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Disciplines

Insurance

Risk-Based Pricing and Risk-Reducing Effort: Does the Private Insurance Market Reduce Environmental Accidents?

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1. Introduction

Many risks facing firms and individuals are spread across the economy through government assurance programs. Prominent examples include bank deposit insurance, pension benefit guarantee funds, and hazardous material cleanup funds. A salient feature of many government assurance programs is the absence of risk-based pricing: they protect beneficiaries from adverse events for a price that does not vary with the insured's likelihood of loss. A common concern is that this practice may exacerbate moral hazard, increasing the frequency of adverse events by lessening incentives for risk-reducing effort (Kareken and Wallace 1978; Cooper and Ross 1998; Brown 2008).

In contrast, risk-based pricing is widely employed in private insurance contracts.[1] It can attenuate moral hazard problems by rewarding firms with premium discounts for risk-reducing activities (Freeman and Kunreuther 1997; Boyd 1997). In this paper, we investigate whether the absence of risk-based pricing in one class of government assurance programs results in less risk-reducing activity—and more frequent adverse outcomes—than if comparable insurance is arranged in private markets. The policy variation between states in financing the cleanup of underground fuel tank leaks provides an important setting in which to examine this question.

In the late 1980s, new federal regulations required gas stations and other owners of underground fuel tanks to demonstrate that they are financially capable of cleaning up underground fuel leaks and compensating third parties for consequential damages. Michigan, Illinois, and Indiana soon created state assurance programs to subsidize firms' costs of complying with the new federal regulations. Although the risk of an underground fuel tank leak varies greatly with a tank owner's operating and investment decisions, the price to participate in these state cleanup assurance funds did not vary with the station's risk. Consequently, station owners could have costly tank leaks and their consequential damages covered at the state's expense, while facing little program-related incentives to take care to prevent such leaks.

By the mid-1990s, the assurance funds in Michigan and Illinois became insolvent. However, these states took different approaches to their insolvency crises. While Illinois increased its gasoline excise tax to restore its program's solvency, the Michigan legislature terminated its state assurance program. Tank owners in Michigan subsequently turned to the emerging market for commercial cleanup and liability coverage in order to comply with the federal financial responsibility requirements. In contrast to state assurance funds, the price structure for market-based insurance gives tank owners incentives to invest in equipment that reduces the chance of accidental fuel tank leaks. This variation provides an opportunity to evaluate whether switching from a government assurance program to the

[1] By "risk-based pricing," we mean insurance premiums that are based on an assessment of the insured party's risk of future losses and vary with the insured party's loss history (experience rating).

private insurance market promotes risk-reducing activity and reduces the frequency of these adverse events.

Despite its importance, few studies directly evaluate the performance of private- versus public-sector insurance programs in addressing moral hazard. The empirical difficulty is that moral hazard is typically confounded with selection effects. For example, Wheelock and Wilson (1995) find that banks that were members of the Kansas state deposit insurance system had a higher probability of failure than did nonmembers. As they point out, however, it is unclear whether insurance attracted the most risk-prone banks (adverse selection) or banks tended to take more risks once insured (moral hazard).[2]

Several attributes make our research setting more conducive to the study of moral hazard. First, the federal financial responsibility regulations require firms either to purchase private insurance or to participate in a state assurance fund. Because the two systems provide comparable insurance benefits but the cost of a state's fund is borne by taxpayers, it is a dominant strategy for any tank owner—whether low or high risk—to use the state assurance fund. Only when a state fund is not available do tank owners acquire private insurance. Consequently, there is no sorting between private- and public-sector insurance based on a firm's private information about its risk propensity or its cost of risk-reducing effort.

Second, there is little reason to take a reverse-causality interpretation of the data, in which accident rates in Michigan would decline (relative to surrounding states) even if that state did not switch to private-market insurance. In fact, the available evidence indicates that Michigan should—and did—expect to have a larger future tank cleanup problem than other states at the time that it closed its public assurance program (Public Sector Consultants 1995). This makes it difficult to interpret Michigan's policy change as a consequence, rather than a cause, of changes in accident rates.

The findings are quite striking. After Michigan's policy change, the fraction of underground fuel tanks with accidental releases dropped by more than 20 percent relative to surrounding states that maintained state assurance fund programs. This reduction corresponds to more than 3,000 fuel tank releases avoided in Michigan over the following 8 years. At an average cleanup cost of $125,000 per release (Government Accounting Office 2007), this represents an aggregate cleanup cost savings for that state on the order of $400 million.

These findings have a practical policy implication. The U.S. Environmental Protection Agency (EPA) estimates that 6,300 new underground fuel tank releases occur each year in the United States (EPA 2010, p. 5). Gasoline and other petroleum products that leak underground tend to enter groundwater flows; if undetected, these leaks can pose a public health hazard by contaminating public

[2] Empirical studies of private- versus public-sector insurance have proved more successful in analyzing adverse selection, particularly in health care contexts. Hopkins and Kidd (1996) and Sapelli and Torche (2001) argue that adverse selection is more severe for insurers that are restricted from practicing price discrimination, which prevents premiums from varying with an insured party's risk.

drinking water supplies that require costly remediation. For the more than 30 states that presently operate state assurance fund programs, adopting the risk-based pricing mechanisms used in private insurance markets may reduce the costly burden of future accidents and alleviate ongoing solvency crises.

2. Technology and Risk-Reducing Activity

To understand the effects of the government assurance programs that we study, it is useful to briefly summarize the underlying technology, the risks it entails, and what taking care to prevent accidents means in this setting.

2.1. Technology

Most underground fuel tanks are located at retail gasoline stations. A small gas station typically has two tanks, and a large station may have five or six. From regulatory and insurance standpoints, they are treated as one system consisting of the tanks and underground piping, pumps, and ancillary equipment. The most common and serious cause of accidental underground fuel leaks is long-term corrosion (oxidation) of the tank or pipes, catalyzed by groundwater in the surrounding soil.[3]

While leaks underground are not directly visible, they are readily detected by several means. These include inventory monitoring and reconciliation, automatic leak sensors located in the tank system, and groundwater- or soil-monitoring wells located near the tank system. Since 1993, all tank systems in the United States have been required to have some leak detection system in place. Tank system owners can invest in more accurate detection systems than the minimum regulatory requirement, which enables a leak to be identified and rectified more rapidly.

Rapid detection of a leak is essential to minimize its cost and consequential damage to water supplies and adjacent property. Small leaks can be resolved by removing the remaining fuel, replacing the tank and piping, and cleaning (excavating or pumping) surrounding contaminated soil. Although total costs vary, in the early to mid-1990s, typical cleanup costs in these situations ranged from $60,000 to $100,000 (*Environmental Information Digest* 1993; Soesilo and Wilson 1997). In contrast, a leak that remains unresolved will not stop of its own accord and tends to grow progressively worse over time, spreading into groundwater systems beyond the station site. In severe cases, fuel from leaking tanks can contaminate drinking water sources, forcing the permanent closure of municipal and private wells and the acquisition of new water supplies.[4] For these reasons, investing in equipment and operating practices that can prevent accidental un-

[3] Other causes include improper installation, structural collapse, and uncontained surface spills during deliveries.

[4] Benzene and other compounds in gasoline are hemotoxic and neurotoxic to humans in high doses and carcinogenic with long-term, low exposure levels (Agency for Toxic Substances and Disease Registry 2005). Benton (1990) examines cleanup costs for groundwater contamination.

derground leaks—and detecting and remediating leaks with alacrity—is desirable to minimize the total social costs of underground fuel storage.

2.2. Preventing Leaks: Maintenance and Capital Investment

Since the mid-1980s, new technologies have enabled tank system owners to greatly reduce the likelihood of an underground fuel leak. Prior to 1990, nearly all underground fuel tanks were single walled and constructed of bare steel that is prone to corrode. Two types of capital investment can greatly reduce this risk. The first, and most effective, is to replace a steel tank with one constructed of, or coated with, noncorroding material (such as reinforced fiberglass). Installing a double-walled tank further reduces the corrosion risk to negligible levels. Short of replacing an existing bare steel tank, a tank system owner can invest in corrosion-attenuating equipment that reduces the likelihood of underground tank leaks. Several anticorrosion technologies are available, with more effective systems carrying higher installation and ongoing maintenance costs (see EPA 2008).

