JOURNAL OF ENVIRONMENTAL ECONOMICS AND MANAGEMENT **31,** 19–36 (1996)
ARTICLE NO. 0029

Environmental Inspections and Emissions of the Pulp and Paper Industry in Quebec*

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Received August 25, 1994; revised March 14, 1995

Although it has long been recognized that monitoring and enforcement problems are an important pitfall of environmental regulation, little empirical work has been done on the impact of current monitoring strategies on pollution emissions. The purpose of this study is to measure the impact of inspections on the self-reported emissions levels of plants in the pulp and paper industry in Québec. It extends in numerous ways the empirical framework developed by Magat and Viscusi (*J. Law. Econom.* **33**, 331–360 (1990)), who analyzed the impact of inspections in the American pulp and paper industry. In particular, our results suggest that both inspections and the *threat* of an inspection have a strong negative impact on pollution emissions. Furthermore, we find that inspections also induce more frequent self-reporting from the industry.

1. INTRODUCTION

Since the beginning of the 1970s, governments of developed countries have enacted (or amended) a large number of environmental laws and regulations directed mainly at controlling and improving air and water quality. However, imposing a ceiling on a plant's emissions does not necessarily imply that emissions will fall and that environmental quality will improve. For the objectives of the regulation to be attained, the behavior of the regulated community has to be monitored, and environmental standards have to be enforced. However, while a large amount of resources is devoted to designing environmental regulations and defining and negotiating environmental standards with the regulated industries, it has been acknowledged, both in Canada and in the United States, that the resources devoted to monitoring and enforcement are insufficient.[1] This lack of

*We are very grateful to two anonymous referees, Wesley Magat, Chuck Howe, and Paul Lanoie for valuable comments and suggestions. Participants at the Third Canadian Conference on Environmental and Natural Resources Economics (Ottawa, October 1993) and the Fourth Annual Conference of the European Association of Environmental and Resource Economists (Fontainebleau, June 1993) have also provided helpful comments. Finally, we thank Martine Bossi and Chantal Dallaire for their research assistance. Financial support from SSHRC is gratefully acknowledged. Usual disclaimers apply.

[1] Russell [15] writes "What is missing is a commitment of resources to checking up on whether those covered by the law and regulations are doing (or not doing) what is required of (or forbidden) them" (p. 243).

0095-0696/96 $18.00

resources has forced the regulator to rely on a system by which a polluter (i) is presumed to comply with the environmental standard if it is using the appropriate emissions control technology (*initial compliance*) and (ii) has to report at regular interval its emissions of the regulated pollutants (*self-monitoring*). On-site inspections of plants are rare events.[2]

Monitoring and enforcement issues have attracted relatively little research effort.[3] Moreover, most of this effort has been theoretical.[4] Except for Deily and Gray [6] and Magat and Viscusi [12], we can only note the mere absence of empirical analysis.[5] Magat and Viscusi ([12], henceforth MV) have estimated the impact of inspections on the *self-reported* discharges of biological oxygen demand (BOD) by the pulp and paper industry in the United States. Since the pulp and paper industry is the largest discharger of BOD, it has been the focus of a considerable amount of regulatory effort. This explains why there is, for this industry, an extensive data base on BOD discharge measurements per plant (the EPA Permit Compliance System, also known as the PCS data base) and on-site sampling inspections by the regulator.[6] MV have found that each inspection reduces the mean value of reported discharges of BOD by approximately 20%. They also found that inspections have a permanent effect on discharges.

The purpose of this study is to measure the impact of inspections on the self-reported emissions levels of plants in the pulp and paper industry in Québec. Our analysis differs from MV on a number of important accounts. *First*, MV measured the impact of inspections on the absolute level of emissions as well as on the status of compliance of the plants, i.e., whether plants comply with the standard. However, even though inspections may not affect the compliance status of a plant, they may affect the level of emissions *exceeding* the standard. Indeed, if inspections do not induce a plant to comply with the standard, they may nonetheless induce the plant to reduce the amount of emissions by which it exceeds the standard. MV wrote ‘‘Unfortunately, it is not possible to construct a reliable measure of the amount of pollution in excess of the permitted amount since data pertaining to the level specified in the permit are not available from the PCS data base’’ [12, p. 345]. In our data set, we do have access to the standard per plant. Hence, we are able to test for the impact of inspections on the level of emissions *relative* to the standard.

Second, the most obvious question which arises in the context of the current analysis concerns the possible endogeneity of inspections. Indeed, while past inspections have been given, the regulator’s current decision to inspect a plant may

[2] For more detail, see [1, 8, 14, 20].

[3] We note, along with Cropper and Oates [5], that most of the literature in environmental economics simply makes the (implicit or explicit) assumption that polluters comply with the regulation.

[4] Among others, see [3, 11, 16].

[5] Fisheries have attracted a certain number of empirical analysis (among others, see [7, 19]). Deily and Gray [6] examine the EPA’s enforcement activities ‘‘for evidence that enforcement was responsive to the possible economic disruption from plant closings’’ (p. 260). Deily and Gray claim that their paper is ‘‘the *first* empirical study of the EPA’s enforcement activity at the plant level’’ (p. 260).

[6] A ‘‘sampling inspection’’ is an inspection where the regulator samples the plant’s effluents and measures the BOD content of the samples. Sampling inspections are considered to be the regulator’s ultimate device to assess compliance with the standard and give credibility to the self-reporting procedure. Other types of monitoring activities are also performed. See MV (p. 338) for more details.

itself be affected by the plant's emissions level. Therefore, one might reasonably expect that in the current period, it is the perceived probability or threat of an inspection (rather than an inspection per se) which is the variable of interest. In other words, both inspections and the probability of an inspection may have an effect on emissions. MV have rejected the hypothesis that current inspections are exogenous and perform their estimations using only lagged inspection variables.

