,\varepsilon_{pi}<x'_{pi}\beta_p+\delta_p,\varepsilon_{qi}<x'_{qi}\beta_q+\delta_q\right)$$
$$=\Phi_3\left(x'_{ai}\beta_a,x'_{pi}\beta_p+\delta_p,x'_{qi}\beta_q+\delta_q,\rho_{ap},\rho_{aq},\rho_{pq}\right) \quad (10)$$

where $\Phi_3(\cdot)$ denotes the trivariate standard normal CDF, ρ_{aq} represents the correlation between ε_{ai} and ε_{qi}, and ρ_{pq} represents the correlation between ε_{pi} and ε_{qi}.

Expressions (5)–(10) combine to provide the log likelihood function for the model described in Eqs. 1–4. We simulate the trivariate CDF using the Geweke–Hajivassiliou–Keane (GHK) simulator.[15] Following Cappellari and Jenkins (2006), we derive our draws using Halton sequences to improve the coverage of the domain of integration and to ensure a negative correlation between the draws from different observations.[16] The bivariate CDF does not require simulation (Stern 1997).[17] Maximization of the

[15] The GHK simulator uses draws from upper truncated standard normal distributions and recursively computes the trivariate probabilities using Cholesky factorization of the covariance matrix. See Train (2003, pp. 126–137) for a detailed discussion of the GHK simulator.

[16] We generate Halton draws in Stata using the mdraws.ado program written by Cappellari and Jenkins.

[17] However, we also estimated a fully simulated model. The results of the fully simulated model are consistent with the results from the partially simulated model in terms of sign, significance, and magnitude of the estimated coefficients. The fully simulated results are available from the authors by request.

log likelihood function yields estimates of the parameters of the audit, inspection, and compliance equations as well as estimates of and ρ_{ap}, ρ_{aq} and ρ_{pq}.

6 Data

Because there are numerous factors that may influence a facility's decision to audit, any analysis of the causes of environmental auditing needs to include explanatory variables that capture the nature of the environmental regulations to which the facility is subject, the facility's level of environmental exposure, its size, the nature of its operations, and its enforcement and compliance history. As discussed in Sect. 4, the universe for our analysis consists of the 3,395 manufacturing facilities (i.e., facilities that have two-digit SIC codes between 20 and 39) in Michigan that are regulated under RCRA because they generate hazardous waste. We collected data on each facility's characteristics and inspection and compliance history from EPA's RCRAInfo database. We linked RCRAInfo to EPA's FRS database to collect additional information about other media programs under which the facility is regulated.[18] Table 2 provides descriptions for the variables included in the analysis as well as summary statistics by auditing status. Unless otherwise indicated, the data were taken from the RCRAInfo database. The binary variable *Audit* is equal to one if the facility filed at least one intent-to-audit notice with the DEQ between 1998 and 2003. Difference of means tests indicate significant differences among those facilities that filed intent-to-audit notices and those that did not for all variables listed in the table except three: *SQG*, *County Income* and *County Conservancy*.

The variable $Inspected_{04-06}$ indicates whether the facility was inspected at least once between 2004 and 2006. Thirty one percent of auditing facilities were inspected at least once during this period while only 13% of non-auditing facilities were inspected. Thus, without controlling for the factors that may jointly impact the audit decision and the likelihood of inspection, a simple comparison of means suggests higher (future) inspection intensity among auditing facilities. The variable $Complied_{04-06}$ is equal to one if a facility is found to be in compliance at each regulatory inspection that takes place between 2004 and 2006. If a facility is found to be in violation during at least one inspection, $Complied_{04-06}$ is equal to zero. If a facility is never inspected during the 2004–2006 period, $Complied_{04-06}$ is missing (recall that our empirical method accounts for the missing variable) and thus the statistics reported in Table 2 for this variable only represent inspected facilities. Note that while the means and standard deviations for this variable are relatively similar, such a comparison fails to account for factors that might jointly impact the audit decision, the likelihood of inspection, and the decision to comply with regulations.

RCRA classifies each facility into one of three generator status categories—large quantity generator (LQG), small quantity generator (SQG), and conditionally exempt small quantity generator (CEG)—based on the amount of hazardous waste the facility

[18] For some FRS facilities there is more than one hazardous waste facility identified in the RCRAInfo database. Because RCRAInfo data cannot easily be aggregated across observations, we chose to consider the RCRAInfo observations as the primary observations.