Tank system leaks can also be reduced, in severity and in likelihood, through assiduous operations and maintenance activities. These include regularly performing pressure tests on the tank system, calibrating inventory-monitoring systems after each fuel delivery, replacing underground sacrificial anodes (a common means of corrosion resistance in steel tanks), operating impressed-current anticorrosion devices, and the like. All of these activities are costly, and some require periodic closure of the station and attendant lost revenue.[5]

3. Regulation and Its Incentives

During the 1980s and 1990s, changes in federal and state regulations altered the incentives for tank owners to undertake risk-reducing measures. We describe these changes next.

3.1. Federal Regulations and Owners' Responsibilities

In response to mounting scientific evidence of and public concern over the adverse health consequences of leaking underground fuel tanks, in 1984 Congress directed the EPA to regulate public and private underground fuel storage tanks.[6] The EPA's final regulations, issued in 1988, had three distinct provisions: financial responsibility requirements, tank system technical standards, and disclosure and corrective-action obligations. The first of these provisions is the impetus for the state-level policy variation that we examine.

[5] The technical literature on leak prevention practices is extensive (see, for example, Kreiger 2000; Noyes 1992).

[6] See 40 C.F.R. 280–81, which implements the Resource Conservation and Recovery Act, subtitle 1, amendments of 1984. Underground fuel tanks were not a public concern until the early 1980s; in 1983 a CBS *60 Minutes* episode, "Check the Water," brought national attention to the health consequences of leaking underground gasoline storage tanks.

3.1.1. Financial Responsibility Requirements

The EPA's financial responsibility requirements enjoin tank system owners to either purchase environmental liability and site remediation insurance for fuel tank leaks from a qualified insurer, with a minimum coverage of $1 million per occurrence, or participate in a state-administered underground storage tank financial assurance program that provides comparable coverage.[7] State and federal regulators believe that compliance with financial responsibility requirements is (essentially) universal.[8]

In creating these new obligations, Congress did not alter any tort system remedy available to third parties injured by a tank leak. Rather, Congress effectively concluded that such remedies alone are apt to be administratively and socially costly relative to prophylactic regulation and that the desired incentive effect of a pure liability rule may be adversely tempered by the limited liability provisions of the bankruptcy code (Boyd 1997).[9] This second concern is particularly acute with respect to the risk posed by underground fuel storage tank leaks at gasoline stations, as many are small businesses and the cost of cleaning up a substantial leak can easily exceed the present value of a station's profit stream.[10]

3.1.2. Technical Requirements

Although changes in technical standards for tank systems are not the focus of our analysis, they affect the data interpretation and merit brief discussion. The EPA chose compliance deadlines for technical standards that differed for new and existing (grandfathered) underground fuel tanks. Any new tank installed after 1988 was required to have one or more leak detection systems and to meet a basic requirement for corrosion resistance. In contrast, existing (grandfathered) tanks were obligated to meet the leak detection technology requirement within 5 years (by December 1993) and the corrosion resistance requirement within 10

[7] Large petroleum marketers can self-insure after satisfying stringent financial tests specified by the EPA (40 C.F.R. 280.95). This is rare if a state assurance fund exists (EPA 1995) for the reasons noted below.

[8] Sammy Ng, Director, Office of Underground Storage Tanks, EPA, e-mail correspondence, May 19, 2006; Kevin Wieber, Hazardous Materials Storage Inspector Specialist, Michigan Department of Environmental Quality, Waste and Hazardous Materials Division, e-mail correspondence, June 15, 2006.

[9] The administrative inefficiency of a pure liability rule rests on the observation that tank leak litigation centers on competing expert testimony in geology, epidemiology, engineering, and other scientific areas that courts are often ill equipped to evaluate. In addition, Congress recognized that time is of the essence in acting to resolve an underground fuel storage tank leak. This makes corrective action and assured financing for it stipulated a priori by a regulatory agency preferable to the delay of judicial decisions regarding cleanup programs made in the course of civil litigation or a bankruptcy proceeding.

[10] Questions commonly arise regarding the allocation of liability between owner and operator at franchised gasoline stations. Effective liability varies depending on who holds title to the tank system and provisions regarding these contingencies in the specific franchise agreement.

years (by December 1998). The corrosion resistance requirement could be met by retrofitting an existing steel tank with technology readily available in 1988.

The principal consequence of these technical standards is that, even in the absence of state-level policy variation, we would expect the frequency of underground tank leaks to decrease over time as older, substandard tanks are closed or upgraded to meet the 1998 deadline.

3.1.3. Reporting and Corrective Action Requirements

The 1988 federal regulations stipulate that underground storage tank leaks of any detectable quantity be promptly reported to federal and/or state regulatory agencies and specify the required corrective actions in detail. Importantly for our purposes, the penalty for failing to report a suspected underground tank leak is extraordinarily high: $11,000 per day (42 U.S.C. 6991[e]). In Section 4.3, we discuss this and other incentives facing owners to report and remediate tank leaks. It is useful first to summarize state policy responses to these federal regulations.

3.2. States' Responses: Government Assurance Funds

The federal financial responsibility requirements generated a storm of political protest from gasoline retailers and small-business advocates. They argued that many stations would not survive because private insurance was not widely available in the 1980s and was expensive when available (see Government Accounting Office 1987; Boyd and Kunreuther 1997).[11] In response to these political pressures, many state legislatures created financial assurance funds for underground fuel tank leaks.

State assurance funds function as a publicly financed insurance program for tank owners. In the event of a tank leak, the state assurance fund pays for the cost of cleanup at the site and third-party consequential damages. To participate in a state assurance fund program, a tank system owner must pay a nominal registration fee (typically $100 per tank per annum), comply with applicable technical standards for tank systems, and promptly report (within 1 day) any detected or suspected underground fuel leaks.

Two features of these programs are important. First, most states' assurance funds are financed by an incremental excise tax on motor fuel (typically about 1 cent per gallon). The nominal registration fee that a tank system owner pays to participate in a state assurance fund is a small fraction of the actuarially fair price of underground fuel leak cleanup and liability insurance. As a consequence, in states with assurance fund programs, the participation rate is effectively 100 percent.

Second, the fee that tank owners pay to qualify for state fund benefits is the

[11] Commercial insurers frequently declined to cover tank systems that did not meet the EPA's new technical standards, even though these standards were (nominally) not binding on grandfathered facilities until 1998.

same for everyone. It does not vary with respect to the age of the tank being insured; tank capacity, prior leak history, and proximity to groundwater; whether or not the tank system has been retrofitted with advanced corrosion protection equipment; whether the tank is single or double walled; or any of a host of quantifiable factors that directly affect the chance of a leak and the cost of remediating it. Consequently, the structure of state fund programs provides little incentive for an owner to invest in or maintain leak prevention equipment beyond the minimum necessary to meet federal technical requirements.

Indeed, it is possible that state assurance fund programs in fact attenuate tank owners' incentives to comply with federal technical requirements. Our discussions with regulatory officials indicate that while state assurance funds nominally require participants to comply with federal technical standards, that requirement is not well enforced. William Foskett, an official at the EPA's Office of Underground Storage Tanks, indicates how administrators view the problem:

> Anecdotes that have come to my attention indicate that where a state has the authority to limit coverage based on compliance, that authority is not necessarily exercised. Withholding payment for noncompliance poses state fund administrators two very practical problems: 1) both the owner/operator and state legislators tend to think of payment for cleanups as an entitlement, except in the most egregious violations; and 2) the public interest (public welfare) purpose of protecting the environment and health by cleaning up release sites is not served if the public monies allocated for cleanups are not in fact applied to accomplishing that public goal expeditiously. . . . Assured financing for cleanups is a higher goal than bringing non-compliers to justice.[12]

In practice, this perspective has a potential to create misaligned incentives for tank owners to comply with tank system technical standards. Still, whether the absence of strong incentives to prevent accidental leaks among state assurance fund participants manifests in more adverse outcomes is an empirical matter. We now turn to the policy variation that informs this question.

