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ORIGINAL ARTICLE

The geographic distribution of environmental inspections

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Abstract Models of the enforcement of environmental regulations regarding point source pollution suppose that the probability of inspection or audit is independent across facilities. However, there are a number of reasons why regulators may choose to inspect many sites in a particular geographic area at one time. If the probability a site is inspected also depends on its compliance behavior, the expected payoff from choosing to violate will depend upon the compliance decisions of neighboring sites, creating a game of strategic interdependence between firms. In this paper, we use a dataset of inspections at petroleum storage sites in Manitoba between 1981 and 1998 to consider to what extent inspections are spatially correlated and whether inspection probabilities are a function of the inspection and violation history of the site and its neighbors. Further, we examine to what extent firms take into account whether their neighbors have been previously found in violation in determining compliance.

Keywords Enforcement · Inspections · Warnings · Petroleum storage regulations · Transportation costs

JEL Classification K4 · Q2

1 Introduction

Economic models of the enforcement of regulations governing point source pollutants assume that a firm's decisions whether and by how much to violate a regulation or law

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is independent of the actions of other polluters.[1] This assumption may be reasonable if the inspection of a firm in a particular time period is uncorrelated with whether other firms are inspected. However, if such a correlation exists, and if a firm's actions influence the probability that it will be inspected, then such actions may also increase or decrease the probability of inspection of another firm. In such circumstances, firms may not act independently, but rather play a game of strategic interdependence. In this paper, we provide an initial examination of whether regulatory inspections are spatially correlated and whether such correlation creates a game of strategic interdependence between regulated parties within the context of petroleum storage regulation in the Canadian province of Manitoba.

The fact that one firm's actions may influence the probability of inspection of other firms is understood when regulators use ambient inspections to determine inspections for non-point source pollution. Franckx (2002, 2004) considers a model of two firms in which the regulator can first inspect ambient emissions (the sum of the emissions of the firms) and then decides whether to inspect the firms directly. The choice of emissions level by one firm affects ambient emissions levels and therefore the probability of an inspection for the other firm.[2]

To our knowledge, there is no existing work that considers that a similar situation may be created for point source pollution. An enforcement agency may choose to inspect a number of sites in a geographic area at one time for a number of reasons. If inspectors face significant transportation costs when conducting inspections, such costs can be reduced by clustering inspections geographically. Alternatively, if the expected damages from violations differ systematically across geographic areas then all firms in high risk areas will face higher inspection probabilities than similar sites in low risk areas. Finally, if owners' resources differ systematically across areas then all firms in low resource areas, which are more likely to violate, will face higher inspection probabilities.

Geographic correlation of inspection probabilities has a number of implications including the possibility of a game of strategic interdependence when a firm's inspection probability depends on its behavior. For example, a firm's inspection probability may depend on past violations or the observance of a signal of noncompliance such as emissions into a waterway. If inspection probabilities are spatially correlated, previous violations or noncompliance signals that increase a firm's inspection probability will also increase the probability that nearby sites are inspected. Because compliance decisions depend on the expected probability of inspection, the actions of one site may influence the compliance decisions of neighboring sites.

Beyond changing the way we should view the compliance decisions of firms, correlations in inspection decisions may have policy implications. For example, consider a regulator that currently inspects a large geographic area from a head office located in a

[1] For example, see Harrington (1988), Heyes and Rickman (1999), Livernois and McKenna (1999), and Raymond (2004). See Heyes (1998) for a survey of early theoretical models

[2] A similar situation arises with the enforcement of criminal law. It is well documented that cities often contain criminal "hotspots" and the mapping of such areas has become an important component of research into policing and criminology. Such mapping is used in part for resource planning (see Craglia et al. (2000) for a discussion) in order to target police effort in high crime areas. Therefore, if those around an individual are committing more crimes, the probability of being detected for a crime increases.

single city. Reasonably, this agency may be expected to spatially correlate inspections in order to reduce transportation costs. If so, the decision to inspect one firm increases the likelihood of inspecting nearby firms. Now, suppose that the agency sets up satellite offices in several towns, which effectively decreases the marginal cost of conducting an additional inspection. This policy will also decrease the correlation between the inspection of a firm and its neighbors and weaken any effect that a signal by a firm or a warning to a firm has on the compliance decision of its neighbors.

This paper uses data on petroleum storage sites in the Canadian province of Manitoba over the period 1981–1998, to provide an initial examination of whether inspections by the government regulator are spatially correlated, and whether violations by a site's neighbors increase the subsequent likelihood that a site will be inspected and the probability that the site will comply with regulations. Our analysis is related to a number of empirical papers examining the relationship between firm level enforcement and compliance. For example, Laplante and Rilstone (1996) find that past inspections reduce emissions and promote self-reporting in the Quebec pulp and paper industry while Gray and Deily (1996) find that lagged enforcement actions increase compliance and that the number of enforcement actions is falling in the probability of compliance in the U.S. steel industry.[3]

Eckert (2004) uses data on petroleum storage sites in Manitoba for the same period to study the use of warnings to enforce certain inventory regulations. In particular, she examines the extent to which warnings signal an increased probability of inspection, and to what extent this is taken into account in the compliance decisions of firms. She finds that the probability of an inspection at a specific site is higher if that site was warned in the past and that the site's probability of a violation is decreasing in its probability of an inspection. That is, warnings can improve compliance.[4] Notably, however, the study did not consider whether a violation by a firm could increase the probability that neighbor firms will be inspected, and therefore influence the compliance decisions of neighbor firms.[5]

This paper makes a contribution to the literature examining the enforcement of environmental regulations by providing an empirical examination of the spatial relationship between inspections and compliance at nearby sites. To anticipate findings, when sites are considered neighbors if they are located in the same town, we find evidence that inspections are spatially correlated, with a site being more likely to be inspected if neighbor sites are inspected in the same quarter. Further, we find that, for the portion of

3 Nadeau (1997) finds that monitoring and enforcement actions reduce the duration of noncompliant spells for US manufacturing facilities while Helland (1998) finds evidence that US pulp and paper plants use self reporting to avoid future enforcement. Earnhart (2004) finds that the threat of federal inspections and enforcement, as well as actual federal and state enforcement actions, reduces wastewater discharge from municipal wastewater treatment plants in Kansas. See Cohen (2005) for a review of empirical enforcement studies.

4 Kang and Myunghun (2004) use simulations to show that state-dependent enforcement is more effective than static enforcement in reducing violation days by manufacturing firms in Korea.