Interviews with employees of the Québec Ministry of the Environment strongly suggest that in any given period, the plants chosen to be inspected are not randomly picked, and in fact, that the probability of an inspection may be inversely related to the number of previous visits. This reflects the Ministry's desire to visit as many plants as possible. From a statistical perspective, this amounts to sampling without replacement. Our interviews also indicate that changes in production capacity may trigger an inspection.[7] Consequently, we estimate an "inspections equation" in which inspections are a function (among others) of a variable indicating the number of inspections which have been conducted at the plant *prior* to the period of reporting as well as capacity. In our sample of analysis, we also reject the exogeneity of current inspections. We then re-estimate our basic model by instrumental variables using expected inspections as instruments. Our results strongly suggest that the threat of an inspection as well as actual inspections has an impact on pollution emissions.

Third, though the EPA Permit Compliance System lists 194 sources with BOD discharges, only 77 of these sources submitted discharge monitoring reports to the EPA. If the missing information is not governed by a random process, this obviously raises the possibility of a selection bias. MV are aware of this problem and inform the reader that "[our] results need to be interpreted as estimates of the response to EPA inspections of firms whose discharge levels are regularly reported to the EPA's national data base" [12, p. 342]. We also face the same issue in Québec. Indeed, there were 59 plants in operation over the period 1985–1990. In principle, as required by the regulation, each of these plants must submit a monthly discharge report to the Ministry of the Environment. However, only 46 of the 59 plants filed reports on a regular basis during the sample period. In order to allow for sample selection problems, we compute a simple binary choice model of reporting and then augment our basic model with a correction term suggested by Heckman [9].[8]

Finally, we estimate the impact of inspections not only on the reported discharges of BOD, but also on reported discharges of total suspended solids (TSS). It should be noted that the technology used to abate BOD differs from that used to reduce TSS. It is found that inspections do not have the same effect on the emissions of these two pollutants. The rest of the paper proceeds as follows. In Section II, we present and describe our data set. In Section III, models and results are presented. We conclude in Section IV.

[7] In such cases, the purpose of the inspection is to verify whether the change in capacity affects compliance with the standard and/or environmental quality.

[8] MV do address non-reporting, although not with a formal model. They test whether or not there is a statistically significant difference in the frequency of reporting before and after an inspection, for the 77 plants of their sample. They find that inspections increase the frequency of reporting of those plants.

II. THE INDUSTRY AND THE DATA SET[9]

A. The Industry

The pulp and paper industry is an important economic agent in the province of Québec. In 1989, more than 31,000 individuals were employed by the industry which paid more than one billion dollars in wages and salaries [13]. In that same year, it was estimated that the industry's capital made up 25% of the capital of the entire manufacturing industry in the province. Newsprint represents by far the most important output with 56% of total production [2]. The province of Québec is the largest producer of newsprint in Canada with 45% of Canadian production and one of the largest in the world with 14% of world production in 1989. Most of its output (73%) is exported to the United States; this represents 20% of Québec's total exports [13].

If the industry is a major contributor to Québec's economic activity, it is also one of the most important sources of conventional pollutants.[10] The BOD load produced by the industry is estimated to represent more than 60% of the total BOD load produced by the manufacturing industry in Québec. This represents the equivalent of the BOD produced by approximately 15 million individuals. Hence, one may expect that a reduction in the production of conventional pollutants by the pulp and paper industry would have a significant impact on water quality in the province. This presumably explains why so much attention has been devoted to the emissions control activities of the industry.

In Canada, jurisdiction over water pollution control (and more generally over pollution control) is shared by the federal and provincial governments. The basis of the overlap relies on the Constitution Act of 1867.[11] Insofar as water pollution is concerned, the federal government has played an important role through its *Fisheries Act*[12] under which it introduced the *Pulp and Paper Effluent Regulations*[13] in 1971. Similarly, the government of Québec, pursuant to its *Environmental Quality Act*,[14] introduced the *Règlement sur les fabriques de pâtes et papiers*.[15] As of May 1992, new federal and provincial regulations were introduced for the pulp and paper industry whereby new emissions standards for TSS, BOD, toxicity, dioxins, and furans have been defined. The standards contained in the provincial regulation are at least as stringent as those contained in the federal regulation.[16] However,

[9] For a more detailed discussion of the industry and the regulation, see [18].

[10] These include BOD and TSS. Conventional pollutants do not include toxic emissions such as dioxins and furans.

[11] The involvement of the federal government in matters of environmental protection is made possible through its jurisdiction over fisheries, harbors, and criminal law, and its residual power to legislate for the peace, order, and good government of Canada. The appropriate roles and responsibilities of federal and provincial governments are the subject of an everlasting debate (see [10]).

[12] Revised Statutes of Canada, 1970, c. F-14.

[13] C.R.C. 1978, c. 830.

[14] L.R.Q. c. Q-2.

[15] R.R.Q., 1981, c. Q-2, r. 12.