4. States' Policy Variation and Market Insurance

4.1. State Assurance Fund Changes

The states that we examine—Michigan, Illinois, and Indiana—established substantively identical state assurance fund programs in 1988 or 1989. Indiana initially chose a high (relative to subsequent claims) gasoline excise tax to finance its assurance fund and has operated its program without major changes since that time. However, claims in both Michigan and Illinois significantly exceeded their initial funding levels and rendered both states' assurance funds insolvent by the mid-1990s.

In response, Illinois raised its (wholesale) motor fuels tax by .8 cent per gallon

[12] William Foskett, Office of Underground Storage Tanks, Division of Cleanup and Revitalization, EPA, e-mail correspondence, August 18, 2004.

and continued to operate its state assurance fund. Studies performed in Michigan at the time concluded that a significant ($234 million) increase in funding would be necessary to restore that state's fund solvency and meet existing claims (Public Sector Consultants 1995). The analysis of future liabilities predicted more than 3,000 additional claims between March 1995 and December 1998. Facing public opposition to further gasoline taxes, in 1994 the Michigan legislature elected to close its state assurance fund program to new claims (Mich. Comp. Laws, secs. 324.21101–21563). All tank owners operating in Michigan needed to obtain private-market insurance starting July 1, 1995.

4.2. Market Insurance and Incentives

Environmental liability and cleanup insurance for underground fuel tank releases is available on similar terms from a number of commercial insurance companies. In contrast to state assurance fund programs, these commercial insurance policies are explicitly structured to encourage risk-reduction efforts. For example, insurance premiums reward owners for replacing tanks constructed of corrosive-prone material (bare steel) and aging tanks. A review of major insurers' policies indicates that the primary factors determining commercial tank insurance premiums are the age of the tank system, tank and piping material and coatings, construction (single or double walled), contents, capacity, and the history of prior leaks at the facility.

Some evidence of the magnitudes involved is summarized in Tables 1 and 2. Table 1 lists two rate factors for one major commercial environmental liability insurer (Zurich in North America) (see also EPA 1997; Public Sector Consultants 1995). Base premiums vary with tank construction and age by a factor of 10, from $185 per annum for a new, double-walled tank to $1,850 per annum for a single-walled tank that is 35 years or older. As we show in Section 6.4, this premium structure makes it cost-effective for facility owners to replace aging tanks sooner with commercial insurance than with public insurance.

Similarly, commercial premium structures create economic incentives for facility owners to purchase leak-resistant equipment when they replace tank systems. For instance, the data in Table 1 imply that the 30-year present value (at 5 percent per annum) of the insurance premium savings from installing a double- versus a single-walled tank exceeds $5,300. In practice, the procurement cost differential between a basic single-walled (cathodically protected) steel tank and a noncorroding double-walled composite (fiberglass and steel) tank of standard size is approximately $2,600–$3,000; the latter carries a 30-year manufacturer warranty against corrosion.[13] Thus, for reasonable discount rates, commercial

[13] Cost data are from interviews with four major tank manufacturers (Kennedy Tank & Manufacturing Co., Highland Tank Manufacturing, Modern Welding Co., and Palmer Manufacturing & Tank, Inc.); price comparisons are for two widely available tank models (the STI-P3 UL58-rated single-walled and STI Permatank F-922 double-walled composite) with a 6,000-gallon capacity. Installation costs are similar.

Table 1
Base Insurance Premiums by Tank Type and Age

	0–5 Years	6–10 Years	11–15 Years	16–20 Years	21–25 Years	26–30 Years	31–35 Years	>35 Years
Single walled	284–339	350–470	500–700	760–1,030	1,100–1,380	1,450–1,690	1,750	1,850
Double walled	185–221	228–302	320–356	365–426	441–509	441–509	526–582	620

Note. Values are dollars per tank per annum. Insurance premium information is for environmental liability and tank pollution insurance per $1 million coverage with a $5,000 deductible. Data are from Zurich in North America for 2004.

insurance pricing can make it economic to install higher quality (noncorroding) tanks when a facility replaces them. Public insurance lacks similar incentives.

Table 2 shows insurance premiums for several common three-tank system configurations of different vintages in 1997, which is approximately the midpoint of our study period. Premiums vary significantly: lower premiums apply if owners invest in tank and piping equipment that is less likely to corrode and for systems with superior monitoring and inventory control. Similarly, Table 2 indicates that commercial insurance premiums are reduced for additional corrosion protection equipment and other preventive measures that exceed federal technical standards.

Experience-rated prices for commercial insurance contracts provide additional incentives for tank owners to take care. A prior accidental fuel release (a tank leak or a surface spill exceeding 25 gallons) increases the premium per tank charged by Zurich in North America by 10 percent (for closed claims) to 20 percent (for open claims) per annum. To our knowledge, no state assurance fund program incorporates experience rating—the most basic form of risk-related information—into its program participation fee. Commercial insurers also provide incentives for tank owners to purchase detection and maintenance services from specific third-party providers, an arrangement that insurers view as a means to reduce moral hazard in gasoline retailers' maintenance and operations activities (see, for example, *National Petroleum News* 1998).

In sum, because the price of commercial insurance is closely tied to tank systems' attributes, leak history, and risk-reducing activities at the station level, we hypothesize that stations with commercial insurance are less likely to have accidental fuel tank leaks than stations participating in state assurance fund programs. Before turning to the data that inform this conjecture, however, it is important first to describe how leaks are reported.

4.3. Leak Disclosure Compliance

The data that we examine include all underground tank fuel leaks and spills (formally known as accidental releases) reported to—or discovered by—state regulatory agencies and commercial insurers. The issue that we confront is whether the true number of releases discovered by tank system owners differs from the reported number of releases. This poses a concern for our study if underreporting is more prevalent with private insurance than public insurance.

Table 2

Variation in Private Insurance Premiums in 1997 for Typical Tank System Configurations of Several Vintages

	System Attributes					Insurance Premiums for a Three-Tank System		
	Tank Material	Piping Construction	Anticorrosion Equipment	Overfill Protection	Inventory Monitoring	Insurer A	Insurer B	Insurer C
1997	Reinforced fiberglass	Double walled	N.A.	Yes	Automated	$1,350	$825	$1,320
1991	Coated steel	Single walled	Yes	Yes	Automated	$1,500	$1,250	$1,320
1985	Bare steel	Single walled	Yes	No	Manual	$3,500	$1,500	$2,563
1975	Bare steel	Single walled	No	No	Manual	Decline coverage	$3,800	$5,610

Note. Premiums are in 1997 U.S. dollars. Minimum deductibles are $10,000 for Insurer C, $5,000 for Insurer B, and $5,000 for Insurer A (except bare steel, which has a minimum deductible of $10,000 if Insurer A does not decline coverage). Anticorrosion equipment (cathodic) applies only to steel tanks. N.A. = not applicable.

Table 3
Regulatory Compliance and Facility Inspection Rates

	Michigan	Illinois	Indiana
Tanks inspected annually (actual) (%)	30–40	30–40	10–20
Frequency of state UST inspections (nominal)	3 Years	2 Years	3 Years
Active tanks with required leak detection equipment (%)	91–95	91–95	91–95
Full-time employees who conduct field UST inspections	21	23	6

Note. UST = underground storage tank.

Three observations argue against this possibility. (1) The likelihood that an unreported release is ultimately detected is high. (2) The costs imposed by the marketplace and the legal system upon discovery of an unreported release are severe. (3) The costs of reporting an insured accidental release are comparatively small. These observations suggest that a tank owner's interests are best served by reporting and cleaning up any leaks promptly, regardless of insurance system.

As to observation 1, there are two mechanisms at work: routine inspections and on-site testing when a tank is replaced or a facility is closed. Table 3, which summarizes information from a General Accounting Office (2000) study of state tank regulations during the 1990s, indicates that Michigan and Illinois inspected between 30 and 40 percent of facilities in each state annually; Indiana inspected somewhat fewer (between 10 and 20 percent). A primary purpose of routine state inspections is to detect previously unreported leaks. In addition, when a facility owner closes or replaces a tank, state regulators require its removal and inspection for leaks. The site assessment at closure is designed to be diagnostic and highly unlikely to erroneously conclude that a site is clean if a release has in fact occurred.