5 In another study of petroleum storage tanks, Alberini (2001) uses data for Florida to determine whether regulation of underground storage tanks resulted in widespread closure and substitution towards above ground tanks, and whether tank installation and substitution are associated with local characteristics. To our knowledge, no empirical study of petroleum storage (or any other environmental regulations) has considered spatial patterns in enforcement and compliance.

the sample period during which transportation costs can be considered most significant, a site is more likely to be inspected if neighbor sites were recently found in violation than if neighbors were found in compliance. Finally, over the same time period, a site is less likely to violate when more neighbors have recently been found in violation. Our analysis motivates both theoretical and empirical analyses of enforcement of environmental regulations when inspection probabilities are dependent across sites.

The remainder of the paper proceeds as follows. Section 2 briefly outlines petroleum storage regulation in Manitoba while Sect. 3 presents a model of enforcement and compliance in the context of petroleum storage regulation. Section 4 describes the data and in Sect. 5 we examine whether Manitoba Environment was more likely to inspect a site if nearby sites are inspected and if this changed following the regionalization of enforcement in 1991. In Sect. 6, we examine whether the compliance decisions of sites influence the compliance decisions of neighboring sites. Section 7 concludes.

2 Petroleum storage regulation in Manitoba[6]

The primary threat from petroleum storage leaks in Manitoba is ground water contamination, with the province experiencing a "long history of groundwater contamination from leakage of petroleum products from underground storage tanks" (Betcher et al. 1995). In Manitoba, the *Storage and Handling of Gasoline and Associated Products Regulation* (1976) and its subsequent amendments govern all aspects of the construction, maintenance, and monitoring of almost all storage tanks.[7] In order to prevent spills and promote their early detection, the regulation specifies a number of construction, maintenance and monitoring requirements. For example, underground tanks must have leak protection either by impressed current cathodic protection or fiberglass construction and operators are required to regularly reconcile withdrawals and additions with inventories.

Petroleum storage regulation was enabled under the *Clean Environment Act* (1972) until 1987 and under the *Environment Act* in subsequent years. According to both Acts, the enforcement of regulations was to be accomplished in part through inspections. In the event that an environment officer detects a violation, the officer can issue a warning, initiate a fine, or issue a legal order to undertake corrective action. In fact, the response to most violations has been a warning, intended to indicate a more serious response to future violations. Finally, under the *Environment Act*, maximum penalties are higher for repeat offenders.

A significant change in the way petroleum storage regulation was enforced occurred in 1991. Prior to 1991, a single enforcement officer located in Winnipeg conducted all inspections and only inspected petroleum storage sites. Beginning in 1991, inspections were conducted by a number of enforcement officers in 11 offices located throughout the province and inspecting a variety of facilities regulated under the *Environment Act*. This restructuring reduced the transportation costs involved in inspecting petroleum storage sites, but had an unclear effect on the costs of maintaining enforcement

[6] Further discussion of the regulations is provided in Eckert (2004).

[7] The regulation excluded aboveground tanks holding less than 4545 l connected to a heating appliance and overhead tanks holding less than 4545 l.

offices and staff because the larger number of offices and inspectors were tasked with inspecting all facilities governed by the *Environment Act*, rather than just petroleum storage sites.

3 Theoretical framework

In general, enforcement agencies choose several decision variables, including broad decisions such as the number and location of enforcement offices and officers, as well as decisions of whether to inspect particular sites in a particular period. A number of different objectives can be attributed to the enforcement agency. For example, Gray and Deily (1996) suppose the regulator maximizes political support, Harrington (1988) supposes the regulator acts to minimize the cost of achieving a particular compliance target, and Harford and Harrington (1991) suppose the regulator maximizes social welfare. In the context of petroleum storage, the enforcement agency can be viewed as minimizing the sum of expected damages from leaks and enforcement costs.[8]

Consider a simple two stage model of inspections and compliance.[9] In the first stage, the inspection agency minimizes the sum of expected damages from leaks and enforcement costs by choosing an inspection probability p_i for each site i, conditional on the number and location of enforcement offices. We denote the probability of a leak as ℓ_i and the damages from a leak as D_i. In the second stage, each site operator chooses whether or not to comply in order to maximize profits.

In the second stage, an operator will comply if the expected costs of doing so are less than the costs of noncompliance. The costs of noncompliance are equal to the product of the probability of an inspection and the sanction. Therefore, the probability that a given site is in compliance will depend on its probability of inspection.

Consider the inspection agency's first period decision. We suppose that the probability of a leak (ℓ_i) depends on whether the operator complies with the regulation, storage tank characteristics (T_i), and facility characteristics (F_i). For example, the probability of a leak is expected to be higher at sites with more tanks, as well as sites with underground tanks or unprotected tanks. Because the compliance choice depends on the probability of an inspection, the probability of a leak can be represented by $\ell_i(p_i, T_i, F_i)$. In the event of a leak, the damages are determined by p_i (through compliance), T_i, F_i, and location characteristics (L_i), including soil characteristics.

Ignoring the fixed costs already incurred, the enforcement costs are the variable inspection costs (ϑ_i) which may depend on tank characteristics as well as the distance from the closest enforcement office. To the extent that variable costs reflect transportation costs, a regulator can reduce their costs by inspecting neighboring sites at the same time, and p_i will depend on whether sites near site i are inspected. Therefore, in the first stage, the inspection agency solves

8 Heyes (2002) and Franckx (2002) consider analogous objective functions on the part of the regulator.

9 If instead the regulator and site operator make their choices simultaneously, the resulting equilibria may include equilibria in mixed strategies, such as in Franckx (2002, 2004).

$$\min_{p_1,\cdots,p_N} \left\{ \Sigma_{i=1}^{N} \ell_i \left(p_i, T_i, F_i\right) D_i \left(p_i, T_i, F_i, L_i\right) + p_i \vartheta_i \right\},$$

where N denotes the total number of sites.

Finally, there is strong evidence that the enforcement decisions made by Manitoba Conservation are best represented by a state dependent enforcement model. Eckert (2004) finds that, as predicted by a state dependent model, Manitoba Conservation conditions its inspection decisions on a site's compliance record and that a past warning reduces the probability of a violation. As well, discussions with Manitoba Conservation suggest that warnings are used in part to indicate stronger future enforcement, consistent with state dependent enforcement.

State dependence in environmental enforcement was first formalized in Harrington (1988),[10] which supposes that the regulator classifies sites into two groups, with the "good" group facing a lower inspection probability and a lower fine. If a site in the "good" group is found in violation, it is moved to the "bad" group, while a site in the "bad" group found in compliance moves to the "good" group with some probability. In this context, a warning is simply a way of indicating a move from the "good" group to the "bad" group. In the first stage of the game, the regulator chooses and commits to inspection probabilities and fines for the two groups. In each subsequent period, site operators decide whether to comply. In equilibrium, low compliance cost operators will comply in both groups, high cost operators will violate in both groups, and intermediate cost operators will comply only in the "bad" group.[11]

State dependent enforcement implies that the probability of inspection for site i may also depend on its compliance history, which determines whether it is in the "good" group and faces a low inspection probability or the "bad" group in which it faces a high inspection probability. Furthermore, if the regulator reduces transportation costs by inspecting nearby sites during the same trip, the probability of inspection at site i may also depend on the compliance history of nearby sites.[12]

4 Data description

Our dataset, obtained from Manitoba Conservation, includes all 4443 petroleum storage sites registered between 1976 and 1998. Our analysis focuses on the period between 1981 and 1998 because little enforcement was done before 1981. The dataset includes the location of the site, site-specific characteristics such as ownership and type of storage, and a record of each inspection at the site. The inspection record includes the date and nature of the inspection and the results of the inspection. Figure 1 depicts the location of sites across the province. Sites are predominantly located in the southern half of the province with more than 25% of sites located in the city of Winnipeg.