[16] These regulations were preceded by the adoption of an administrative agreement which makes Québec the primary agent in dealing with the industry on environmental issues. In particular, Québec is solely responsible for collecting data on pollution emissions. The federal government will have ongoing access to the information thus compiled and is therefore able to oversee the plants' compliance with the federal regulation.

for the period covered by our sample of data (1985–1990), only the Québec regulation contained standards for BOD and TSS (and not on toxicity). Hence, only the latter is relevant for the current study. These standards are uniform and apply to every plant in the industry. They are set in kilograms per ton of production. It is therefore important to understand that the total amount of BOD and TSS that a plant can emit in any given period is a function of its output production during that period: the greater its production, the greater is the allowable discharge. A plant's compliance with the regulation is assessed by comparing the allowable discharge with the total load reported by the plant.[17]

B. The Data Set

According to the *Règlement sur les fabriques de pâtes et papiers,* plants are required to submit monthly reports of their TSS and BOD discharges. Measures have to be taken at times and intervals specified by the regulation. *Self-monitoring* is the most important source of information used by the regulator to assess a plant's compliance with the standards. All the data used in this study have been provided by the Québec Ministry of the Environment; most of them are issued from the Department's annual publication *Bilans annuels de conformité environnementale—secteur des pâtes et papiers*. These documents are based on the monthly reports of all mills of the province and contain the mill's monthly discharges of BOD and TSS. The reports also indicate the allowable discharges of each individual plant for each individual month.[18]

As mentioned above, observations are missing from the monthly reports filed by the plants of the industry. A natural and important question arises as to whether these are missing in a random or systematic manner. In the former case, estimation can proceed in a fairly straightforward manner with the missing observations smoothed over in an appropriate way. On the other hand, if there is a systematic pattern to the non-reporting, this can lead to a selection bias in the usual least-squares estimates. After an examination of the data, we decided to divide the missing observations into two categories. In a number of cases, some of the plants had neglected to report their emission levels on a few occasions in what seemed to be an unsystematic way. These observations were treated as randomly missing and were replaced by forecasts from 12th-order univariate autoregressions. This left us with a data set that included information on 46 of the 59 plants. This data set was used to estimate the effect of inspections without controlling for sample selection issues. The 13 remaining plants had failed to report their emissions to such an

[17] In the United States, the regulation set a limit per pound of pulp and paper produced. Then, the total amount of BOD that a plant can discharge on any given day is obtained by multiplying the limit by the total number of pounds of pulp and paper the plant produces on that day. It appears difficult to compare the Québec emissions standard to their American counterpart since they were defined very differently. In particular, in Québec, allowable discharges were defined for each and every stage of production, from wood washing (whether it be logs or wood chips) to the making of the final product. They also varied according to the production process. However, interviews with the Québec Ministry of the Environment suggests that the allowable discharges *per ton of output* of Québec and the United States were similar.

[18] The reports also indicate the monthly production of each plant. However, this information is confidential. Moreover, given the complexity with which allowable discharges are calculated, it is not possible to find out what was the output production in any given period from knowing what was the allowable discharges for that same period.

extent that it was not even possible to smooth these over with autoregressions. These were treated as possibly missing in a nonrandom manner, thus leading to a sample selection problem. This issue will be discussed in more detail below.

The Québec Ministry of the Environmental performed 54 sampling inspections from 1985 to 1990. However, since 13 plants are excluded from our initial sample of analysis, only 47 of these inspections are initially accounted for. Inspections consist of (i) the regulator and the producer each taking samples from the mill's effluents, (ii) measuring their TSS and BOD contents, and (iii) comparing these measures with the applicable standards.[19]

Before presenting our model, some descriptive statistics are of interest. These appear in Table I. Note first that the average production of both BOD and TSS is above the norm. In fact, 37.38% of the self-reported discharges of TSS are above the norm (35.75% for BOD). In MV's sample of analysis, the occurrence of reported violations for BOD is 25.2%. Note also that the unconditional probability

[19] It is important to recognize that the purpose of an inspection is *not* to determine the accuracy of previous reports filed by plants. This is technically impossible to do since the TSS and BOD discharges of previous months have ‘‘disappeared’’ from the mill's vicinity.

TABLE I

Descriptive Statistics of Sample

(Monthly Data 1985:1–1990:12 for 46 Plants)

Variable	Mean	Standard deviation
Total effluent production	47.309	49.5464
Total suspended solids		
Emissions (TSS)	5.5386	6.1210
Standards	5.2679	4.0883
Biological oxygen demand		
Emissions (BOD)	19.2401	28.4372
Standards	18.4768	26.7975
Inspections	0.0148	0.1207
Violation of TSS standard	0.3738	0.4839
Violation of BOD standard	0.3575	0.4793
$PROD_1$ (1 = kraft pulp)	0.1957	0.3968
$PROD_2$ (1 = newsprint)	0.4130	0.4925
$PROD_3$ (1 = recycled pulp)	0.0652	0.2469
$PROD_4$ (1 = office paper)	0.0217	0.1459
$PROD_5$ (1 = chemical pulp)	0.1522	0.3592
$PROD_6$ (1 = other)	0.1522	0.3592
REG_1 (1 = located in region 1)	0.1087	0.3113
REG_2	0.1304	0.3368
REG_3	0.1522	0.3592
REG_4	0.2174	0.4125
REG_5	0.0652	0.2469
REG_6	0.1087	0.3113
REG_7	0.1087	0.3113
REG_8	0.0652	0.2469
REG_9	0.0435	0.2040
Capacity of production	15.8922	12.0868

of inspections in any given month is 0.0148, or approximately 1.5%. In MV, this probability is approximately 4.25%. Variables of the form PROD_i $(i = 1, \ldots, 5)$ represent dummy variables for the plant's type of production. Newsprint is by far the most important good produced by these plants. These will be used to reflect that plants have different operations and technology. Finally, variables of the form REG_i $(i = 1, \ldots, 8)$ are dummy variables for the region in which the plant is located.