With regard to observation 2, market mechanisms provide considerable incentive to report and clean up leaks. It is standard practice for a prospective buyer of any site with underground fuel storage tanks to have the site tested prior to purchase (via direct soil sampling and monitoring of wells). A facility that does not test clean is difficult, if not impossible, to sell and to be insured by a future owner (absent cleanup). Consequently, unless the market value of the site is already negligible before an accidental release, it is in the facility owner's best interest to have any leak cleaned up promptly—at the current insurer's expense—so as to preserve the asset's future value.

Separately, failing to report an accidental release has significant legal consequences. First, as noted earlier, federal law stipulates that a tank owner or operator who fails to report a suspected accidental release within 24 hours is subject to civil penalties of $11,000 per day. Second, to renew commercial tank insurance, a facility owner must make a detailed declaration of whether it experienced an accidental release in the past. Nondisclosure of a prior release is a breach for which the insurer may legally rescind coverage, leaving the tank owner liable for the full cost of the cleanup. In contrast, by reporting the release promptly, a facility owner can avoid this loss and have the release cleaned up at the insurer's expense.

As for observation 3, the owner of an insured facility bears some costs after an accidental release occurs. However, much of this cost is the same under either insurance system. The major costs to the owner are the insurance policy deductible, future increases in experience-rated commercial premiums, any uninsured losses associated with business interruption during cleanup, and the cost of accelerated replacement of the tank system. Since public insurance programs do not cover losses due to business interruption or the cost of new equipment, only the experience rating and (potentially) the deductible amounts differ between commercial and public insurance systems.

Although hard data on the prevalence of unreported tank leaks remain elusive, the totality of these considerations leaves us skeptical that tank owners with private insurance are systematically less likely to report an accidental release than owners participating in state assurance fund programs.[14] Similarly, EPA officials who oversee compliance policies nationally assert that there is no evidence that tank owners using state assurance funds and those using commercial insurance differ in reporting accidental releases.[15]

5. Data and Measurement

5.1. Data

We examine accidental release rates over a 14-year period at all facilities in Michigan, Illinois, and Indiana. Using these states is informative for several reasons. First, as noted earlier, all three states adopted substantively identical assurance fund programs at the same time (either in 1988 or 1989). Second, each of these states maintains comprehensive data on all underground fuel storage tanks and accidental releases in the state. These databases have been continuously updated for more than 20 years as old tanks exit and new tanks enter service.[16] Third, as indicated in Table 3, these states' on-site inspections of tank facilities show a similarly high rate of compliance (between 91 and 95 percent)

[14] In fact, it is conceivable that reporting might increase after a state switches to commercial insurance, since private insurers provide financial incentives (premium discounts) for station owners to install more sophisticated leak detection systems and to use third-party leak-monitoring services.

[15] Sammy Ng, Director, Office of Underground Storage Tanks, EPA, e-mail correspondence, May 25, 2005; Mark Barolo, Deputy Director, Office of Underground Storage Tanks, EPA, e-mail correspondence, May 25, 2005.

[16] The EPA also maintains a national Underground Storage Tank Performance Measures database (http://www.epa.gov/oust/cat/camarchv.htm) of underground storage tanks and releases, based on data voluntarily supplied by state regulatory agencies. Couch and Young (2001, p. 18) report that this national database contains errors and inconsistencies for numerous states that are extensive enough to "compromise the validity of regression analyses performed on it." This shortcoming of the national data motivates our attention to three states that maintain higher quality data on tanks and release events.

Table 4
Facility Statistics and Trends by State

	Michigan	Illinois	Indiana
Vehicle-miles traveled, 1990 (billions)	81.1	83.3	53.7
Growth rate (%)	2	2	2
Active facilities, 1990	25,253	22,809	17,089
Growth rate (%)	−7	−7	−6
Average tanks per facility, 1990	2.8	2.7	2.4
Growth rate (%)	−.2	.8	−.4
Average tank capacity, 1990 (gallons)	4,428	4,732	4,248
Growth rate (%)	5	4	5
Median active tank age (years)			
1990	14	11	10
2003	16	13	13

Source. U.S. Department of Transportation (1990, table VM-2; 2003, table VM-2).
Note. Growth rates are average annual compound rates from 1990 to 2003. Tank-level attributes are means for active facilities.

with leak detection system installation requirements. Last, these neighboring states have similar climates, a contributing long-term factor to tank corrosion.

Two databases are maintained by each state's environmental protection and tank regulatory agencies. One is the tank database, which reports a tank's installation date, closure date (if applicable), facility, and location. The second database contains information on all reported releases in the state, including the facility, release date, and cleanup progress. A central feature of all three states' databases is that they retain information on tanks closed since 1986. Information on closed facilities allows us to avoid attrition and survivor biases that would otherwise confound measurement of release rate changes over time. In total, there are approximately 236,000 individual underground fuel storage tanks in the data.[17]

Our analysis of release rates is conducted at the facility level. Release data record only the facility at which a leak occurs, not which individual tank (if any) at the facility had a leak. This is a technological limitation: leak detection systems often do not distinguish which tank is leaking if several are located near the detector, and leaks can occur in piping systems rather than from a specific tank. The states that we examine began collecting comprehensive release data in 1990, after implementation of their assurance fund programs.

Table 4 summarizes facility attributes and trends by state. Michigan and Illinois are quite similar with respect to the number of facilities with underground fuel storage tanks, vehicle-miles traveled (an indicator of fuel storage demand), and most tank-level attributes. Indiana, which has two-thirds as many residents, has commensurately fewer facilities and vehicle-miles but similar tank-level attrib-

[17] The data (and state and federal tank insurance regulations) also cover underground fuel storage tanks at airports, railroad yards, car dealerships, municipal service lots, manufacturing plants, and other sites. Federal law excludes residential heating-oil tanks from financial responsibility regulations; they are not in our data.

utes. All three states exhibit similar growth rates (within 1 percentage point) on these dimensions over our 14-year study period. One noteworthy difference in Table 4 is that Michigan's tanks are slightly older than tanks in adjacent states. We return to this in Section 6.3.

A striking feature of the data is the dramatic facility exit rate in all three states. Sixty-five percent of the active facilities in Michigan in 1990 closed permanently over the following 14 years. Entry was slight over this period, resulting in a net facility exit rate of 61 percent from 1990 through 2003. Net exit rates are similarly high in Illinois and Indiana over the same period (61 and 56 percent, respectively). There was also a trend toward larger stations: the mean tank capacity of active facilities increased steadily over time, by 4–5 percent per year. These trends mirror the industry's view that only the most profitable, high-volume gas stations can cover the fixed cost of upgrading their tank systems to meet the regulatory requirements phased in during the 1990s.

5.2. Measuring Facilities' Release Risk

The empirical task is to measure how accidental release rates changed in Michigan relative to other states after Michigan's policy change. To do so, we compute two measures of accidental release risk. These two measures are distinguished by whether or not they condition on a facility's status. A facility's status is active if it has at least one active tank; otherwise, the facility is closed. We classify a tank as active from installation date until closure as recorded by state regulatory agencies.[18]

These distinctions are important because there are two margins on which a facility owner might respond to risk-based insurance pricing. One is to make capital investments and improve maintenance practices, as described in Section 2.2, that reduce the chance of a tank system leak. Such actions are not obligatory, however; a station owner might choose to pay higher insurance premiums and not undertake any risk-reducing activities. The second is that a station owner might opt to close a leak-prone facility entirely. This avoids the need for additional capital expenditures and/or higher insurance expenses after a state requires commercial insurance, and it will be preferred if these expenses are high relative to the station's profit stream.

Our data enable us to determine whether the policy shift to risk-based pricing affected only release rates at active facilities or whether it manifests primarily through the closure of facilities. To be precise, some notation is useful: let A_{ft} indicate if the status of facility f in year t is active and R_{ft} indicate if an accidental release occurs.[19] A state's total release rate in year t is $P(R_{ft})$, where the probability

[18] This definition mirrors regulatory practice: closure requires a tank to be removed from the ground (or rendered unusable in situ), an on-site assessment, and approval from a state tank regulatory agency to terminate insurance requirements. Tanks that are de facto unused but have not been officially closed are still subject to insurance, leak-monitoring, and leak-reporting requirements.