[10] Further discussion of the Harrington model in the context of petroleum storage regulation is given in Eckert (2004).

[11] Harford and Harrington (1991), Harford (1991) and Raymond (1999) extend Harrington model for the cases of a social welfare maximizing regulator, measurement error, and asymmetric information.

[12] In fact, the regulator's problem can be written to reflect that both the probability of a leak and the subsequent damages depend on the compliance history of the site operator as well as operators of neighboring sites. However, formally writing this model is notationally cumbersome.

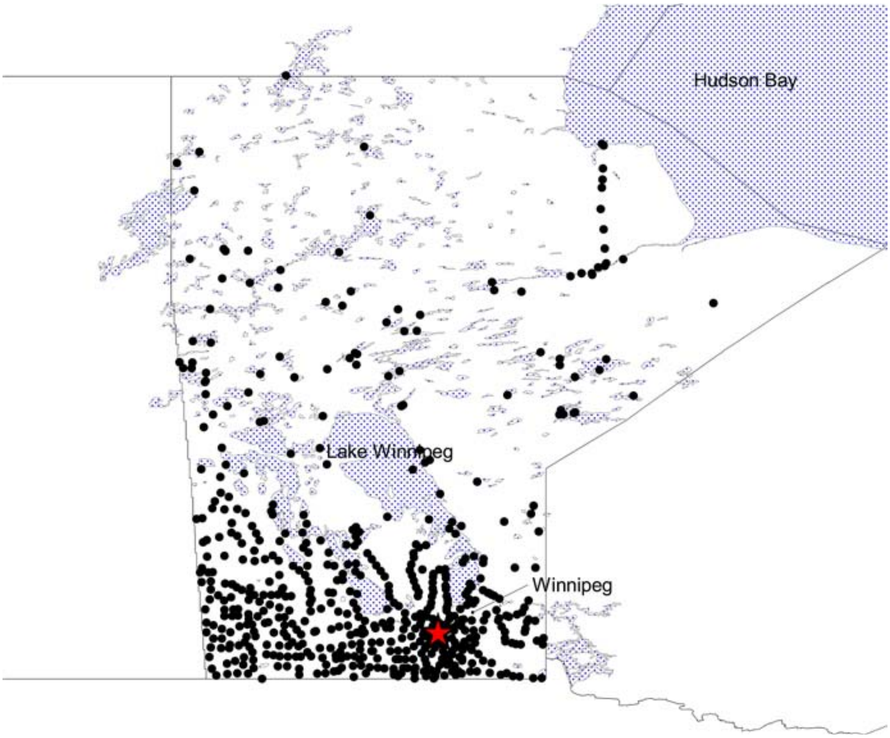

Fig. 1 Locations of all petroleum storage sites in Manitoba operating during sample period

Our sample consists of 222,592 quarterly observations on sites that stored petroleum for at least one quarter between 1981 and 1998.[13] Over this period, there were 7,169 observations of at least one inspection at a site in a given quarter. Manitoba Conservation lists several motivations for an inspection. Verifying whether a site was adequately monitoring and recording the inventories of its tanks is listed as a purpose of 45% of inspections over the sample period. Other purposes of inspection include checking cathodic protection of the tanks, checking proper dike construction, responding to a leak or contamination complaint, checking changes or upgrades made to the site, and performing tests.

Over our sample period, there were 3,036 observations of at least one violation at a site in a given quarter. Of these 3,036 observations, 93% involved warnings, while the remaining violations led to orders, tickets, summons and prosecutions, or remediation. Table 1 provides the breakdown of the enforcement response across violations for inspections that were primarily related to inventory measurement and reconciliation, those checking cathodic protection, and those related to a leak, spill, or

[13] Certain sites were removed from the sample because data were incomplete. These statistics include sites in all locations in the province.

Table 1 Breakdown of enforcement responses by primary purpose of inspection

Primary purpose of inspection	Warnings	Non-warnings	Fraction of violations leading to a warning
Inventory	2781	88	0.97
Cathodic protection	599	105	0.85
Leak, spill, or contamination	137	35	0.80

contamination.[14] Given the large number of warnings, we classify enforcement responses as either a warning or a non-warning. Not surprisingly, violations involving monitoring and paperwork violations are most likely to be warned while those related to the occurrence of an environmental incident are the least likely to lead to a warning.

5 Spatial patterns in inspections

In this section, we use data on the enforcement of petroleum storage regulations in Manitoba to ask whether: (i) a site was more likely to be inspected if nearby sites were inspected in the same quarter, (ii) a site was more likely to be inspected if it had recently been found in violation, and (iii) a site was more likely to be inspected if nearby sites had recently been found in violation. We first present the results from informal analysis on the two periods, 1981–1990 and 1991–1998, in order to investigate whether the spatial patterns in inspections changed following regionalization. We then present econometric evidence using the whole sample, controlling for regionalization.

We consider two sites to be close if their locations, as given by Manitoba Conservation, list the same town. A finer measure of proximity between sites is prohibited because our data set does not accurately specify the locations of many sites outside of Winnipeg beyond specifying their hometown. A proximity measure based on whether sites feed the same aquifer would better capture the possibility that spatial correlation reflects geographic differences in damages. However, the available aquifer maps of Manitoba represent only major bedrock and sand/gravel aquifers for the southern portion of the province. As such, the polygons are very large and treat sites located a considerable distance apart as “neighbors”. Moreover, basing our proximity measure on these maps would remove a number of storage sites and much of the geographic variation in the dataset.

[14] If more than one purpose was reported, the primary purpose was assumed to be related to the most serious potential infraction. Note that the number of violations is larger than the observations of at least one violation because some inspections or quarters involve multiple violations by a single site. Finally, these three categories are not an exhaustive list as there is a very large number of inspection purposes, many of which have few or zero violations over the sample period.