Table 2 Variable descriptions and summary statistics for RCRA manufacturing facilities in Michigan

Variable	Description	Filed audit notice Mean (Std. dev)	Did not file audit notice Mean (Std. dev)
Audit	= 1 if facility filed at least one intent-to-audit notice between 1998 and 2003	1 (0)	0 (0)
$Inspected_{04-06}$	= 1 if facility was inspected at least once between 2004 and 2006	0.31 (0.46)	0.13 (0.33)
$Complied_{04-06}$	= 1 if facility was found to be in compliance at all regulatory inspections[a]	0.43 (0.50)	0.42 (0.49)
LQG	= 1 if facility is a RCRA large quantity generator	0.55 (0.50)	0.14 (0.35)
SQG	= 1 if facility is a RCRA small quantity generator	0.27 (0.44)	0.33 (0.47)
CEG	= 1 if facility is a RCRA conditionally exempt generator	0.18 (0.39)	0.53 (0.50)
$Generated_{99}$	Log of the tons of hazardous waste generated in 1999	1.96 (4.95)	−1.21 (3.37)
$Managed_{99}$	Log of the tons of hazardous waste managed in 1999	−9.99 (5.39)	−11.09 (2.86)
$Managed_{05}$	Log of the tons of hazardous waste managed in 2005	−2.79 (7.98)	−9.49 (5.22)
$Inspections_{94-98}$	Number of RCRA inspections at the facility between 1994 and 1998	2.28 (5.04)	0.64 (2.74)
$Violations_{94-98}$	Number of RCRA violations detected at the facility between 1994 and 1998	1.46 (2.14)	0.71 (2.17)
$Inspections_{01-03}$	Number of RCRA inspections at the facility between 2001 and 2003	1.92 (6.32)	0.35 (1.28)
$Violations_{01-03}$	Number of RCRA violations detected at the facility between 2001 and 2003	1.01 (2.23)	0.37 (1.21)
$OtherViolation_{04-06}$	= 1 if facility had a significant non-RCRA violation between 2004 and 2006	0.08 (0.28)	0.02 (0.13)
CAA	= 1 if the facility is regulated under the CAA	0.73 (0.45)	0.24 (0.43)

Table 2 continued

Variable	Description	Filed audit notice Mean (Std. dev)	Did not file audit notice Mean (Std. dev)
NPDES	= 1 if the facility has a National Pollution Discharge Elimination System permit	0.23 (0.42)	0.06 (0.23)
TRI	= 1 if the facility is subject to TRI reporting	0.82 (0.38)	0.27 (0.44)
NEPT	= 1 if the facility is a member of the National Environmental Performance Track	0.03 (0.17)	0.001 (0.03)
$CountyInspections_{04-06}$	Number of RCRA inspections in the county between 2004 and 2006 as a fraction of the number of RCRA facilities in the county	0.05 (0.03)	0.05 (0.03)
County Republicans	Percent of the voters in the county that voted Republican in the 2000 Presidential election	0.43 (0.12)	0.48 (0.11)
County Income	Per capita income in the county in 1999 in $100,000	0.22 (0.04)	0.22 (0.05)
County Conservancy	Number of individuals in the county that belonged to the Nature Conservancy in 2005 per 1,000 residents	2.69 (1.21)	2.83 (1.06)
Number of observations		131	3,264

[a] Only facilities that were inspected were used to calculate these summary statistics

generates each month.[19] The amount of waste produced, and therefore the facility's generator status, determines the stringency of the regulations to which the facility is subject with stringency increasing in waste production. As facilities that generate larger quantities of waste tend to be larger facilities, generator status also provides a rough proxy for facility size. We control for the facility's RCRA generator status

[19] LQGs generate at least 2,200 lbs. of hazardous waste a month, SQGs generate between 220 and 2,200 lbs. of hazardous waste a month, and CEGs generate less than 220 lbs. per month. See http://www.epa.gov/osw/hazard/generation/ for more detailed information on the differences in the RCRA regulations to which the various generator categories are subject.

with the variables *LQG* and *SQG* (*CEG* is the omitted category). Not surprisingly, we observe more auditing among LQGs.

The next two variables, $Generated_{99}$ and $Managed_{99}$, respectively measure the quantity of waste generated and managed at a facility and thus proxy for environmental exposure. $Generated_{99}$ is calculated from the quantity of waste reported in the 1999 Biennial Reporting System (BRS) for those facilities required to report to the BRS. For facilities that are not required to report to the BRS (most SQGs and CEGs) we used the log of the maximum possible quantity of waste that the facility could generate. In addition to generating hazardous waste, some facilities in the analysis also manage (i.e., treat and/or dispose of) hazardous waste on-site. These facilities are primarily large waste generators that find it cost-effective to manage their own waste or waste generated by other facilities within their company. Because any facility that manages hazardous waste must report to the BRS, $Managed_{99}(Managed_{05})$ is taken directly from the 1999 (2005) BRS.[20]