[19] The term R_{ft} indicates at least one release in year t. However, it is exceptionally rare for a facility to report more than one release in the same year.

P corresponds to drawing a facility at random from the population of all (active and closed) facilities in the state. A state's active release rate is $P(R_{ft} \mid A_{ft})$, the chance that an active facility has an accidental release. Because we observe the history of closures and releases at both active and closed facilities, we measure these rates directly from the data:

$$\hat{P}(R_{ft}) = \frac{\text{number of facilities with a release in year } t}{\text{total number of facilities}} \tag{1}$$

and

$$\hat{P}(R_{ft} \mid A_{ft}) = \frac{\text{number of active facilities with a release in year } t}{\text{number of active facilities in year } t}. \tag{2}$$

These two measures are related by Bayes's law, which implies

$$P(R_{ft}) = P(R_{ft}|A_{ft})P(A_{ft}) + P(R_{ft} \text{ and } {\sim}A_{ft}), \tag{3}$$

where ${\sim}A_{ft}$ indicates a nonactive (closed) facility. The last term on the right in equation (3) is nonzero but an order of magnitude smaller than the total release rate. (Newly discovered releases at closed facilities are rare but can occur if a site is retested before redevelopment.) As a result, changes in the total release rate $P(R_{ft})$ are overwhelmingly determined by changes in the active release rate, $P(R_{ft} \mid A_{ft})$, and active status rate, $P(A_{ft})$.

One implementation issue is to define the population of facilities, the denominator in equation (1). The databases that we employ contain reliable information for (that is, a census of) tanks in the ground after 1986, when reporting requirements for underground fuel tanks were first implemented (40 C.F.R. 280.22). In contrast, it is not possible to know (with any accuracy) how many tanks were removed in the 1970s or earlier. Cognizant of this, we define the total facility population as the set of facilities that were active at least once after 1986. According to this definition, if a facility was closed and had all its tanks removed before 1986, it is excluded from the population and from our analyses. This restriction is unlikely to materially affect our conclusions regarding the effects of risk-based insurance pricing, as a decision to close a facility before 1986 amply predates any of the tank regulations, insurance requirements, and state policies studied here.

One limitation of the data is that for some tanks we do not observe the installation year or, to a lesser extent, the closure year. Specifically, installation dates are missing for 14 percent of the tanks in Michigan, 53 percent in Illinois, and 64 percent in Indiana (see Table A1). While this does not impair measurement of the number of releases, it does complicate measurement of release rates. We address this issue using a stratification and imputation procedure. The basic idea is that if a particular tank closed in year s but its installation date is unrecorded, we set the tank's active-status indicator, A_{it}, $t < s$, equal to the relative frequency of active status among all tanks in the state that closed in the same year but have an observed installation date. This yields a time-varying estimated probability in place of the unobserved active or closed status of the tank. We use this probability to compute the facility-level active status counts in equation (2). The precise imputation procedure, which conditions on additional facility characteristics, is detailed in the Appendix.

This probabilistic imputation procedure rests on a conditional independence assumption: the conditional distribution of tanks' installation years in a state, given the observed closing year, is the same whether or not the installation year was recorded in the data. Some support for this assumption comes from discussions with state database administrators in Illinois, who indicated that a major reason for missing data is that the missed information "may not have been processed yet."[20] This suggests that missing installation dates (in Illinois) may well be random or at least unrelated to a tank's release propensity. However, in the Indiana data, it appears that observed installation and closure dates are for disproportionately newer tanks (installed from the 1990s onward). This does not affect the usefulness of the Indiana data on total releases, but it means that the data for Indiana relating to facility status and tank age should be interpreted cautiously. Overall, we place our primary emphasis on comparisons between Michigan and Illinois, with comparisons to Indiana serving as supplemental corroborative evidence.

6. Results

This section presents empirical evidence indicating that after the policy change to a private insurance market, overall release rates fell in Michigan by 20 percent more than in adjacent states. The data also suggest that after the change, tank owners in Michigan tended to take more care to prevent leaks than owners in Illinois or Indiana.

6.1. Changes in Total Release Rates

Table 5 summarizes the three states' average annual release rates before and after 1995, when Michigan switched to private insurance. It omits 1995 because Michigan's policy change took effect midyear (we present 1995 separately below).

The data indicate that, on an average annual basis, Michigan's total release rate fell from 6.51 to 2.56 per 100 facilities before versus after the policy change, a drop of 60.6 percent. By contrast, the total release rate in Illinois was lower initially and declined by less: 5.23 to 2.82 per 100 facilities, a reduction of 46.2 percent. The ratio of relative risk changes (60.6/46.2), known generally as the etiologic ratio, is 1.31. It indicates that Michigan's relative risk reduction exceeded that of Illinois by 31 percent. The relative risk reduction in Michigan exceeded that in Indiana by a similar amount, 24 percent.

Reductions in environmental risks should also be considered in absolute terms.

[20] Jan Spoor, database administrator, Illinois Office of State Fire Marshall, e-mail correspondence, May 19, 2005.

Table 5
Changes in Total Release Rates over Time, by State

	Releases per 100 Facilities		Absolute Risk Reduction		Relative Risk Reduction	
	Pretransition (1990–94)	Posttransition (1996–2003)	Post − Pre	Contrast with Michigan	Post versus Pre	Etiologic Ratio
Michigan	6.51	2.56	−3.95		−60.6	
	(.09)	(.06)	(.10)		(1.0)	
Illinois	5.23	2.82	−2.42	−1.53	−46.2	1.31
	(.09)	(.06)	(.11)	(.15)	(1.5)	(.05)
Indiana	3.62	1.84	−1.77	−2.18	−49.0	1.24
	(.09)	(.06)	(.11)	(.15)	(2.2)	(.06)

Note. Standard errors are in parentheses and assume a (symmetric) misclassification error rate of 5 percent. Relative risk reduction (RRR) is 100 × ($rate^{post}/rate^{pre}$ − 1). The etiologic ratio is $RRR^{MICH}/RRR^{OtherState}$.

On an average annual basis, Michigan's total release rate fell by 3.95 per 100 facilities after its policy change. In contrast, the total release rate in Illinois declined by only 2.42 per 100 facilities. The absolute risk reduction in Michigan exceeds that in Illinois by 1.53 (or 3.95 − 2.42) releases per 100 facilities, which is 23 percent of Michigan's initial (1990–94) average annual release rate.

Is a reduction of 1.53 releases per 100 facilities economically significant? Yes. The number of facilities in Michigan after its policy change averages approximately 26,000 (see Section 6.2). An annual reduction of 1.53 releases per 100 facilities corresponds to about 400 fewer accidental releases per year and approximately 3,200 fewer releases over our 8-year posttransition study period. Table 5 also indicates that Michigan's excess absolute risk reduction (the difference in differences) is even greater than that of Indiana. Taken together, these data suggest that Michigan had some 3,000–4,000 fewer underground tank leaks over the 8 years following its policy change than the number predicted by neighboring states' experience over the same period. Given an average cleanup cost of $125,000 per release (Government Accounting Office 2007), this represents an aggregate cleanup cost savings for Michigan that is on the order of $400 million over 8 years.

Figure 1 shows the annual differences in total release rates for Michigan and Illinois. The greater drop in Michigan's pre- versus posttransition release rate, relative to the change in Illinois's rate, is not driven by the data for any one particular year. Michigan's total release rate was consistently higher than that of Illinois through 1995. The difference in release rates decreases in 1996, after Michigan requires private insurance. (A decrease is also observed in 1993, the year of the federal deadline to install or upgrade leak detection at grandfathered facilities. All states' release rates decreased that year, Michigan's slightly more than the others.) After Michigan's policy change in 1995, its release rate not only falls relative to that of Illinois but is actually lower than the rate in Illinois most years thereafter.