Table 2 Distribution of number of sites in the same town, first quarter 1990

	Mean	Percentiles		
		25%	50%	75%
Same town	16.0	4	8	17

Table 2 provides the distribution of the number of neighbor sites for each site for all sites not located in Winnipeg.[15]

To analyze the relationship between whether a site is inspected and whether close sites are inspected, several variables are defined. The variable $inspect_{it}$ equals one if site i was inspected in quarter t. For each site, the variable $town\_insp_{it}$ measures the fraction of other sites of the same town as site *i* that were inspected in quarter t. Towns that have only one site are excluded from the analysis. We consider two samples: sample A consists of all towns other than Winnipeg, sample B consists of all towns with fewer than 30 sites. We consider sample B because it seems likely that an inspection at one site does not greatly influence another site in locations with a large number of sites. The distribution of sites across locations indicates 6 towns that contain substantially more sites than the rest of the sample, all of which contain more than 30 sites.[16]

5.1 The years 1981–1990

First, tests based on joint count statistics were conducted, testing the null hypothesis that the locations of inspections in each quarter were random, against the alternative that inspections at a site are associated with inspections at nearby sites.[17] The test was conducted for the entire sample, and separately for each quarter. The null hypothesis is rejected in favor of the alternative at the 5% level of significance for the entire sample and for all but three quarters.

These test statistics indicate a statistically significant relationship between whether a site is inspected and whether neighboring sites are inspected, but do not reflect the magnitude of this association. To understand this magnitude, we compute the correlation coefficients between *inspect* and *town_insp* for samples A and B to be 0.41 and 0.43, which are statistically significant at the 1% level. As further evidence, Table 3 presents the number of observations for which $inspect_{it} = 1$, according to whether no nearby sites were inspected or whether some nearby sites were inspected.

According to Table 3, the percentage of observations (a given site in a given quarter) in which the site is inspected, given that no other site in the town is inspected in the same quarter, is 0.6% for both samples. In contrast, given that at least one other site

[15] Winnipeg is excluded from our sample because the spatial relationship is expected to be different within the city than in the remainder of the province. In particular, Winnipeg is substantially larger and contains a greater number of sites than any other municipality, inspectors face relatively low transportation costs to all sites in the city, and the location of sites is defined by street address rather than town.

[16] The six towns or cities are Brandon, Dauphin, Portage le Prairie, The Pas, Thompson, and Winnipeg.

[17] See Griffith and Amrhein (1991) for a discussion of joint count tests in spatial analysis.

Table 3 Breakdown of whether each site was inspected in each quarter according to whether other sites in the same town were inspected in the same quarter, 1981–1990

Was the site inspected?	Sample A: towns other than Winnipeg Were any sites in the same town inspected?			Was the site inspected?	Sample B: towns with fewer than 30 sites Were any sites in the same town inspected?		
	No	Yes	Total		No	Yes	Total
No	77,962	9,795	87,757	No	71,631	5,232	76,863
Yes	474	844	1,318	Yes	435	719	1,154
Total	78,436	10,639	89,075	Total	72,066	5,951	78,017

in the town has been inspected in the same quarter, the percentage of observations in which the site is inspected is 7.7% for sample A and 12% sample B.[18]

Our second question regards whether, as predicted by models such as Harrington (1988), being found in violation increases the probability that a site will be inspected in the future. As a first approach to this question, we compute the fraction of sites that are inspected in a quarter, given that they were inspected and found innocent in the last year, and given that they were inspected and found in violation in the last year.[19]

In sample A, the percentage of sites that are inspected given that they were inspected and found innocent in the last year is 3.8% compared to 6.1% for sites that were found in violation in the last year. In sample B, the percentages are 3.6% and 6.0% respectively. Spearman correlation coefficients of the correlation between *inspect* and a variable measuring whether a site inspected in the last year was found in violation, computed only over sites that were inspected in the last year, were significant at the 1% level for both samples. This suggests that sites recently found in violation are more likely to be inspected than sites recently found to be in compliance.

Finally, we wish to consider whether a site is more likely to be inspected if neighbor sites have recently been inspected and found in violation. The statistics presented above indicate that in general, a site is more likely to be inspected if it has recently been found in violation, and that if one site is inspected, neighbor sites are likely to be inspected. However, it may be that while in general a site is more likely to be inspected if neighbor sites are inspected, this may not apply specifically to sites that are being inspected because of the past behavior of the site operator. That is, when the regulator is performing random inspections, a number of local sites are inspected, but if the regulator is inspecting a site because of past violations, only that site is inspected.

First, we compute the fraction of sites that are inspected, conditional on whether neighboring sites were inspected in the last year but all were found in compliance, and whether at least one was found in violation. For sample A, we find the percentage of sites that are inspected given that at least one other site in the town was inspected in the

[18] An examination of these patterns for sites owned by the same owners and by different owners indicates that the observed relationship between inspections and neighboring inspections is not simply reflecting the fact the regulator chooses to inspect all sites owned by a single owner in a single trip.

[19] In addition, statistics based on a one-quarter history were computed, with similar qualitative results.

Table 4 Breakdown of whether each site was inspected in each quarter according to whether other sites in the same town were inspected in the same quarter, 1991–1998

Was the site inspected?	Sample A: towns other than Winnipeg Were any sites in the same town inspected?			Was the site inspected?	Sample B: towns with fewer than 30 sites Were any sites in the same town inspected?		
	No	Yes	Total		No	Yes	Total
No	44,399	15,386	59,785	No	42,768	10,089	52,857
Yes	1,089	2,347	3,436	Yes	1,065	1,819	2,884
Total	45,488	17,733	63,221	Total	43,833	11,908	55,741

last year and all inspected neighbor sites were found to be in compliance to be 1.4% compared to 2.9% if at least one neighbor site was found in violation in the last year. For sample B, the percentages are 1.5% and 3.7% respectively. Spearman correlation coefficients between *inspect* and whether at least one neighbor site was found in violation in the last year, conditional on at least one neighbor site being inspected in the last year, are significant at the 1% significance levels. Therefore there is evidence that if a neighbor site was recently found to be in violation, a site is more likely to be inspected.

5.2 The years 1991–1998

In this subsection, we undertake the same analysis for the period in which there was a number of satellite offices located throughout the province, each with their own inspectors. As in the earlier time period, tests based on joint count statistics, testing the null hypothesis that the locations of inspections in each quarter were random, against the alternative that inspections at a site are associated with inspections at nearby sites were conducted. Again, the null hypothesis is rejected in favor of the alternative at the 1% level of significance for the entire sample and for all but three quarters.

Table 4 presents the number of observations for which $inspect_{it} = 1$, according to whether no nearby sites were inspected or whether some nearby sites were inspected. The relationship between whether a site is inspected and whether neighboring sites are inspected in the same quarter is present and of similar magnitude as in earlier years.