$Inspections_{94-98}$ and $Violations_{94-98}$ are also extracted from the RCRAInfo database to represent the enforcement and compliance history of each facility prior to the decision to file an intent-to-audit notice. $Inspections_{01-03}$ and $Violations_{01-03}$ are similarly constructed and capture a facility's more recent enforcement and compliance history. The variable $OtherViolation_{04-06}$ indicates whether the facility had a significant violation in an environmental program other than RCRA during the 2004–2006 period and was extracted from EPA's Enforcement and Compliance Online (ECHO) database.[21]

The next four variables, all extracted from EPA's FRS database, indicate other environmental programs under which the facility is regulated. *CAA* is equal to 1 if the facility is regulated under the CAA. *NPDES* is equal to 1 if the facility is a point source regulated under the Clean Water Act and has a National Pollution Discharge Elimination System permit. *TRI* is equal to 1 if the facility is subject to TRI reporting requirements and *NEPT* is equal to 1 if the facility was a member of EPA's National Environmental Performance Track voluntary initiative.[22]

The final four variables measure the characteristics of the county in which the facility is located. $CountyInspections_{04-06}$ measures the total number of RCRA inspections in the county between 2004 and 2006, normalized by the total number of RCRA facilities in the county to provide a general indication of county-level regulatory intensity. Following the enforcement literature, we include controls for the general political and economic climate of the county in which the facility is located. *County Republicans* indicates the percentage of voters in the 2000 Presidential election that voted for the Republican candidate, George W. Bush.[23] *County Income* indicates the

20 For facilities that generate or manage no hazardous waste, we took the log of 0.00001 tons.

21 To address any potential concerns that this variable might be endogenous, we also ran the model without $OtherViolation_{04-06}$. The results of the model excluding this variable are qualitatively the same as the results when it is included.

22 EPA discontinued the National Environmental Performance Track in May of 2009.

23 These data were taken from the Michigan Department of State's website (http://miboecfr.nicusa.com/election/results/00gen/01000000.html).

per capita income in 1999 in the county.[24] Finally, we include a variable to measure the size of the environmental constituency in each county. *County Conservancy* measures the number of Nature Conservancy members per 1,000 residents of the county.[25] As noted by Innes and Sam (2008), a larger environmental constituency may suggest a higher degree of public awareness of a facility's environmental performance and more successful lobbying of local government by environmental interest groups.

7 Regression results

The results of the Censored Trivariate Probit are presented in Table 3.[26] Table 4 presents the associated marginal effects, calculated as the change in the predicted probability (in percentage points) that a "representative" facility submits an intent-to-audit notice between 1998 and 2003, is inspected between 2004 and 2006, or is in compliance from 2004 to 2006 for various changes in the explanatory variables. The representative facility has the mean values for all continuous explanatory variables and the median values for discrete explanatory variables. This implies a baseline audit probability of 0.44%, a baseline inspection probability of 5%, and a baseline compliance probability of 84%.

In discussing Tables 3 and 4, we first focus on the results for the Audit equation to get a better understanding of the factors that encourage facilities to conduct environmental audits. As shown in the top panel of Table 3, LQGs are significantly more likely to audit than CEGs. The estimated marginal effect suggests that LQG status increases the predicted probability of an audit by 1.31 percentage points to 1.75%, over a three-fold increase. Since LQGs face the most stringent level of regulation, these results suggest that the stringency of regulation is positively related to the decision to audit. This result is also consistent with larger facilities being more likely to conduct audits. We detect no significant difference in the likelihood of auditing among SQGs relative to CEGs.

Similarly, as indicated by the positive and significant coefficient on $Generated_{99}$, the larger the quantity of waste generated, the more likely the facility is to audit. On the other hand, the negative and significant coefficient on $Managed_{99}$ suggests that the larger the quantity of waste managed, the less likely the facility is to audit. Those facilities that engage in on-site waste management may have more knowledge of the applicability of hazardous waste regulations or how to increase environmental performance because hazardous waste management is an important part of the

[24] These data were taken from the 2000 Census.

[25] County-level data on membership in environmental organizations is not readily available. We thank Mary Thomas and Donald Zeilstra from the Nature Conservancy, Michigan Field Office, for providing these data.

[26] The simulated trivariate probabilities are based on 500 Halton draws with antithetic acceleration. We report robust standard errors. In addition to the regression reported, we estimated this model four additional times using different sequences of 500 Halton draws. The results of each of those regressions were consistent with the results reported here in terms of sign, significance, and magnitude of the coefficients. We also estimated our model with 250 and 800 Halton draws and obtained results that are consistent with those we report in terms of sign, significance, and magnitude of coefficients.