Are these differences statistically significant? Since we have a census of the

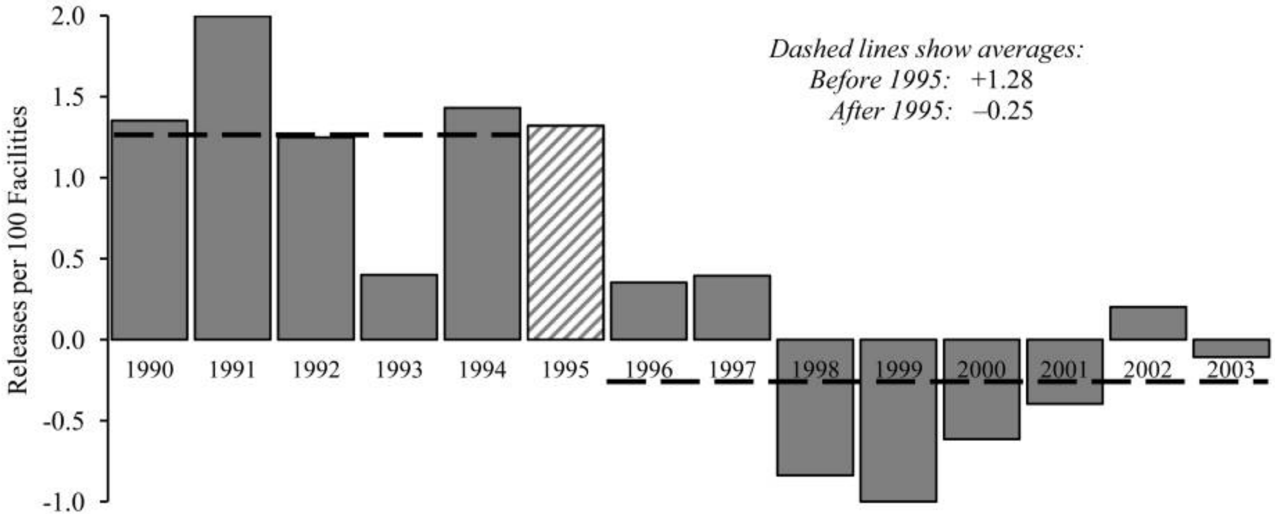

Figure 1. Differences in overall release rates, 1990–2003: Michigan – Illinois

facilities in each state, the principal source of error is likely misclassification or mismeasurement. If binary outcomes are recorded with misclassification errors, the standard error (of the mean) is a concave function of the misclassification probability. For our sample sizes, the former is bounded above by approximately .0014. (This assumes independent errors across facilities.) That means that even with extraordinary measurement error in recording release events—say, a 50 percent error rate—differences in observed release rates larger than about .3 per 100 facilities are statistically significant. In administrative data like these, misclassification rates of 50 percent stretch credulity; the standard errors that we report in Table 5 are based on a lower misclassification rate of 5 percent. Adjusting for within-facility correlation in release events over time (that is, clustering on facility) yields de minimus changes in the standard errors, as few facilities have more than one release during the 14-year span of our data.

6.2. Mechanisms

Why did accidental release rates decrease more in Michigan than in neighboring states after 1995? Conceptually, it is useful to distinguish among three possible mechanisms.

1. Because releases at closed facilities are rare, shifting facilities from active to closed status tends to reduce a state's overall release rate. A greater facility closure rate in Michigan—for any reason—tends to reduce its total release rate more than that of neighboring states.
2. There is greater selective attrition of the most leak-prone facilities into closed status in Michigan than in adjacent states. Note that selective attrition may reduce release rates in Michigan more than in other states, even if overall facility exit rates are similar—that is, even if explanation 1 does not hold.
3. There is greater risk-reducing effort at active (surviving) facilities in Michigan than in adjacent states. Tangibly, this means replacing or relining older tanks, improving maintenance practices, installing anticorrosion equipment, and similar activities after Michigan's insurance policy change.

Explanation 1 is potentially problematic for conclusions about the role of insurance pricing. Conceivably, high closure rates for gas stations during the 1990s could have come about for a number of reasons unrelated to insurance reform: adverse demand conditions, the federal tank system technical standards phased in during the 1990s (see Section 3.2), the industry's trend to replace smaller stations with larger facilities that have convenience stores, and so on. These pose a potential concern if they resulted in higher facility closure rates in Michigan than in comparison states after 1995. We consider this possibility in light of the data next and explanations 2 and 3 subsequently.

6.3. Facility Closings

Figure 2 displays the total numbers of facilities and active facilities from 1986 to 2003 in Michigan and Illinois. A state's total number and active number of

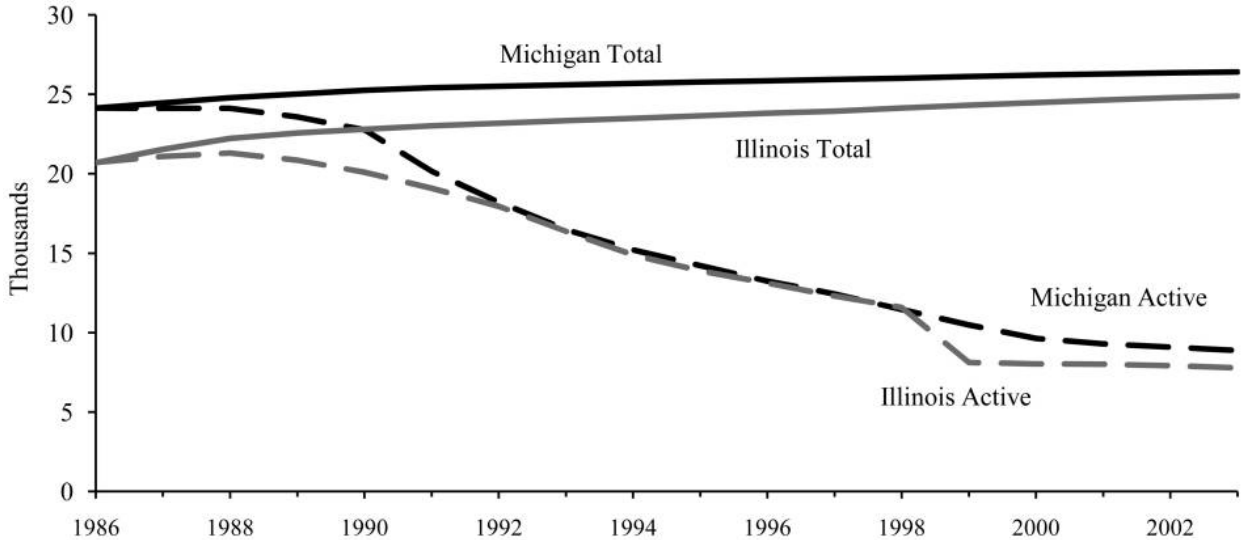

Figure 2. Facilities in Illinois and Michigan, 1986–2003

facilities are the same in 1986, when record-keeping requirements began. In both states, the total number of facilities grew incrementally over time because of modest de novo entry by new gasoline stations. However, the number of active facilities plummeted in both states. The decline in Indiana's active facilities is substantively the same (see Table 2).

Figure 2 reveals several important points. First, the decline in the number of active facilities commenced in 1988–89, when the EPA issued its final regulations regarding financial responsibility requirements (effective in 1988) and tank technical requirements (effective a decade later, in 1998, for existing facilities.) Second, there is an abrupt drop in the number of active facilities in Illinois (and in Indiana) in 1999, the year that grandfathering of existing facilities ended. We do not observe an abrupt decline in Michigan at the same time, which indicates that most of its grandfathered facilities had either exited or been upgraded by then. Third, there is a slightly greater rate of de novo entry in Illinois than in Michigan. Since newly installed tanks are unlikely to corrode, this difference in entry rates should tend to reduce the overall release rates in Illinois relative to Michigan over time. That is, the difference in new entry rates does not help account for Michigan's greater drop in release rates; it makes Michigan's greater decline more remarkable.

Last, and perhaps most important, there is little evidence that closure rates in Michigan exceeded those in Illinois. From 1990 to 2003, the proportion of facilities that were active—that is, $\hat{P}(A_{ft})$ in equation (3)—declined by essentially identical amounts in both states: 56 percentage points (from .90 to .34) in Michigan and 57 percentage points (from .88 to .31) in Illinois. The proportion of active facilities decreased 59 percentage points (from .97 to .38) in Indiana over the same period, nearly the same as in Michigan.