A question which naturally arises with self-reporting is whether the plants accurately report their emissions levels. To some extent, this is an unresolvable problem and the results should be interpreted conditional on the fact that the reporting was conducted by the plants themselves. However, there are several reasons to expect that the reported emissions are not completely inaccurate. First, the technology used by the plants is by now well known and has been used for a relatively long period of time. Hence, knowing the precise technology used by any given plant, its actual production, and the waste water treatment facilities it is using, relatively good estimates of its pollution load can be obtained. Second, it should be noted that fraud in reporting is a serious criminal offense. Third, our discussions with various parties indicate that unionized employees are very prone to inform the regulator about a plant's wrongdoing with respect to the management of its waste. Finally, at the same time a sampling inspection takes place, plants are also required to perform a sampling, independently of those usually conducted for their monthly reports. Given the presence of an inspector, one would therefore expect the plants' measurements of BOD and TSS to be accurate for at least those samplings. This provides an additional source of information regarding the accuracy of their reports. We thus conducted paired difference of means tests using, as a measure of reporting accuracy, the difference between the plants' load measured in presence of an inspector and the levels indicated on the monthly reports for that same period.[20] As indicated in Table II, the resulting test statistics do not indicate any systematic falsification of results.[21]

III. MODELS AND RESULTS

In this section, we proceed in three steps. First, we discuss least-squares estimates of the basic model to examine the effects of inspections without controlling for either possible endogeneity of the inspections or possible selection biases (Section A). Second, we allow and test for the possibility that current inspections are endogenous and then estimate our model by instrumental variables (Section B). In both of these sections, the estimates are calculated using the data for the 46 plants whose reports were basically complete. Finally, we test for the possibility that the process governing non-reporting may not be random and then modify our model as suggested by Heckman [9]. In this last section (Section C), we also allow inspections to be endogenous.

[20] For example, if an inspection took place on May, we would compare the plant's measure from the sample taken in presence of the inspector with the load reported by the plant for the month of May.

[21] It should be said that this is a very simple measure of reporting accuracy; it would not be an accurate measure under a number of scenarios.

TABLE II
Paired Difference of Means Tests
(from 54 Sampling Inspections)

	BOD	TSS
Mean measurements with regulator present	19.1593	8.2632
Mean self-reported measurements, regulator absent	19.0697	6.6543
Difference	0.0896	1.6089
t difference	0.10230952	0.2144231

A. The Basic Model

Our objective is to test for the impact of inspections on two sets of variables: (i) the *absolute* discharges of BOD and TSS and (ii) the level of discharges of BOD and TSS *relative* to their respective standards. The basic model we estimate is of the same form regardless of the pollution variable of interest. Let P_{it} denote the pollution variable associated with plant i in period t.[22] In the absence of sample selection corrections, the equations estimated are of the form

$$P_{it} = \alpha + \phi P_{i,t-12} + \theta_0 \ \mathrm{INS}_t + \sum_{j=1}^{12} \theta_j \ \mathrm{INS}_{t-j} + \beta_2 \ \mathrm{REG}_i + \beta_3 \ \mathrm{PROD}_i + \beta_4 \ \mathrm{CAP}_{it} + \gamma t + \varepsilon_{it}$$

$$i = 1, \dots, 46; \ t = 1, \dots, 60. \quad (1)$$

The first variable is the plant's lagged value of pollution. This variable is included to capture potential seasonal effects, which may be strong (especially for BOD) in Québec with important variations of temperature between summer and winter. This variable also reflects the fact that the installation of emissions control equipment typically requires a long time. To this extent, the lagged pollution variable could also be interpreted as a proxy for the production technology. Hence, we would expect that the (12-month) lagged value of pollution to be a good explanatory variable for current pollution.[23] The second group of variables reflects the effect of current inspections and indicate whether the plant was inspected in period t. The third group of variables indicates whether the plant was inspected in any previous period. An empirical question concerns the appropriate number of lag lengths to include in the analysis. When we include four lags in the model, the corresponding coefficient estimates were generally negative, of the same magnitude, and statistically significant. However, as a referee pointed out, to test whether the effects of inspections are persistent, it is preferable to include also less recent inspections. With 12 lagged inspections, the estimates were still generally negative and of the same size, but the individual coefficients had small t ratios. To circumvent this problem, we then conducted Wald tests to see whether we could

[22] In some specifications, P_{it} is the absolute discharges, while in others, it is the discharges in excess of the norm.

[23] We have also experimented with other lag lengths. It had little effect on the overall results.

reject the hypothesis that the coefficients were equal. Since we were unable to reject this hypothesis for each of the models, we have imposed this constraint on the coefficients of lagged inspections. The resulting point estimates are substantially sharper and, in fact, yield considerable evidence that the effects of inspections are persistent, if not permanent.

REG and PROD are 8×1 and 5×1 vectors of dummy variables reflecting the plant's location and type of output.[24] The CAP variable indicates plant i's daily productive capacity at time t. It should be noted that plants periodically change their productive capacities, and this is in fact the case in the sample period. Ceteris paribus, plants with higher capacities should produce higher levels of pollution. However, it is important to remember that allowable discharges are also a function of output and consequently, higher levels of pollution do not necessarily imply that a plant is more likely to be out of compliance. The final variable allows for a time trend in pollution emissions. Using quarterly data, MV have instead used a set of quarterly dummy variables and report that there was no interesting pattern in the results. With monthly data, a similar procedure leads to an important loss in the degrees of freedom and so we used a simple time trend. Moreover, a time trend has a straightforward interpretation, namely, the overall trend in pollution emissions in the absence of inspections. MV reports having regressed the absolute level of discharges against a linear time trend and found no significant relationship. As shown below, this is not so in our case.