Table 3 Results of the censored trivariate probit using simulated maximum likelihood[a]

Explanatory variable	Estimated coefficient	Robust standard error
Audit equation		
LQG	0.512**	0.152
SQG	0.029	0.129
$Generated_{99}$	0.041**	0.013
$Managed_{99}$	−0.029**	0.014
$Inspections_{94-98}$	0.021*	0.011
$Violations_{94-98}$	−0.061**	0.027
CAA	0.470**	0.125
NPDES	0.187	0.140
TRI	0.702**	0.138
NEPT	1.437**	0.526
County Republicans	−2.680**	0.547
County Income	2.319*	1.192
County Conservancy	−0.002	0.053
Constant	−2.102**	0.342
Inspection equation		
Audit	−0.265	0.755
LQG	0.771**	0.165
SQG	0.499**	0.073
$Managed_{05}$	0.034**	0.010
$Inspections_{94-98}$	0.087**	0.020
$Inspections_{01-03}$	0.047*	0.022
$Violations_{01-03}$	−0.117**	0.038
CAA	0.176**	0.087
NPDES	−0.101	0.124
TRI	0.104	0.097
NEPT	0.479	0.579
$CountyInspections_{04-06}$	6.464**	0.808
County Republicans	0.206	0.367
County Income	−1.507*	0.840
County Conservancy	−0.031	0.034
Constant	−1.349**	0.262
Compliance equation		
Audit	0.321	0.808
LQG	−0.908**	0.311
SQG	−0.557**	0.174
$Managed_{05}$	−0.012	0.021
$Inspections_{94-98}$	−0.005	0.011
$Inspections_{01-03}$	−0.003	0.020

Table 3 continued

Explanatory variable	Estimated coefficient	Robust standard error
$Violations_{01-03}$	0.047	0.045
$OtherViolation_{04-06}$	0.375	0.244
CAA	−0.229	0.155
NPDES	0.297	0.194
TRI	−0.018	0.171
NEPT	0.251	0.793
County Republicans	2.472**	0.750
County Income	−4.049**	1.982
County Conservancy	0.180**	0.069
Constant	0.313	0.612
Correlation coefficients		
ρ_{ap}	0.143	0.395
ρ_{aq}	−0.118	0.431
ρ_{pq}	−0.515**	0.258

* Significant at the 0.10 level
** Significant at the 0.05 level
[a] Trivariate distribution simulated using GHK simulator, 500 Halton draws with antithetic acceleration. Number of observations is 3395. p-value for likelihood ratio test that correlation coefficients are jointly zero is 0.00

facility's operations. If this is the case, then they would stand to benefit less from an audit.

The coefficient on $Inspections_{94-98}$ is positive and marginally significant, indicating that facilities that faced higher enforcement scrutiny in the recent past are more likely to audit. The negative and significant coefficient on $Violations_{94-98}$ suggests that facilities with poor compliance records are less likely to submit intent-to-audit notices than facilities with better records. Facilities cannot receive penalty mitigations for self-disclosed violations that have been detected at the facility in the past. This may dilute the incentive to audit among facilities with poor compliance records. Additionally, facilities with poor compliance records may be more concerned that audit documents could be used by third parties than facilities with fewer past compliance issues.[27]

The positive and significant coefficients on two of the next three variables, *CAA* and *TRI* suggest that facilities subject to multiple environmental regulations are more likely to undertake environmental audits. The next variable, *NEPT*, identifies whether the facility voluntarily joined EPA's National Environmental Performance Track. Facilities on the NEPT set measurable goals for going "beyond compliance" in exchange for public recognition of their achievements. As one might expect, facilities that vol-

[27] See the discussion in Feeley (1995), among others, of the Colorado-Coors case in which the Colorado Department of Public Health and Environment sought over $1 million in fines from Coors Brewing Company following Coors' disclosure of a violation discovered during a voluntary environmental audit. Feeley notes "A self-audit can become a 'prosecutorial road map'…"

Table 4 Marginal effects for a representative facility[a]