These data support two intermediate conclusions: the net exit of stations in Michigan over time was not induced by that state's private-market insurance requirement in 1995, and the difference in absolute risk reduction between Michigan and its neighbors is not attributable to a greater rate of facility closure over time in Michigan. The second implication is important, as it argues against the possibility that there exist confounding factors—that is, something other than insurance reform—that caused different changes in release rates between states by inducing different facility closure rates.

It is (perhaps) puzzling that Michigan's overall closure rate from 1996 to 2003 is essentially the same as in Illinois and Indiana. After all, the cost of operating a facility in Michigan rose in mid-1995; why was there not greater exit after a cost shock? The likely explanation lies in the magnitudes. Gasoline retailing entails an up-front sunk cost (upward of \$100,000–\$200,000 for initial site acquisition and development), which owners expect to recoup on annual gross margins. Insurance cost increases of \$1,000–\$3,000 annually (Table 2) are too small to make this expected annual gross margin negative and so are unlikely to induce exit among compliant facilities.

Of course, the cost of commercial insurance for older, noncompliant facilities could be substantially higher (if available at all; see note 11). That might drive out marginally profitable noncompliant establishments and induce more profitable ones to accelerate replacement of leak-prone tanks to reduce their insurance premiums. This may explain why Michigan's exit rate declines steadily over 1995–99, as shown in Figure 2, but Illinois exhibits an abrupt drop in the number of active facilities in 1999. Both states' noncompliant facilities could not operate after the federal grandfathering provision expired in 1998 (without costly upgrades), but in Illinois there was less incentive to close a noncompliant facility before 1998.

6.4. Changes in Active Release Rates

Explanations 2 and 3 in Section 6.2 point to the possibility of changes in release rates at active facilities as a result of insurance reform. Table 6 summarizes each state's active facility release rate, or $\hat{P}(R_{ft}|\ A_{ft} = 1)$ in equation (2). Note that this is not a fixed set of establishments; the number of active facilities declines steadily over time (Figure 2).

After 1995, Michigan's active release rate falls by 3 percentage points. By contrast, Illinois' release rate declines by slightly more than 1 percentage point, and Indiana's falls by less than 1. The excess absolute risk reduction among active facilities in Michigan versus Illinois is 1.78 per 100 facilities, and 2.09 per 100 facilities compared to Indiana.

Changes in active facility release rates and total release rates are mechanically related: a greater decline in Michigan's total release rate compared to other states implies a greater decline in its active facility release rate, and vice versa. (This follows from equation [1] and two facts: facility closure rates are similar in Michigan and Illinois [Table 4 and Figure 2], and changes in releases at closed facilities are negligible.)[21] Thus, the information content in Table 6 lies primarily in its interpretation.

Because the set of active facilities declines steadily over time in each state, changes in active-facility release rates may arise from two conceptually different mechanisms. The first is direct risk-reducing effort at facilities that continue to operate (explanation 3 in Section 6.2), which involves investment in risk-reducing technologies and their maintenance. Alternatively (or in combination), selective attrition of the most leak-prone active facilities over time would result in a progressively lower risk set of surviving active facilities. Note that the latter mechanism would reduce active release rates, as measured in Table 6, even if firms made no effort to reduce release risks at ongoing establishments.

[21] In the data, the release rate at closed facilities in Michigan during 1990–94 is .0027, and during 1996–2003 it is .0018, a decrease of nine releases for every 10,000 closed facilities. The decrease in the release rate at closed facilities in Illinois is less than one release per 10,000 closed facilities, and there is a small increase for Indiana of nine releases for every 10,000 closed facilities. For all three states, the changes in release rates at closed facilities are 2 orders of magnitude smaller than the changes in the total and active release rates, which is far too small to explain the overall decline in either.

Table 6
Changes in Active Facility Release Rates over Time, by State

	Releases per 100 Facilities		Absolute Risk Reduction		Relative Risk Reduction	
	Pretransition (1990–94)	Posttransition (1996–2003)	Post − Pre	Contrast with Michigan	Post versus Pre	Etiologic Ratio
Michigan	8.81	5.78	−3.03		−34.4	
	(.11)	(.10)	(.15)		(1.4)	
Illinois	5.74	4.48	−1.25	−1.78	−21.8	1.58
	(.10)	(.10)	(.14)	(.21)	(2.3)	(.18)
Indiana	4.20	3.26	−.95	−2.09	−22.5	1.53
	(.10)	(.10)	(.14)	(.20)	(3.0)	(.21)

Note. Standard errors are in parentheses and assume a (symmetric) misclassification error rate of 5 percent. Relative risk reduction (RRR) is 100 × ($rate^{post}/rate^{pre}$ − 1). The etiologic ratio is $RRR^{MICH}/RRR^{OtherState}$.

Which of these mechanisms accounts for the larger reduction in release rates in Michigan, relative to those in other states, after its policy change? Ideally, the most compelling data to address this question are information on facility-level investments in specific risk-reducing technologies (such as corrosion protection equipment, tank relinings, maintenance logs showing more frequent pressure testing, and so on) before and after 1995. To our knowledge, such data have not been systematically collected, and it is far from clear that they could be assembled reliably in retrospect. Nevertheless, we can draw useful inferences about whether these activities must have occurred by examining surviving and attriting facilities separately.

6.5. Continuously Operated Facilities

The majority of the facilities that were active at the end of our study period were active since (at least) 1990. Table 7 summarizes the average annual release rates for these continuously operated facilities.[22] The average annual release rate in Michigan decreases by 4.57 releases per 100 facilities after 1995. In contrast, the rate in Illinois falls by about half as much. The situation in Indiana is similar to that in Illinois. In both absolute and relative terms, the reduction in Michigan's release risk exceeds that in Illinois and Indiana. These magnitudes are substantial, greater than the excess absolute risk reduction and etiologic ratios for facilities overall (Table 5).[23]

The facilities in Table 7 are unlikely to be representative of all facilities, as surviving facilities are apt to be more profitable than average. Still, these facilities operated underground fuel storage tanks in the same location, with the original

[22] Tables 7 and 8 omit facilities operating in 2004 for which operational status in 1990 is unknown because of missing data for year of tank installation. Similar calculations (omitted) treating these facilities as continuously operated do not materially change these results. Information on the prevalence of missing installation dates is provided in Table A1.

[23] The decline in absolute release rates at continuously operated facilities in Indiana and Illinois (presumably) results from periodic replacement of old tanks with new tanks, since new tanks are constructed to higher leak-prevention standards (see Section 3.1).

Table 7

Changes in Total Release Rates at Continuously Operated Facilities, 1990–2003

	Releases per 100 Facilities		Absolute Risk Reduction		Relative Risk Reduction	
	Pretransition (1990–94)	Posttransition (1996–2003)	Post – Pre	Contrast with Michigan	Post versus Pre	Etiologic Ratio
Michigan (N = 6,985)	8.08	3.51	−4.57		−56.6	
	(.18)	(.12)	(.21)		(1.7)	
Illinois (N = 4,103)	6.27	3.72	−2.55	−2.02	−40.6	1.39
	(.22)	(.15)	(.26)	(.34)	(3.2)	(.12)
Indiana (N = 2,606)	6.04	3.84	−2.20	−2.37	−36.4	1.55
	(.27)	(.19)	(.33)	(.42)	(4.3)	(.19)

Note. Standard errors are in parentheses and assume a (symmetric) misclassification error rate of 5 percent. Relative risk reduction (RRR) is 100 × ($rate^{post}/rate^{pre}$ − 1). The etiologic ratio is $RRR^{MICH}/RRR^{OtherState}$.