The results from these estimates are presented in Table III. There are four sets of results corresponding to the four measures of pollution emissions.[25] First note that the coefficient on the 12-month lagged dependent variable is, as expected, positive and has a strong effect on absolute discharges, especially so for BOD. MV obtained a similar result for BOD. Second, the coefficients on current and past inspections are always negative, although not always statistically significant. This is especially the case when discharges are measured relative to the norm. This suggests that the means by which BOD and TSS emissions are reduced also have an impact on the norm.[26] MV found that each inspection reduces the mean value of absolute BOD discharges by approximately 20%. Our results indicate that lagged inspections reduce absolute discharged of BOD by approximately 7%. Significant coefficients on regions (especially on REG_1 and REG_2) indicate that there might be important regional differences in the nature of the relationship that exists between the regulator and the regulatees and/or the monitoring and enforcement procedure across regions. As expected, other things being equal, plants with larger capacity should have higher levels of absolute discharges, but need not be out of compliance. The statistically significant negative coefficient on time indicates that once the impact of inspections is accounted for, there is a trend for both pollution discharges and discharges relative to the norm to fall over time. This is in contrast to the results reported by MV.

[24] For identification, REG_9 and $PROD_6$ are left out of the estimated models.

[25] These equations were estimated separately. We also computed seemingly unrelated regression. The results were very similar.

[26] This would be the case if output were to fall as a result of inspections. Unfortunately, we are unable to substantiate this possibility since we did not have access to plant's production data.

TABLE III

Emissions Equations Ordinary Least Squares[a]

(Sample Size = 2716)

Independent variables	Absolute discharges BOD	Absolute discharges TSS	Discharges relative to norm BOD	Discharges relative to norm TSS
CONSTANT	0.8783	3.6740	0.1063	2.1150
	(0.6566)	(8.8756)	(0.0347)	(4.4517)
$P_{i,t-12}$	0.8144	0.4228	0.1511	0.4196
	(80.812)	(33.796)	(8.0051)	(31.199)
INS_t	−4.6976	−0.5796	−2.5810	−0.7632
	(−2.9283)	(−1.1704)	(−0.7014)	(−1.3377)
INS_{t-i}	−1.3115	−0.6413	−1.0186	−0.4082
	(−2.5466)	(−4.0472)	(−0.8648)	(−2.2364)
PROD_1	0.9211	1.9236	−2.0380	1.1488
	(1.0119)	(6.7883)	(−0.9758)	(3.5403)
PROD_2	1.3253	1.3577	1.9298	0.6156
	(1.4742)	(4.8576)	(0.9373)	(1.9234)
PROD_3	8.5664	3.6086	19.270	2.0956
	(6.3952)	(9.0274)	(6.7732)	(4.6436)
PROD_4	0.3520	0.3841	0.5537	−0.0703
	(0.2582)	(0.9127)	(0.1771)	(−0.1450)
PROD_5	−0.1381	0.0784	0.9640	0.1465
	(−0.1869)	(0.3439)	(0.5688)	(0.5579)
REG_1	−4.6449	−5.4594	−8.4068	−3.0172
	(−3.2435)	(−12.392)	(−2.6303)	(−6.0522)
REG_2	−3.8455	−3.5180	−6.3141	−1.5032
	(−3.0151)	(−8.9461)	(−2.1723)	(−3.3394)
REG_3	−0.4137	−2.5488	−1.7323	−1.1595
	(−0.3340)	(−6.6878)	(−0.6118)	(−2.6440)
REG_4	−0.1182	−3.3124	3.3458	−1.6605
	(−0.0989)	(−8.9735)	(1.2239)	(−3.9180)
REG_5	−1.2703	−3.3482	−1.3965	−1.8530
	(−0.8952)	(−7.6601)	(−0.4308)	(−3.6891)
REG_6	−0.5655	−2.6949	1.0118	−1.4283
	(−0.4162)	(−6.4467)	(0.3258)	(−2.9672)
REG_7	−1.7044	−3.8094	−1.6109	−2.4143
	(−1.3197)	(−9.6178)	(−0.5489)	(−5.3086)
REG_8	1.0611	−3.2194	2.7014	−1.5990
	(0.7671)	(−7.5468)	(0.8522)	(−3.2504)
CAP	5.9976	4.0212	3.0602	−0.5524
	(7.5076)	(17.105)	(1.9065)	(−2.2230)
TIME	−1.7881	−1.7016	−3.8478	−1.7560
	(−2.8668)	(−8.7511)	(−2.6881)	(−7.8269)
R^2	0.891	0.720	0.115	0.370

[a] The dependent variable is the appropriate pollution variable divided by 1000.

B. Endogenous Inspections

The most obvious question which arises in the context of this study concerns the possible endogeneity of inspections and the consequent impact on the least-squares estimates. If inspections are endogenous and correlated with the same variables which determine current pollution levels, then the least-squares estimates will be biased in general. To put this another way, it may not be contemporaneous inspections which have an effect on effluent levels so much as the probability of an inspection. To control for this (and to identify the resulting parameters), it is necessary to model the inspections using some variables which do not enter the basic model. Interviews with employees of the Quebec Ministry of Environment indicate that inspections are motivated by two considerations. First, plant size seems to be a factor: smaller plants are less likely to be inspected than larger plants. Moreover, plants which make changes to their productive capacities are more likely to be inspected. Second, there seems to be an effort to visit as many plants as possible. In other words, the plants to be inspected in any given period do not appear to be chosen randomly. An obvious implication of this ‘‘sampling without replacement’’ strategy is that a plant knows that, all things being equal, the probability of an inspection is inversely related to the number of previous visits.