	Audit (%)	Inspection (%)	Compliance (%)
Baseline probability for a representative facility[b]	0.44	5.00	84.00
Change in the probability of audit, inspection, or compliance if			
Facility submitted intent-to-audit notice		− 2.19	+ 6.58
Facility is a *LQG*	+ **1.31**	**+14.13**	**−30.56**
Facility is a *SQG*	+ 0.04	+ **7.59**	**−17.08**
Increase $Generated_{99}$ by one standard deviation	+ **0.22**		
Increase $Managed_{99}$ by one standard deviation	− **0.10**		
Increase $Managed_{05}$ by one standard deviation		+ **2.25**	+ 1.53
Increase $Inspections_{94-98}$ by one standard deviation	+ **0.08**	+ **3.16**	− 0.34
Increase $Violations_{94-98}$ by one standard deviation	− **0.14**		
Increase $Inspections_{01-03}$ by one standard deviation		+ **0.94**	− 0.14
Increase $Violations_{01-03}$ by one standard deviation		− **1.35**	+ 1.40
Facility had $OtherViolation_{04-06}$			+ 7.45
Facility is subject to *CAA*	+ **1.13**	+ **2.10**	− 6.21
Facility is subject to *NPDES*	+ 0.31	− 0.96	+ 6.18
Facility is subject to *TRI*	+ **2.31**	+ 1.17	−0.44
Facility is subject to *NEPT*	+ **11.36**	+ 7.20	+ 5.35
Increase $CountyInspections_{04-06}$ by one standard deviation		+ **2.59**	
Increase *County Republicans* by one standard deviation	− **0.26**	+ 0.23	**+5.60**
Increase *County Income* by one standard deviation	+ **0.16**	− **0.67**	− **4.92**
Increase *County Conservancy* by one standard deviation	− 0.002	− 0.33	+ **4.23**

[a] Statistically significant changes (at 0.10) indicated in bold

[b] The representative facility has the mean values for all continuous explanatory variables and the median values for discrete explanatory variables

untarily joined the NEPT are also significantly more likely to voluntarily conduct an environmental audit. The estimated marginal effect suggests that participation in NEPT has the largest effect, 11.36 percentage points, on the predicted probability of auditing. Finally, note that two of the three county-level variables in the Audit Equation are significant. *County Republican*s has a negative coefficient indicating that the higher the percentage of Republican voters in the county, the lower the probability of an environmental audit. Facilities located in counties with a higher percentage of Republicans may face less community pressure to take voluntary measures to increase environmental performance. *Per Capita Income* has a positive coefficient indicating that the higher the per capita income in the county, the higher the probability of an environmental audit. Facilities located in counties with a higher income may face more community pressure to take voluntary measures to increase environmental performance.

Before turning to the results of the other two equations, note that the variable $Violations_{94-98}$ is used to identify the model. We expect both the number of inspections and the number of violations at a facility between 1994 and 1998 to have a significant effect on the probability that the facility audits between 1998 and 2003. However, the time period of interest for the inspections and compliance outcomes is 2004–2006, 6–12 years after the period covered by $Violations_{94-98}$. We do not expect violations that occurred approximately a decade earlier to have a significant effect on inspections and compliance, particularly since we include more recent compliance history variables in the inspection and compliance equations. Moreover, when $Violations_{94-98}$ is included in a censored bivariate probit model of inspections and compliance for the 2004–2006 period (i.e., without the *Audit* variable), neither of the coefficients on $Violations_{94-98}$ is significant.[28]

Next consider the results of the inspection equation, presented in the second panel of Table 3. First, note that facilities that have filed intent-to-audit notices are not significantly more or less likely to face future inspections than facilities that have not filed a notice. This contrasts with Stafford's (2007) finding that facilities that self-disclose violations under the Audit Policy are less likely to be inspected in the future. We offer two possible explanations for these differing results. First, regulators may only reward self-disclosures, not environmental audits more generally. Second, the extent of information sharing between the Michigan DEQ and EPA inspectors is unclear. If information sharing between the Michigan DEQ and EPA is infrequent, then EPA inspectors may be generally unaware of a facility's auditing status. The remaining results for the inspection equation are generally consistent with other analyses of RCRA inspections (see, for example, Stafford, 2006). Larger hazardous waste generators are more likely to be inspected than smaller facilities. Additionally, the more waste a facility manages, the higher the probability of inspection, as shown by the positive coefficient on $Managed_{05}$.[29] The positive and significant coefficients on $Inspections_{94-98}$ and $Inspections_{01-03}$ suggests that there may be unobserved factors at the facility the regulator is targeting. However, the negative and significant coefficient on $Violations_{01-03}$ is unexpected, as targeting models such as Harrington (1988) and related empirical work in the enforcement literature suggest that facilities with poor compliance records will be inspected with a higher probability than facili-

[28] We include $Inspections_{94-98}$ in both the inspection and compliance equations because in the censored bivariate probit model of inspections and compliance for the 2004–2006 period, this variable was significant in the inspection equation. However, the results do not change qualitatively if we also exclude $Inspections_{94-98}$ from these two equations. Full results of these additional specifications are available upon request from the authors.