We again compute the fraction of sites that are inspected in a quarter, given that they were inspected and found innocent in the last year, and given that they were inspected and found in violation in the last year. In sample A, the percentage of sites that are inspected given that they were inspected and found innocent in the last year is 6.5% compared to 7.8% for sites that were found in violation in the last year. In sample B, the percentages are 5.9% and 7.5%, respectively. Spearman correlation coefficients between *inspect* and whether a site inspected in the last year was found in violation, computed only over sites that were inspected in the last year, were significant at the 1% level for both samples. This suggests that, following regionalization, sites recently found in violation are more likely to be inspected than sites recently found to be in compliance.

Finally, in sample A, we find the percentage of sites that are inspected given that at least one other site in town was inspected in the last year and all inspected neighbor sites were found to be in compliance to be 6.2% compared to 5.7% if at least one neighbor site was found in violation. For sample B, the percentages are 6.0% and 5.3%, respectively. The Spearman correlation coefficient between *inspect* and whether at least one neighbor site was found in violation in the last year, conditional on at least one neighbor site being inspected in the last year, is not significant at any reasonable level for sample A, and is significant at the 5% level and *negative* for Sample B. Therefore there is no evidence that, following regionalization, a site is more likely to be inspected if a neighbor site was recently found to be in violation.

5.3 Econometric analysis

To have more confidence in the existence and magnitude of a relationship between whether a site is inspected and whether a neighboring site was recently found to be in violation, we estimate the probability of an inspection based on the theoretical framework discussed in Sect. 3. We estimate the probability of an inspection at site i in period t as

$$P\left(I_{it}=1\right)=\Phi\left(X_{1it}^{T}\beta_{1}\right)$$

where $\Phi(\cdot)$ is the standard normal cumulative distribution function.[20] X_{1it} includes variables determining the probability of a leak, the damages from a leak, the variable costs of an inspection, and variables expected to influence the probability of a violation.[21]

The site characteristics included as regressors are dummy variables indicating the type of outlet, the type of ownership, the total number of tanks at the site, as well as the number of underground tanks at the site, the number of unprotected tanks at the site, and the total number of sites located in the town (*Localsites*).[22] We include the distance between the town and Winnipeg (*PreWinnipeg*) for observations before 1991 and the distance between the town and the closest regional office (*PostOffice*) for observations after 1991.

Four regressors control for geographic differences in the expected damages from a leak. *Depth* is a dummy variable indicating the depth to the water table.[23] Sensitivity is a measure of the local sensitivity to leaks from underground petroleum storage tanks. The measure was constructed by Manitoba Conservation based on hydrological and

[20] One concern is that because the probability of a site being inspected appears correlated with whether neighboring sites are inspected in the same quarter, there may be spatial correlation in the residuals from the latent variable equation underlying the probit model. While econometric techniques have been developed to estimate linear regression models with spatial correlation, techniques to estimate limited dependent variable models are currently in development. We are aware of no techniques that have been used to estimate spatial probit models over an unbalanced panel.

[21] A reduced form approach is taken because there is no reasonable identification restriction by which to identify a structural model. As well, we feel that a reduced form model is sufficient to examine the effect that neighboring sites have on a site's inspection probability.

[22] Appendix A provides a discussion of the ownership, outlet type, and region variables.

[23] See Eckert (2004) for details concerning the construction of *Depth*.

Table 5 Probit results for the probability of inspection, 1981–1998

Variables	Specification A ($N = 109302$) Coefficients (Standard errors)	Specification B: fixed effects ($N = 95037$) Coefficients (Standard errors)
Insp_lag	0.15† (0.08)	−0.12 (0.08)
Viol_lag	0.20** (0.09)	0.10 (0.09)
Townviol_lag	0.31* (0.09)	0.32** (0.05)
Towninsp_lag	0.10 (0.14)	0.13 (0.10)
Post X insp_lag	−0.22** (0.09)	−0.22** (0.09)
Post X viol_lag	−0.09 (0.10)	−0.06 (0.10)
Post X townviol_lag	−0.43* (0.10)	−0.44* (0.06)
Post X towninsp_lag	−0.07 (0.15)	0.02 (0.11)

* Indicates significance at 1%, ** at 5%, and † at 10%

geological data available in 1996 and takes on values of 0.1–11.0 with higher values corresponding to greater vulnerability.[24] Population density (*Density*) and real average income (*AvgIncome*) by census subdivision control for differences in the threat to health, property, and the ability of people to find alternate sources of drinking water.[25]

To control for the effect that a site's regulatory history has on its inspection probability, we include *Insp_lag*, which equals 1 if the site was inspected in the last year, and *Viol_lag*, which equals 1 if the site was found in violation at least once in the last year. To control for the recent regulatory history of neighboring sites, we include *Towninsp_lag*, which equals the fraction of other sites in the same town that were inspected in the last year, and *Townviol_lag,* which equals the fraction of those neighbor sites that were inspected in the last year that were in violation at least once (and zero if none were inspected). Because the role of own history and neighbor history may be different after regionalization, we also include these four variables interacted with *Post,* a dummy variable that equals one for the years 1991–1998.[26]

Table 5 provides the results for the regulatory history and neighbor variables from two specifications: specification A does not include fixed effects while specification B includes site level fixed effects.[27] Note that for specification B, the sample cannot include observations for sites that were never inspected. Full regression results are provided in Appendix B. Robust standard errors clustered by town and time period are reported for specification A. The sample includes all non-federal government sites in towns of at least 2 and fewer than 30 sites.

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[24] *Sensitivity* was obtained from the Manitoba Land Initiative, https://mli2.gov.mb.ca/.

[25] Data on the source of drinking water is not available for Manitoba.

[26] Alternate versions of the model that use dummy variables for neighbor inspections and violations provide similar results. In addition, models that control for the average characteristics of neighboring sites yielded similar conclusions regarding the role of site and neighbor history on the probability of an inspection.

[27] We are not aware of techniques that allow the inclusion of fixed effects in joint probit models and we report the results from the estimation of the inspection probability equation separate from the violation equation. Moreover, because the probability of a violation is a function of all variables entering the inspection equation, estimation of a joint probit model is identified only be functional form, which is unsatisfactory. See Sartori (2003) for a discussion of the problems with identification based on functional form.

The key difference between the results for the two specifications concerns the own site history variables prior to 1991. With no fixed effects, the coefficients on the own-site history variables are statistically significant at the 5% level for violations and the 10% level for inspections. The results suggest that, prior to regionalization, sites were more likely to be inspected if they were inspected in the last year and are even more likely to be inspected if they were found in violation in the last year. The positive effect of being in violation in the last year supports the theory that a site with a recent violation is more likely to be inspected, while the positive effect of an inspection in the last year may be reflecting unobservable variation that prompts the regulator to repeatedly inspect the same sites.[28] When fixed effects are included, the coefficients for own-site history are not significantly different from zero. This result may indicate that there is insufficient time series variation with which to identify the coefficients, or simply that Manitoba Conservation does not condition its inspection decisions on a site's inspection and compliance history.