It therefore appears appropriate to estimate an ‘‘inspections equation’’ where inspections are a function of variables in the basic pollution equation as well as a variable indicating the number of inspections which have been conducted at the plant prior to the current period:

$$\mathrm{CUM}_{it} = \sum_{\tau<t} \mathrm{INS}_{i\tau}. \tag{2}$$

Since inspections are a qualitative variable, a simple way to model inspections is

$$\mathrm{INS}_{it} = 1[\delta' X_{it} > \eta_{it}] \qquad i = 1, 2, \ldots, 46;\ t = 1, 2, \ldots, 60, \tag{3}$$

where $1[\cdot]$ is the usual indicator function, X_{it} contains the variables determining inspections, and η_{it} is a variable which could capture, for example, some unobserved tolerance level above which an inspection is conducted. For simplicity, we assumed that η_{it} are identically and independently distributed normal random variables so that Eq. (3) is simply a probit model. Table IV provides the results of this probit regression of inspections on a constant, the number of past inspections, capacity and a time trend.[27] As far as inspections are concerned, it is interesting to note that they are not clumped together at the beginning of the period, but rather

[27] We also ran regressions using the region and product indicators, change in productive capacity instead of level of productive capacity, and yearly dummies rather than the quadratic tend. These did not improve the overall fit of the model.

TABLE IV

Inspections Equation
(Sample Size = 2716)

Independent variables	Coefficient	t Stats
CONSTANT	−2.5442	−10.586
CUM_{it}	−0.1956	−1.912
CAP_{it}	0.5955	3.525
TIME	−0.7887	−0.844
TIME^2	1.2067	1.400
Log-likelihood test statistics: 17.345		

seem first to decline and then jump at the end of the period.[28] As a result of this, we made the inspections equation quadratic in the time trend variables. The results confirm what one could expect: the probability of an inspection is a decreasing function of past inspections of an increasing function of capacity.[29] Also, all things being equal, the probability of being inspected appears to be increasing over time. This can be interpreted as a proxy for additional resources being committed over time to monitoring activities.

Given this, it is sensible to consider testing for the exogeneity of current inspections. In fact, for three of the four Wald tests (see Table V), exogeneity of current inspections is strongly rejected so that the least-squares estimates of the parameters in Eq. (1) are most certainly biased. This being the case, it is instructive to consider the effects of re-estimating the model using the fitted values from the inspections Eq. (3) and the other right-hand side variables of Eq. (1) (apart from current inspections) as instruments.

The results appear in Table VI. With the exception of BOD emissions relative to the norm, the coefficient estimates on current and lagged inspections from the IV estimation are all negative and strongly significant. Apart from being substantially more significant, note that the magnitude of the coefficient on current inspections is much larger when estimated with instrumental variables. This is attributable to the fact that with IV estimation, the current inspection variable (varying between 0 and 1) is replaced by the conditional inspection probability (varying in a narrow range around 0.02), effectively multiplying the coefficient by 50 or more. The strongly negative coefficient estimates on lagged inspections indicate a persistent, if not permanent, effect from inspections. The results indicate that past inspections reduce absolute BOD discharges by approximately 28% (compared to 20% obtained by MV). Since an alternative interpretation of the IV estimates is that inspections in our basic model (Eq. (1)) are replaced by expected inspections, it appears that the threat of an inspection may have most effect on pollution emissions.[30] This is not to say that actual inspections have no impact on a plant's

[28] The number of inspections for each year in the data set is the following: 15 (1985); 9 (1986); 6 (1987); 8 (1988); 3 (1989); 13 (1990).

[29] Estimates were also obtained using other variables such as previous pollution levels. Results were not improved.

[30] An alternative way to introduce expected inspections would be to rewrite Eq. (1) directly as a function of expected inspections rather than inspections per se. There are several ways to estimate such a generated regressors model and in fact the two-stage procedure we have used provides consistent estimates.

TABLE V

Wald Specification Test
for Exogeneity of Current Inspections
(Sample Size = 2716)

Variables	Value of Wald's statistic
BOD	49.321
TSS	22.398
BOD-NORM	0.6235
TSS-NORM	27.620

TABLE VI

Emissions Equations Instrumental Variable Estimation[a]

(Sample Size = 2716)

Independent variables	Absolute discharges BOD	Absolute discharges TSS	Discharges relative to norm BOD	Discharges relative to norm TSS
CONSTANT	6.5776	4.9203	1.6032	3.7160
	(1.6989)	(5.4476)	(0.4309)	(3.2848)
$P_{i,t-12}$	0.8198	0.4116	0.1524	0.3946
	(32.854)	(17.579)	(7.7901)	(13.816)
INS_t	−193.40	−40.402	−51.927	−52.318
	(−2.8843)	(−2.5961)	(−0.8032)	(−2.6467)
INS_{t-i}	−5.3703	−1.5054	−2.0836	−1.5240
	(−2.7960)	(−3.3786)	(−1.1268)	(−2.7116)
$PROD_1$	3.2633	2.4485	−1.4241	1.8301
	(1.3620)	(4.3735)	(−0.6188)	(2.6148)
$PROD_2$	2.6024	1.6674	2.2683	1.0202
	(1.1488)	(3.1582)	(1.0446)	(1.5480)
$PROD_3$	6.3182	3.3143	18.725	1.7864
	(1.8573)	(4.4550)	(6.1936)	(1.9610)
$PROD_4$	−0.0397	0.3026	0.4529	−0.1917
	(−0.0118)	(0.3908)	(0.1401)	(−0.1973)
$PROD_5$	−1.2867	−0.1679	0.6605	−0.1719
	(−0.6885)	(−0.3904)	(0.3681)	(−0.3186)
REG_1	−10.294	−6.7833	−9.9133	−4.7418
	(−2.5331)	(−7.0605)	(−2.5791)	(−3.9634)
REG_2	−6.5861	−4.1565	−7.0414	−2.3073
	(−1.9986)	(−5.4348)	(−2.2365)	(−2.4234)
REG_3	−5.4460	−3.6407	−3.0557	−2.5434
	(−1.5380)	(−4.4394)	(−0.8993)	(−2.4809)
REG_4	−5.3100	−4.4456	1.9752	−3.1003
	(−1.5268)	(−5.4882)	(0.5907)	(−3.0648)
REG_5	−6.0546	−4.4013	−2.6602	−3.1937
	(−1.5554)	(−4.8760)	(−0.7126)	(−2.8294)
REG_6	−7.0729	−4.0936	−0.7028	−3.2133
	(−1.7369)	(−4.3426)	(−0.1796)	(−2.7205)
REG_7	−8.4692	−5.2892	−3.3973	−4.3181
	(−2.1223)	(−5.6912)	(−0.8879)	(−3.7032)
REG_8	−3.2430	−4.1279	1.5830	−2.7202
	(−0.8669)	(−4.7956)	(0.4416)	(−2.5326)
CAP	6.9972	4.3558	3.3644	−0.2397
	(3.4841)	(9.6463)	(1.9739)	(−0.4686)
TIME	−0.2092	−1.3085	−3.3238	−1.2794
	(−0.1234)	(−3.3634)	(−2.0401)	(−2.6369)
R^2	0.555	0.379	0.077	0.068