[29] We opted to exclude a variable measuring the quantity of waste the facility generated in 2005 from our final specification. We estimated a specification that included this variable in the Inspection and Compliance equations. However, the variable was insignificant in both equations, suggesting that the included generator categories captured most of the variation that would be explained by a variable measuring the actual quantity of waste generated.

ties with good compliance records. We offer one potential explanation for this result. A facility with a large number of violations in the recent past (i.e., a high value for $Violations_{01-03}$) may have entered into a long period of negotiation with regulators about fees, penalties, supplemental environmental projects, etc. A facility in the midst of such negotiations may be less likely to face traditional enforcement inspections.

Regulation under alternative environmental programs plays only a limited role in explaining inspections. As one might expect, the higher the county-wide inspection intensity, the higher the probability of inspection at a given facility. Higher county-level per capita income reduces the likelihood the facility is inspected. Together, these results imply that for a given level of inspection intensity, inspections in wealthy counties are either more focused on particular manufacturing facilities (i.e., fewer facilities are inspected with some facilities inspected multiple times) or are targeted towards facilities outside of the manufacturing sector.

The final panel of Table 3 reports results for the compliance equation. The coefficient on the *Audit* variable is positive but insignificant, suggesting that facilities that filed an intent-to-audit notice do not differ in terms of long-term compliance from facilities that did not file. Thus, unlike the results of KW, we do not find any evidence that auditing improves compliance among the Michigan manufacturers in our sample.

Next note that the coefficients on *LQG* and *SQG* indicate significantly poorer compliance among larger hazardous waste generators. As shown in Table 4, compared to the representative CEG whose predicted probability of compliance is 84%, a representative SQG's predicted probability of compliance falls to just under 67% while a representative LQG's predicted probability is approximately 53%. Interestingly, we find no significant effect of regulation under other environmental programs on RCRA compliance. We do find that facilities in counties with a high percentage of Republican voters or low per capita income are more likely to be in compliance. The per capita income results are inconsistent with some findings from the environmental justice literature and may indicate that income is as a proxy for some other effect, perhaps indicating differences among urban and rural facilities. Our finding that facilities in counties with a larger number of Nature Conservancy members are more likely to be in compliance than facilities located in less environmentally active counties is consistent with the notion that active citizen groups may be able to lobby regulators to increase enforcement measures.

Finally, we reject the hypothesis that the three correlation coefficients are jointly zero (p-value = 0.00). Only the correlation between the Inspection and the Compliance equation is individually significant. The fact that neither of the other correlation coefficients is significant suggests that the decision to audit may not in fact be endogenous to either future inspection or future compliance outcomes.

We explored a number of alternative models to assess the robustness of our findings with respect to auditing and long-run compliance.[30] First, we estimated a censored trivariate probit on a sample of all RCRA generators, not just manufacturing facilities. This expands the analysis to over 16,000 facilities and increases the number of audits to 191, although the percentage of facilities that audit actually falls to just over

[30] The results of all of these analyses are available upon request from the authors.

1%. The results for all RCRA generators are qualitatively quite similar to the results for manufacturing facilities. Most importantly, the coefficient on the Audit variable in the Compliance equation is insignificant, although in this specification it is negative as well. Next, given the insignificance of the correlation coefficients between the audit equation and the other two equations, we ran a censored bivariate probit (which implicitly assumes that the audit decision is exogenous) on both the manufacturing facility subsample and the full RCRA-generator sample. In neither regression was the coefficient on the Audit variable in the Compliance equation significant.[31]

8 Discussion of results

The goal of this paper is to investigate whether environmental auditing has a significant lasting effect on compliance with environmental regulations. We use a dataset from Michigan's DEQ on whether facilities have filed an intent-to-audit notice as a measure of whether the facility has conducted an environmental audit. While this measure could be subject to under-reporting, either due to ignorance or deliberate failure to file such a notice, it is the only facility-level data on environmental auditing of which we are aware. A clear benefit of the Michigan data is its coverage of a wide variety of facilities. This feature helps to answer the question of whether EPA's untargeted encouragement of environmental auditing can be an effective part of its compliance and enforcement strategy.

We focus our analysis on manufacturing facilities that are regulated under RCRA. In examining the causes of environmental auditing, we find that larger facilities and facilities subject to more stringent regulations are more likely to audit. We find that facilities with poor compliance records are less likely to audit. The data also show that facilities that are regulated under multiple environmental programs are more likely to audit as are facilities that voluntarily participated in EPA's now defunct National Environmental Performance Track.