In both specifications, prior to regionalization, the coefficient on the fraction of inspected neighbor sites that were in violation at least once in the past year is positive and significant at the one percent level, consistent with the hypothesis that a neighbor's compliance history affects a site's probability of being inspected. The mechanism through which violations at neighboring sites affect the probability of an inspection is unclear if, as found in the fixed effects specification, own-site past violations do not increase the inspection probability.

To interpret the results for the period following regionalization, note that the last four rows in Table 5 present the estimated coefficients on the four enforcement history variables multiplied by *Post*, a variable that equals 1 for the years 1991–1998. A test that these four coefficients are zero, which is a test of the null hypothesis that the effect of own and neighbor enforcement history was the same before and after regionalization, rejects the null at the 1% level for both specifications.

To determine whether previous inspections and violations have a significant effect on the probability of an inspection following regionalization, we test the null hypotheses that the sum of the corresponding pre- and post-1991 history variables is equal to zero. In Specification A, the null hypotheses are rejected at the 5% level for own-site and neighbor violations and at the 1% level for own-site inspections. In Specification B, the null hypotheses are rejected at the 1% level for own-site inspections, neighbor inspections, and neighbor violations. Therefore, both specifications suggest that, after 1991, the inspection probability is falling in the fraction of neighboring sites that were found in violation in the last year. Finally, while specification A suggests that, following regionalization, an own-site violation in the last year increases the probability of an inspection, when fixed effects are included, we are unable to identify an effect of own-site violations.

The finding that the fraction of neighbors in violation last period has opposite effects on the inspection probability before and after regionalization supports the notion that regionalization substantively changed the enforcement system in Manitoba. One explanation is that, with enforcement officers closer to sites, transportation costs were no

[28] Notice that a violation in the last year does not necessarily coincide with a violation at the last inspection.

longer a significant factor in enforcement, and the incentive to inspect a number of sites in the same town is reduced. If so, an increase in the fraction of neighbors in violation last year may draw inspectors back only to those sites and in fact reduce the probability of an inspection for other sites in the town. A second explanation concerns a change in the duties of the inspectors after 1991. Before 1991, the inspector operating out of Winnipeg was responsible only for inspections of petroleum storage sites. After 1991, the inspectors' duties were expanded to include inspection of other types of sites. It is possible that if the inspector is conditioning the probability of inspecting petroleum storage sites in a town on the enforcement history of other types of sites, this would not be picked up in our data and could result in changes in the estimated coefficients on the neighbor enforcement variables.[29]

Results regarding other variables are given in Appendix B. In both specifications, the probability of an inspection is higher at sites with at least one underground storage tank and is increasing in the number of tanks and the number of other local facilities. The latter result is consistent with the hypothesis that there are scale economies in inspections, so that inspectors are more likely to visit towns where they can inspect many sites at once. For cross sectional variables included only in Specification A, bulk storage and retail gasoline stations are more likely to be inspected than other types of sites while sites owned by the provincial government are less likely to be inspected than other sites.

To illustrate the magnitude of our results, Table 6 presents predicted changes in the probability of an inspection for the own-site and neighbor history variables. We consider an independently owned, retail storage site with at least one underground storage tank for the first quarter of wither 1989 or 1993. The number of sites in the same town, tank characteristics, and distance to the enforcement office, population density and average income are equal to their sample means.[30] When computing the effect of neighbor history, we assume that the-own site history dummy variables are equal to zero.[31] Finally, the effect of own site history is the effect from the variable changing from 0 to 1 while the effect from neighbor history is the predicted change when variable increases by 10% from its sample mean.

6 The compliance decision

In the previous section, we presented evidence that Manitoba Conservation tended to inspect more than one petroleum site in an area. Our analysis suggests that, prior to the regionalization in 1991, the probability that a site is inspected is higher if a nearby site was recently inspected and found in violation. This leads to the question of whether site operators take this spatial relationship into account. In particular, is a

29 Alternate specifications of the model including the proportion of the labor force in the census subdivision employed in the primary and manufacturing industries for the period following regionalization, which is expected to be correlated with the number of environmental inspections in the region, were estimated. The qualitative results remained unchanged.

30 Depending on the year considered, the mean distance to the nearest enforcement office is either the distance to Winnipeg or the distance to the nearest regional office.

31 The predicted percentage change in the inspection probability is the same for all combinations of own-site history.

Table 6 Predicted effects on the probability of inspection

Year	Regressor	Predicted change in P(inspection) specification A (%)	Predicted change in P(inspection) specification B (%)
1989	*Insp_lag*	49.0†	−20.3
	Viol_lag	65.0**	20.9
	Townviol_lag	1.3*	0.9**
	Towninsp_lag	0.3	0.2
1993	*Insp_lag*	−12.4†	−30.8*
	Viol_lag	22.9**	4.9
	Townviol_lag	−0.4**	−0.2*
	Towninsp_lag	0.1	−0.1*

* Indicates significance at 1%, ** at 5%, and † at 10%

site less likely to violate if a nearby site has recently been found in violation, so that the probability of the site in question being inspected is increased?

As a first approach to this question, we compute the Spearman correlation coefficient between whether a site is found in violation and whether at least one neighbor site was found in violation in the last year, conditional on the site being inspected and conditional on at least one neighbor site being inspected in the last year. The correlation coefficients are negative and significant at the 5% level suggesting that sites are less likely to violate if at least one of their neighbors violated in the last year.

To have more confidence in these results, we estimate the probability of a site being found in compliance. We estimate the probability of a violation, conditional on an inspection, as

$$P\left(Y_{2it}>0\right)=\Phi\left(X_{2it}^{T}\beta_{1}\right)$$

where $\Phi(\cdot)$ is the standard normal cumulative distribution function. All of the variables from the inspections probit are included.[32] Preliminary analysis suggested that the violation probabilities for two types of inspections are fundamentally different than other inspections, and we include dummy variables that equal 1 for cathodic protection inspections (*Cathodic*) and for source survey inspections (*Sourcesurvey*).[33]

Table 7 provides the results of the violation probit for the regulatory history and neighbor variables for specifications with and without fixed effects.[34] Complete estimation results are given in Appendix B. Again, robust standard errors clustered by town and time period are reported for specification A.

32 Alternatively, a structural approach would include as a separate (endogenously determined) variable the probability of inspection, and then estimate the inspections and violations equations jointly. We estimate a reduced form model because our primary question is simply whether the probability of a violation decreases as past neighbor violations increase. For a structural approach in a non-spatial setting, see Eckert (2004).

33 One possibility is that these types of violations involve more serious consequences for the operator.

34 Because our unbalanced violations panel does not include a large number of observations for individual sites, it is possible that incidental parameters create bias in the probit coefficients. To examine the extent of bias, we estimated a logit model with conditional fixed effects, which provides unbiased coefficient estimates. The qualitative results were identical to that of the fixed effects probit model.