[a] The dependent variable is the appropriate pollution variable divided by 1000.

pollution control behavior. But it does indicate that this behavior is also a function of the probability of being inspected. If the inspection strategy is determined by sampling without replacement, then one may suggest that lagged inspections might have the opposite sign since once the regulator has come by once, the plant may (correctly) guess that it will not come back for a large number of periods.[31] While

[31] This point was raised by one of the reviewers.

this is possible, it may also be the case that inspections prompt changes in the plant's behavior that are of a permanent nature. One can think of numerous reasons including changes in equipment, employee functions, and simple changes in the employer and employees awareness of the regulations (monitoring may therefore have an educational and restorative function). The sign of these coefficients is therefore an empirical matter. We find them to be significantly negative.[32] The other coefficient estimates are very similar to those when least squares were used.

C. Missing Data

As mentioned above, the exclusion of missing observations can result in a selection bias if the filing of a report is in fact not a random event, leading to inconsistent parameter estimates. As a first step in allowing for sample selection issues, we estimate a "reporting" equation to predict the probability that a plant reports its emission levels. Since we do have some information on the plants even if they do not report, we are able to compute a simple binary choice model of reporting as a function of cumulated inspections, capacity, and a time trend (which is again specified as quadratic). In other words we calculate the coefficients from a model written as

$$\mathrm{REP}_{it} = 1[\delta' X_{it} > \mu_{it}] \qquad i = 1, 2, \ldots, 59;\ t = 1, 2, \ldots, 60. \tag{4}$$

Note that for these estimates the entire data on all 59 plants were used. This was estimated using a probit model, that is, assuming that the μ_{it} are normally distributed. The results for this regression are summarized in Table VII. Note that cumulated inspections have a strong positive effect on reporting. This result is important in itself as it indicates an important secondary function of inspections in

[32] Note moreover that this effect is controlled for when Eq. (1) is estimated by instrumental variables in which case current inspections is effectively replaced by the probability of an inspections given, among other things, cumulated past inspections.

TABLE VII
Nonrandom Reporting Equation
(Sample Size = 3496)

Independent variables	Coefficient	t stats
CONSTANT	0.4720	4.959
CUM_{it}	0.3859	6.443
CAP_{it}	1.5473	13.159
TIME	0.6967	1.689
TIME^2	−0.8375	−2.127
Log-likelihood test statistic for zero slope coefficients: 301.76		

the reporting/monitoring process. It also seems clear that larger plants, having more resources at their disposal, are more likely to file their reports. There does not seem to be any significant trend in report filing that is not captured by the CUM_{it} variable.[33] Overall it seems clear that the act of reporting is not random, although it is not necessarily clear that this is due to any strategic planning on the part of the plants.[34]

Having estimated the parameters in this equation we went back to the subsample of 46 plants and augmented the basic model with a correction term as suggested by Heckman [9]. The equation of interest becomes

$$P_{it} = \alpha + \phi P_{i,t-12} + \sum_{j=0}^{12} \theta_j \,\mathrm{INS}_{t-j} + \beta_2 \,\mathrm{REG}_i + \beta_3 \,\mathrm{PROD}_i + \beta_4 \,\mathrm{CAP}_{it} + \gamma t$$
$$+ \sigma \lambda_{it} + \varepsilon_{it} \qquad i = 1, 2, \ldots, 46; \; t = 1, 2, \ldots, 60, \tag{5}$$

where $\lambda_{it} = \phi\,(\hat{\delta}' X_{it}) / \Phi(\hat{\delta}' X_{it})$, ϕ and Φ are the standard normal density and cumulative distribution, and $\hat{\delta}$ denotes the probit estimate of δ. In this context σ serves as an estimate of selection bias. Under the null hypothesis that the data are missing in a random manner, σ should equal zero. This equation was also estimated using instrumental variables.[35]

With respect to the effects of inspections, in all four cases the instrumental variable estimates of the coefficients on inspections are all significantly negative, except for BOD discharges relative to the norm as shown in Table VIII.[36] Moreover, with the inclusion of a sample selection correction, it is interesting to note that the sign on the time trend is negative and statistically significant in three cases of four. This may be evidence that, apart from inspection inducements, there is no effort on the part of plants to reduce their emission levels.