Our analysis finds no persistent differences between facilities that file an intent-to-audit notice and facilities that do not file such a notice, either in the way in which regulators inspect facilities in the future or in the future compliance behavior of facilities. Because there are only a small number of facilities in our dataset that do file an intent-to-audit notice, we tested a number of different specifications to ensure that our findings were robust. None of the alternative models provided any evidence that auditing had a significant effect on long-term compliance across facilities in our sample.

Our results stand in contrast to that of Khanna and Widyawati (2011) who report a positive short-run effect of auditing on compliance. There are a number of reasons why our results may differ including a different sample of facilities; our consideration of facility-, rather than firm-level, auditing; and our focus on long-term, rather than

[31] We also ran several clearly misspecified models as additional robustness checks. For example, we treated the Compliance variable as a continuous variable and ran a linear regression with a Heckman correction for both samples. We also ignored the censoring issue and ran a probit on the Compliance equation for both samples. In none of these models did we find a significant coefficient on the Audit variable in the Compliance equation.

contemporaneous, compliance. An important next step in this line of inquiry involves identifying which of these differences drives our divergent results. Because of the limitations of the dataset used in this analysis, we are not able to more fully explore these issues, but we hope to do so in the future with other data. In particular, including firm-level characteristics would permit a comparative analysis of auditing at different levels of decision-making within the firm, which would be a valuable extension to our work.

The finding that environmental auditing has no significant lasting effect on compliance across a wide range of facilities does seem to be consistent with the small number of facilities that have filed intent-to-audit notices. If audits did have a long-lasting effect on compliance, one would expect to see more facilities conducting them. These results suggest that environmental auditing is unlikely to be a cost-effective component of EPA's overall enforcement and compliance strategy. However, there are several reasons why environmental auditing may still be an effective part of a facility's environmental management strategy. First, environmental auditing may have important short-term effects on compliance. Facilities that audit should be able to identify and remediate environmental violations when the audit is conducted, rather than waiting for a compliance inspection to identify such violations. Thus, an audit should increase actual compliance in the short-run, although its effect on reported violations depends on whether the auditing facility chooses to disclose the violations it identifies during the audit. However, unless an audit fundamentally changes a facility's internal compliance controls, we would not expect long-term compliance to be affected by an audit.

Second, environmental auditing may have important positive effects on environmental *performance* in both the short- and long-term even without any effect on long-term *compliance*. For example, an environmental audit may help a facility identify ways to reduce its initial generation of hazardous waste. Such a reduction would decrease environmental liabilities and reduce a facility's overall compliance costs in the long-term but is unlikely to change its compliance status as there are no regulatory restrictions on the quantity of hazardous waste that a facility generates. The effectiveness of environmental auditing may vary across facilities; there may be some facilities for whom environmental auditing is particularly effective (or ineffective). If this proves to be the case, EPA may find it cost-effective to promote environmental auditing at particular segments of the regulated universe rather than encouraging it across the board.

Finally, combining our result that environmental auditing alone does not have a long-term effect on compliance with Sam's (2010) finding that EMSs do have a lasting effect on compliance suggests that there might be complementarities between environmental auditing and other components of EMSs that together result in improved compliance. Thus, it may prove more effective to promote adoption of EMS rather than environmental auditing alone. Ideally additional analyses will shed light on the areas in which auditing can be the most effective. Interestingly, although there have been no official changes in EPA policies that impact environmental auditing, EPA's current strategic plan does not discuss environmental auditing.[32] It remains to be seen what

[32] "FY 2011–2015 Strategic Plan," available at http://www.epa.gov/cfo/plan/plan.htm, last accessed January 20, 2011. The term "environmental audit" does not appear anywhere in the plan, in contrast to its presence in all four strategic plans issued between 1997 and 2006.

role environmental auditing will play in EPA's future compliance and enforcement strategy.

References

Anton, W., Deltas, G., & Khanna, M. (2004). Incentives for environmental self-regulation and implications for environmental performance. *Journal of Environmental Economics and Management, 48*, 632–654.

Cappellari, L., & Jenkins, S.P. (2006). *Calculation of multivariate normal probabilities by simulation, with applications to maximum simulated likelihood estimation*. Discussion Papers of DIW Berlin, German Institute for Economic Research.

Dasgupta, S. , Hettige, H. , & Wheeler, D. (2000). What improves environmental compliance? Evidence from Mexican industry. *Journal of Environmental Economics and Management, 39*, 39–66.

Evans, M.F., Gilpatric, S.M., McKee, M., & Vossler, C.A. (2008). Managerial incentives for compliance with environmental information disclosure programs. In T. Cherry, J. Shogren, & S. Kroll, *Experimental methods, environmental economics*. UK: Routledge.

Feeley, M. S. (1995, July 13). Dirty secrets: California moves to protect businesses that conduct environmental self-audits. *Los Angeles Daily Journal*.