Table 7 Probit results: probability of a violation, 1981–1998

Variables	Specification A ($N = 3415$) Coefficients (Standard errors)	Specification B: fixed effects ($N = 2400$) Coefficients (Standard errors)
Insp_lag	0.13 (0.28)	0.72† (0.37)
Viol_lag	−0.60† (0.34)	−2.21* (0.32)
Townviol_lag	−0.30† (0.16)	−0.66* (0.25)
Towninsp_lag	0.12 (0.34)	1.3088* (0.56)
Post X insp_lag	−0.08 (0.30)	−0.17 (0.41)
Post X viol_lag	0.31 (0.35)	0.69 (0.47)
Post X townviol_lag	0.49* (0.19)	0.60** (0.30)
Post X towninsp_lag	−0.22 (0.37)	−1.37* (0.61)

* Indicates significance at 1%, ** at 5%, and † at 10%

In both specifications, we find that, prior to 1991, individual violations and neighbor violations in the last year have negative effects on the probability of compliance, with the coefficients significant at a 10% level in specification A and a 1% level in specification B. These results provide support for the hypothesis that site operators recognize that a violation at a neighboring site increases their own inspection probabilities.[35]

A test of the null hypothesis that the effect of own and neighbor enforcement history was the same before and after 1991 rejects the null hypothesis at the 5% level for specification A, but cannot reject the null hypothesis when fixed effects are included. Likewise, the null hypothesis that the sum of the coefficients on the fraction of neighbors in violation last period for the two time periods is rejected at the 5% level in specification A, but cannot be rejected in specification B. Notice that the result in specification A that, after 1991, the probability of a violation is increasing in the fraction of neighbors in violation last period is consistent with the results of the inspection equation which suggest that a higher level of neighbor violations decreases a site's inspection probability, which is expected to increase the probability of a violation.

Again, to illustrate the magnitude of the results, Table 8 presents predicted changes in the probability of an inspection for the own-site and neighbor history variables. We consider the same examples as for the probability of an inspection.

7 Conclusions

The purpose of this paper has been to consider whether inspections by an environmental regulator are spatially correlated, and whether firms subject to regulation take this correlation into account by conditioning their compliance behavior on the compliance behavior of neighboring sites. These questions were answered using data regarding the regulation of petroleum storage in Manitoba, Canada, from 1981 to 1998.

Our analysis indicates that inspections by Manitoba Conservation were indeed spatially correlated. As well, we find that, prior to regionalization, a site was more likely

[35] Of course, this result could be capturing other effects. One possibility is that a violation at a site increases the awareness of neighboring sites to the regulations and the possibility of enforcement.

Table 8 Predicted effects on the probability of a violation

Year	Regressor	Predicted change in P(violation) specification A (%)	Predicted change in P(violation) specification B (%)
1989	*Insp_lag*	3.0	$0.001^{\dagger}$
	Viol_lag	$-17.3^{\dagger}$	−0.2*
	Townviol_lag	$-0.1^{\dagger}$	−0.00003*
	Towninsp_lag	0.03	0.00003*
1993	*Insp_lag*	2.7	0.1*
	Viol_lag	−19.2**	−1.7*
	Townviol_lag	0.2**	−0.0003
	Towninsp_lag	−0.1	−0.0003

* Indicates significance at 1%, ** at 5%, and † at 10%

to be inspected if neighbor sites had recently been in violation, thus increasing the likelihood that the inspector would return to the area. This relationship between whether a site is inspected and whether neighbor sites have recently violated reverses after 1991 when inspectors were much closer to sites and charged with inspecting all sites regulated under the *Environment Act*.

Our results also suggest that site operators do take into account the violation history of neighbors when making their own compliance decisions. Specifically, prior to regionalization, a site that is inspected is less likely to be found in violation if neighbor sites were recently in violation. This effect is not found in the period following regionalization.

Our results provide motivation for future theoretical work examining how spatial correlation in inspections changes the interaction between regulators and firms, the interaction between firms, and how this correlation might affect policy. At minimum, the economic theory of warnings, as developed by Harrington (1988) and others should be extended to incorporate the influence of neighboring compliance decisions on a site's inspection probability. As well, our results suggest that empirical studies of enforcement and compliance may need to account not only for information regarding the site but also nearby sites.

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Appendix A

This appendix discusses in more detail the data used in the regression analyses presented in the paper. We control for the type of outlet using eight categories that Manitoba Conservation uses to classifies petroleum storage outlets: retail, bulk, fleet, heating, industrial, used oil, aviation/marina, and miscellaneous.[36] Five ownership classes

[36] There are also five categories for combination sites, which we combined with these eight categories.

are controlled for: independent, oil company, municipality, provincial government, and institution. Observations for sites owned by the federal government were dropped from the analysis. The five regions included in the analysis correspond to Manitoba Conservation's regional breakdown over the sample period and are defined as: Winnipeg region, Eastern-Interlake region, South-Central Region, Park-West Region (including Brandon), and the Northern Region.

Appendix B

This appendix provides the full results for the regressions discussed in the paper. Table 9 provides the results for the probit estimation of the probability of an inspection at a site in a given quarter for the period 1981–1998. Table 10 gives the results for the probit estimation of the conditional probability of a violation at a site in a given quarter for the period 1981–1998. In both tables, specification B included site level fixed effects while specification A does not.