IV. CONCLUSION

Securing compliance with environmental standards is a difficult task. Current monitoring practices and enforcement initiatives (or the lack thereof) have been increasingly criticized. Regulators are therefore experimenting new approaches.

> Because of limited resources and the resulting need to establish priorities, each EPA program at agency headquarters in Washington, D.C., has developed compliance monitoring plans and enforcement response policies. These strategies generally direct the most intensive efforts to those segments of the regulated community most likely to be in non-compliance. (Silverman, 1990)

[33] In fact, when REP_{it} was regressed only on CUM_{it} the corresponding coefficient was strongly significant.

[34] In this context, it is interesting to note the following frequencies. The observed unconditional probability of firms filing their reports in the entire sample is 0.88; the probability conditional on having been inspected in some prior period is 0.96. Among the subset of those 13 firms whose reporting is problematic, the corresponding figures are 0.58 and 0.88. Clearly, inspections lead to increased reporting.

[35] Consistent estimates of the standard errors in this case were obtained using the method developed by White [21]. Once again, we constructed Wald tests for endogeneity of current inspections. Here, in all four cases, the test statistics were large enough to reject the exogeneity of inspections.

[36] Overall the inclusion of a sample selection correction led to much precise estimates as evidence by the t statistics.

TABLE VIII
Emissions Equations
Instrumental Variable Estimation[a]
(Sample Size = 2716)

Independent variables	Absolute discharges		Discharges relative to norm	
	BOD	TSS	BOD	TSS
CONSTANT	5.4537	4.4666	1.7141	3.3552
	(0.8149)	(2.9382)	(0.5576)	(1.8645)
$P_{i,t-12}$	0.8191	0.4095	0.1524	0.3922
	(23.058)	(8.8315)	(1.2871)	(7.4901)
INS_t	−210.21	−47.558	−50.218	−58.061
	(−1.8784)	(−1.9156)	(−0.8589)	(−1.9095)
INS_{t-i}	−5.5509	−1.5839	−2.0651	−1.5872
	(−2.4181)	(−2.9996)	(−1.5643)	(−2.5080)
$PROD_1$	3.6189	2.6050	−1.4602	1.9546
	(1.4040)	(4.2949)	(−0.4645)	(2.6977)
$PROD_2$	3.0048	1.8396	2.2286	1.1570
	(1.2620)	(3.2905)	(1.2262)	(1.6884)
$PROD_3$	6.1961	3.2663	18.742	1.7517
	(1.9968)	(4.3360)	(4.5815)	(1.9357)
$PROD_4$	−0.1722	0.2466	0.4663	−0.2378
	(−0.4125)	(2.0029)	(1.5022)	(−1.6863)
$PROD_5$	−1.3209	−0.1836	0.6641	−0.1846
	(−1.0410)	(−0.6257)	(0.8492)	(−0.5232)
REG_1	−10.558	−6.9048	−9.8891	−4.8390
	(−1.6845)	(−4.8202)	(−2.9635)	(−2.9306)
REG_2	−6.6477	−4.1878	−7.0363	−2.3298
	(−1.1857)	(−3.2960)	(−2.6874)	(−1.5842)
REG_3	−5.9189	−3.8413	−3.0088	−2.7011
	(−0.9838)	(−2.8705)	(−1.0849)	(−1.7143)
REG_4	−5.7143	−4.6209	2.0158	−3.2379
	(−0.9576)	(−3.4598)	(0.6825)	(−2.0671)
REG_5	−6.1659	−4.4537	−2.6493	−3.2339
	(−1.0384)	(−3.3582)	(−0.8748)	(−2.0807)
REG_6	−7.7194	−4.3666	−0.6382	−3.4294
	(−1.1948)	(−3.0655)	(−0.2054)	(−2.0291)
REG_7	−8.8416	−5.4508	−3.3605	−4.4467
	(−1.4084)	(−3.8940)	(−1.0930)	(−2.7076)
REG_8	−3.2857	−4.1539	1.5888	−2.7367
	(−0.5512)	(−3.1591)	(0.5303)	(−1.7704)
CAP	8.1369	4.8395	3.2522	0.1314
	(2.6350)	(6.0190)	(2.4415)	(0.1652)
TIME	0.4036	−1.2298	−3.3438	−1.2188
	(0.2233)	(−2.8422)	(−3.2572)	(−2.3644)
RANDOM	4.3839	1.8109	−0.4348	1.4387
	(0.8985)	(1.4787)	(−0.0664)	(0.9963)
R^2	0.519	0.321	0.079	0.058

[a] The dependent variable is the appropriate pollution variable divided by 1000.

Similarly, in Canada,

> Upon evaluating the results of the National Inspection Plan at the conclusion of the 1990−91 year, Environment Canada found that all regulations did not require the same level of compliance verification, and decided on a target-oriented approach. (Canada, 1992)

However, for such an approach to be effective, one must have a clear understanding of plants' pollution control behavior. Regulators must be able to observe characteristics of plants and industries and from these characteristics, predict whose "most likely to be in non-compliance." In particular, one needs to know how current monitoring practices affect pollution behavior and in the light of this knowledge, re-allocate, if necessary, monitoring resources more efficiently.

We have shown evidence in this paper that both inspections and the threat of inspections have an impact on emissions. With the inclusion of a selection variable in the emissions equation, the coefficients on the inspections variables (current and past) were generally slightly larger, although not substantially different. We have also shown evidence that the benefits of inspections are not simply limited to reducing pollution emissions; they also provide the regulator with more information by inducing more frequent reporting. These results have direct implication on the allocation of scarce monitoring resources. In particular, credibly increasing the probability of inspections can induce a significant change in plants' pollution behavior.

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