Friesen, L. (2006). The social welfare implications of industry self-auditing. *Journal of Environmental Economics and Management, 51*, 280–294.

Gamper-Rabindran, S. (2006). Did the EPA's voluntary industrial toxics program reduce emissions? A GIS analysis of distributional impacts and by-media analysis of substitution. *Journal of Environmental Economics and Management, 52*, 391–410.

Harrington, W. (1988). Enforcement leverage when penalties are restricted. *Journal of Public Economics, 37*, 29–53.

Innes, R., & Sam, A. (2008). Voluntary pollution reductions and the enforcement of environmental law: An empirical study of the 33/50 program. *Journal of Law and Economics, 51*, 271–296.

Khanna, M., & Anton, W. R. Q. (2002). Corporate environmental management: Regulatory and market-based incentives. *Land Economics, 78*(4), 539–558.

Khanna, M., & Brouhle, K. (2008). Effectiveness of voluntary environmental initiatives. In M. Delmas & O. Young, *Governing the environment: Interdisciplinary perspectives*. Cambridge: Cambridge University Press.

Khanna, M., & Damon, L. A. (1999). EPA's voluntary 33/50 program: Impact on toxic releases and economic performance of firms. *Journal of Environmental Economics and Management, 37*, 1–25.

Khanna, M., & Widyawati, D. (2011). Fostering regulatory compliance: The role of environmental self-auditing and audit policies. *Review of Law and Economics, 7*, 129–163.

King, A., & Lennox, M. (2000). Industry self-regulation without sanctions: The chemical industry's responsible care program. *Academy of Management Journal, 43*, 698–716.

Michigan Department of Environmental Quality (DEQ). (2006). Environmental audit privilege and immunity: Update with 1997 amendments. http://www.michigan.gov/documents/deq/deq-ess-audit-slfaudit_274862_7.pdf

Mishra, B. K., Newman, D. P., & Stinson, C. H. (1997). Environmental regulations and incentives for compliance audits. *Journal of Accounting and Public Policy, 16*, 187–214.

Pfaff, A. S. P., & Sanchirico, C. W. (2000). Environmental self-auditing: Setting the proper incentives for discovery and correction of environmental harm. *Journal of Law, Economics, and Organization, 16*, 189–208.

Potoski, M., & Prakash, A. (2005). Green clubs and voluntary governance: ISO 14001 and firms' regulatory compliance. *American Journal of Political Science, 49*, 235–248.

Sam, A. (2010). Impact Of government-sponsored pollution prevention practices on environmental compliance and enforcement: Evidence from a sample of US manufacturing facilities. *Journal of Regulatory Economics, 37*, 266–286.

Sam, A. G., Khanna, M., & Innes, R. (2009). Voluntary pollution reduction programs, environmental management, and environmental performance: An empirical study. *Land Economics, 85*(4), 692–711.

Stafford, S. L. (2005). Does self-policing help the environment? EPA's audit policy and hazardous waste compliance. *Vermont Journal of Environmental Law, 6*.

Stafford, S. L. (2006). Rational or confused polluters? Evidence from hazardous waste compliance. *Contributions to Economic Analysis and Policy, 5*: Article 21.

Stafford, S. L. (2007). Should you turn yourself in? The consequences of environmental self-policing. *Journal of Policy Analysis and Management, 26*, 305–326.
Stafford, S. L. (2008). Self-policing in a targeted enforcement regime. *Southern Economic Journal, 74*, 934–951.
Stern, S. (1997). Simulation-based estimation. *Journal of Economic Literature, 35*, 2006–2039.
Train, K. (2003). *Discrete choice methods with simulation*. Cambridge: Cambridge University Press.
Uchida, T., & Ferraro, P. J. (2007). Voluntary development of environmental management systems: Motivations and regulatory implications. *Journal of Regulatory Economics, 32*, 37–65.
U.S. Environmental Protection Agency (EPA). (1997). EPA strategic plan. EPA/190-R-97-002.
U.S. Environmental Protection Agency (EPA). (1999). EPA/CMA root cause analysis pilot project: An industry survey.
U.S. General Accounting Office (GAO). (1995). Environmental auditing: A useful tool that can improve environmental performance and reduce cost savings. GAO/RCED 95–37.
Videras, J., & Alberini, A. (2000). The appeal of voluntary environmental programs: Which firms participate and why?. *Contemporary Economic Policy, 18*, 449–461.
Vidovic, M., & Khanna, N. (2007). Can voluntary pollution prevention programs fulfill their promises? Further evidence from the EPA's 33/50 program. *Journal of Environmental Economics and Management, 53*, 180–195.