Table 9 Probit results: probability of inspection, 1981–1998

Variables	A ($N = 109302$) Coefficients (standard errors)	B ($N = 95037$) Coefficients (standard errors)	Variables	A Coefficients (standard errors)	B Coefficients (standard errors)
Constant	−3.18* (0.13)	−3.34* (0.38)	*Total tanks*	0.03* (0.003)	0.04* (0.01)
Bulk	0.09** (0.04)		*Total underground*	0.03** (0.01)	−0.05† (0.03)
Fleet	−0.14* (0.03)		*Total unprotected*	−0.03* (0.005)	−0.01 (0.01)
Heating oil	−0.40* (0.07)		*Any underground*	0.09* (0.03)	0.23** (0.10)
Industrial	−0.27* (0.05)		*Quarter 2*	−0.07† (0.04)	−0.05** (0.02)
Used oil	−0.27* (0.09)		*Quarter 3*	−0.10* (0.04)	−0.07* (0.02)
Aviation/ marina	−0.33* (0.10)		*Quarter 4*	−0.15* (0.04)	−0.11* (0.02)
Miscellaneous	−0.30** (0.15)		*Year 1982*	0.44* (0.12)	0.65* (0.11)
Oil Company	−0.05† (0.03)		*Year 1983*	0.55* (0.13)	1.32* (0.20)
Institution	0.03 (0.05)		*Year 1984*	0.48* (0.11)	1.30* (0.20)
Municipal govt	−0.04 (0.06)		*Year 1985*	0.53* (0.12)	1.32* (0.20)
Provincial govt	−0.13* (0.04)		*Year 1986*	0.64* (0.12)	1.55 (0.20)
Insp_lag	0.15† (0.08)	−0.12 (0.08)	*Year 1987*	0.66* (0.11)	1.55* (0.20)
Viol_lag	0.20** (0.09)	0.10 (0.09)	*Year 1988*	0.08 (0.12)	0.92* (0.21)
Townviol_lag	0.31* (0.09)	0.32* (0.05)	*Year 1989*	0.30* (0.11)	1.17* (0.20)
Towninsp_lag	0.10 (0.14)	0.13 (0.10)	*Year 1990*	0.40* (0.16)	1.37* (0.20)
Post X insp_lag	−0.22** (0.09)	−0.22** (0.09)	*Year 1991*	0.97* (0.11)	1.93* (0.20)
Post X viol_lag	−0.09 (0.10)	−0.06 (0.10)	*Year 1992*	1.28* (0.11)	2.30* (0.20)
Post X townviol_ lag	−0.43* (0.10)	−0.44* (0.06)	*Year 1993*	1.32* (0.11)	2.37* (0.20)
Post X towninsp_ lag	−0.07 (0.15)	0.02 (0.11)	*Year 1994*	1.17* (0.11)	2.23* (0.20)
Localsites	0.01** (0.003)	0.05* (0.01)	*Year 1995*	1.22* (0.11)	2.37* (0.20)

Table 9 continued

Variables	A ($N = 109302$) Coefficients (standard errors)	B ($N = 95037$) Coefficients (standard errors)	Variables	A Coefficients (standard errors)	B Coefficients (standard errors)
PreWinnipeg	0.00003 (0.0002)	−0.0004* (0.0001)	*Year 1996*	1.22* (0.11)	2.29* (0.20)
PostOffice	0.0003 (0.0003)	−0.0009** (0.0004)	*Year 1997*	0.86* (0.11)	1.92* (0.20)
Density	−0.00002 (0.0001)		*Year 1998*	0.79* (0.11)	1.82* (0.21)
AvgIncome	0.000006* (0.000002)	−0.0002** (0.00001)	*Depth*	0.0003 (0.03)	
Sensitivity	0.03** (0.01)				

* Indicates significance at 1%, ** at 5%, and † at 10%. For all probit models reported in this paper, Wald tests of specification of the hypothesis that the coefficients are jointly zero are rejected at the 1% level

Table 10 Probit results: probability of violation, 1981–1990

Variables	No fixed effects ($N = 3415$) Coefficients (standard errors)	Fixed effects ($N = 2400$) Coefficients (standard errors)	Variables	No fixed effects Coefficients (standard errors)	Fixed effects Coefficients (standard errors)
Constant	1.02** (0.41)	4.51 (3.31)	*Total tanks*	0.03** (0.01)	0.01 (0.05)
Bulk	−0.20 (0.14)		*Total underground*	−0.01(0.03)	−0.19 (0.12)
Fleet	0.27* (0.10)		*Total unprotected*	0.02 (0.01)	0.06 (0.07)
Heating Oil	−0.19 (0.23)		*Any underground*	−0.18 (0.13)	0.56 (0.57)
Industrial	−1.15* (0.22)		*Quarter 2*	−0.13† (0.08)	−0.15 (0.12)
Used Oil	0.31 (0.27)		*Quarter 3*	−0.34* (0.08)	−0.50* (0.13)
Aviation/marina	0.50 (0.35)		*Quarter 4*	−0.10 (0.08)	−0.33* (0.12)
Miscellaneous	−0.52 (0.36)		*Year 1982*	0.57 (0.42)	0.18 (1.22)
Oil Company	−0.16** (0.08)		*Year 1983*	0.62† (0.37)	0.29 (1.52)
Institution	−0.31** (0.16)		*Year 1984*	0.75** (0.38)	0.47 (1.53)
Municipal Govt	0.35** (0.18)		*Year 1985*	0.80** (0.38)	1.07 (1.53)
Provincial govt	0.10 (0.16)		*Year 1986*	0.37 (0.37)	−0.02 (1.52)
Insp_lag	0.13 (0.28)	0.72† (0.37)	*Year 1987*	0.74** (0.37)	0.91 (1.53)
Viol_lag	−0.60† (0.34)	−2.21* (0.43)	*Year 1988*	0.62 (0.41)	0.76 (1.57)
Townviol_lag	−0.30† (0.16)	−0.66* (0.25)	*Year 1989*	0.57 (0.40)	0.59 (1.53)
Towninsp_lag	0.12 (0.34)	1.30** (0.56)	*Year 1990*	0.82 (0.41)	0.35 (1.52)
Post X insp_lag	−0.08 (0.30)	−0.17 (0.41)	*Year 1991*	0.24 (0.37)	−0.14 (1.52)
Post X viol_lag	0.31 (0.36)	0.69 (0.47)	*Year 1992*	0.17 (0.37)	−0.24 (1.52)
Post X townviol_lag	0.49* (0.19)	0.60** (0.30)	*Year 1993*	−0.14 (0.37)	−0.86 (1.52)
Post X towninsp_lag	−0.22(0.37)	−1.37** (0.61)	*Year 1994*	−0.34 (0.37)	−1.45 (1.53)
Localsites	0.01† (0.005)	−0.02 (0.03)	*Year 1995*	−0.55 (0.37)	−1.43 (1.52)

Table 10 continued

Variables	No fixed effects ($N = 3415$) Coefficients (standard errors)	Fixed effects ($N = 2400$) Coefficients (standard errors)	Variables	No fixed effects Coefficients (standard errors)	Fixed effects Coefficients (standard errors)
PreWinnipeg	0.0002 (0.0003)	−0.002* (0.0006)	*Year 1996*	−0.70† (0.37)	−1.83 (1.53)
PostOffice	0.001† (0.0005)	−0.002 (0.002)	*Year 1997*	−0.67† (0.38)	−1.96 (1.54)
Cathodic protection	−2.36* (0.20)	−3.97* (0.35)	*Year 1998*	−0.84** (0.39)	−2.05(1.53)
Source survey	−2.19** (0.10)	−3.62* (0.20)	*Density*	−0.0003** (0.0001)	
Depth	−0.06 (0.06)		*AvgIncome*	−0.000006† (0.000003)	−0.00002 (0.0001)
Sensitivity	−0.04† (0.03)				

* Indicates significance at 1%, ** at 5%, and † at 10%. For all probit models reported in this paper, Wald tests of specification of the hypothesis that the coefficients are jointly zero are rejected at the 1% level

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