Table 8
Tanks in Service at Continuously Operated Facilities, 1990–2003

	Michigan	Illinois	Indiana	Michigan/ Illinois	Michigan/ Indiana
Active tanks per facility:					
Pretransition (1990–94)	3.6	2.9	3.0	1.2	1.2
Posttransition (1996–2003)	3.1	2.9	3.1	1.1	1.0
Change (%)	−16	−1	3	−15	−18
Active tanks >20 years old per facility:					
Pretransition (1990–94)	1.0	.5	.6	1.9	1.7
Posttransition (1996–2003)	1.0	.7	.7	1.5	1.5
Change (%)	0	31	15	−23	−13

Note. Values are annual averages. Ratios are calculated before rounding.

or replacement tanks and equipment, for many years before and after Michigan's policy change. That leaves three possible explanations for Michigan's substantially greater decline in release rates among these states' continuously operated facilities:

1. greater direct risk-reducing activity among facilities in Michigan, whether through closing or replacing old tanks, relining existing tanks, improving maintenance practices, or making similar efforts,
2. greater nondisclosure of releases in Michigan after 1995, financial penalties and insurer monitoring efforts notwithstanding, or
3. a change in the rate at which steel tanks corrode underground in Michigan relative to other Midwest states, for other reasons.

Additional evidence favors explanation 1, as noted presently. Although we cannot completely rule out explanation 2, we find it difficult to support for the reasons discussed in Section 4.3: the facilities in Table 7 are long-term operators at (presumably) profitable locations and therefore should have high opportunity costs of violating release-reporting laws—including significant civil penalties and potential denial of insurance coverage. We can identify no evidence (or reason) to support explanation 3, which would seem to require a heretofore undocumented change in Michigan's geology—and in the same year as its insurance reform.

As for explanation 1, some supporting (if limited) evidence is apparent at the tank level. Table 8 shows that after 1995, the number of tanks in service at continuously operated facilities in Michigan decreased 16 percent. In contrast, the corresponding changes are close to zero in Illinois and Indiana. Continuously operated facilities in Michigan thus reduced the number of tanks in service, in absolute number and relative to adjacent states—as one would expect after their tank insurance costs increased.

More pointedly, Table 8 shows the number of older tanks in service (per facility) at continuously operated facilities. Prior to 1995, facilities in Michigan had nearly twice as many tanks over 20 years old in service (per facility) than Illinois. Michigan had 70 percent more older tanks than Indiana. The greater prevalence of older tanks in service helps explain Michigan's higher initial release rate (Tables 5–7). After 1995, this ratio declines by 23 percent relative to Illinois and by 13 percent relative to Indiana. In sum, after Michigan's policy change the continuously operated facilities in Michigan closed not only more tanks overall but disproportionately more of their older—and ostensibly more leak prone—tanks than Illinois and Indiana.[24]

Interestingly, the proportion of active tanks more than 20 years old increased in both Illinois and Indiana, but not in Michigan. This is consistent with increases in new-tank installation costs during the 1990s (see Section 3.1) and the limited incentive to replace old tanks under a public insurance system, relative to the incentive to replace old tanks under the commercial insurance system adopted in Michigan in 1995. Regarding the latter, some simple calculations are informative. Consider a commercially insured three-tank facility, which is the modal size, with tanks that are 25 years old. The data in Table 1 indicate that replacing the tanks now—instead of 1 year hence—reduces the facility's insurance premium by $3,300 this year ($1,380 − $284 = $1,096 per tank). With 30-year-old tanks, the savings exceed $4,200. For a continuously operating facility, accelerating the tank system's replacement to capture this benefit also entails a cost, which is primarily the forgone interest on the nondeferred capital expense. That can run several thousand dollars, but this cost is independent of the insurance system.[25] Thus, the insurance savings benefit creates an economic incentive for commercially insured tank owners to replace their aging, potentially leak-prone tanks proactively—perhaps after as little as 20–25 years of service. Publicly insured owners face no similar incentive for precautionary behavior.

6.6. Selective Facility Attrition

The foregoing leaves open the possibility that part of Michigan's greater overall risk reduction is due to selective facility attrition. In precise terms, selective attrition means facilities that ultimately closed in Michigan were more leak prone (prior to closure) than facilities that closed in Illinois or Indiana:

[24] There are two reasons that accidental releases are concentrated among older tanks. First, corrosion takes time (years) to develop. Second, regulatory changes after 1989 required new tanks to meet higher leak resistance standards. This means that there is a pure vintage effect that results in most leaks occurring at older tank installations. On these points, the engineering literature is unequivocal: a detailed study of the causes of accidental tank leaks at several hundred facilities in California indicated that more than 75 percent of all leaks occurred in tanks (or piping systems) more than 15 years old (Couch and Young 2001). An independent study conducted for the Michigan Department of Natural Resources (1995) reached similar conclusions, finding that tanks more than 20 years old or of unknown age accounted for a disproportionate 64 percent of accidental tank releases.

[25] The capital expense of removing and replacing tanks can vary widely with location and site conditions; replacement timing is also sensitive to interest rates and leverage. For reasonable assumptions ($100,000 project cost, 80 percent financed at 15 percent per annum via a 10-year term commercial construction loan, a 3 percent per annum project inflation cost, and a 5 percent per annum discount rate), the owner's opportunity cost of accelerating tank replacement by 1 year is approximately $2,700. The age-rated premiums in Table 1 imply that a facility owner's commercial insurance savings from replacing a (single-walled) tank system exceed the gain from deferral if the tanks are 20 years old or older.

Table 9
Release Rates at Attriting Facilities

Rate	Michigan	Illinois	Indiana	Michigan/ Illinois	Michigan/ Indiana
Overall (1990–2003)	18.11	10.07	13.67	1.8	1.3
Pretransition (1990–94)	9.89	5.86	5.37	1.7	1.8
Posttransition (1996–2003)	24.25	13.41	19.59	1.8	1.2

Note. Values are annual averages for facilities closed by 2004. Release rates are per 100 active facilities.

$$P_{\text{MICH}}(R_{ft}|A_{ft},\ {\sim}A_{f,2004}) > P_{\text{OtherState}}(R_{ft}|A_{ft},\ {\sim}A_{f,2004}),\quad t < 2004. \tag{4}$$

Table 9 tabulates empirical frequencies that address expression (4). It reveals that the facilities that ultimately closed in Michigan had significantly higher historical release rates: more than 6 percentage points higher than those in Illinois and 4.5 percentage points higher than those in Indiana.

Note that these frequencies do not say how much selective attrition contributed to the overall absolute risk reduction in Table 5. For this we require a more detailed decomposition of the relative magnitudes.[26]

In principle, we can decompose a state's absolute risk reduction into the release rate changes at continuously operated facilities (stayers), facilities that ultimately close (attritants), and new facilities (entrants), as weighted by their population shares (s^{s}, s^{a}, and s^{e}, respectively):

$$\begin{aligned}\Delta P(R_{ft}) = {} & s^{\text{s}} \times \Delta P(R_{ft}|\text{stayer}) \\ & + s^{\text{a}} \times \Delta P(R_{ft}|\text{attritant}) + s^{\text{e}} \times \Delta P(R_{ft}|\text{entrant}).\end{aligned} \tag{5}$$

In this calculation, groups and population shares are time invariant: only the conditional release rates are changing over time. (Population shares are defined as a proportion of cumulative births through 2003.) The term $\Delta P(R_{ft})$ in equation (5) is the change in a state's total release rate from Table 5 (third column).

A few simple calculations imply that selective attrition accounts for at least half of Michigan's excess absolute risk reduction over adjacent states. Empirically, the last term in equation (5) is negligible: there are few entrants, and their release rates do not change much. The stayer share is $s^{\text{s}} \approx \frac{1}{3}$ in each state (Figure 2 at 2003), and Table 7 reports results for $\Delta P(R_{ft} \mid \text{stayer})$. It declines by 4.6 in Michigan versus 2.5 and 2.2 in Illinois and Indiana (per 100 facilities), respectively. Thus, the first term on the right in equation (5) accounts for an excess absolute risk reduction in Michigan over Illinois of about $\frac{1}{3} \times (4.6 - 2.5) = .7$ per 100 facilities, which is half of Michigan's excess absolute risk reduction (Table 5).

[26] We also estimated survival curves for each state, with generally uninformative results. On theoretical grounds, the usefulness of survival modeling in this context is questionable: standard models assume that transition probabilities vary with time at risk but are invariant with respect to calendar time. This stationarity assumption does not hold here (because of vintage effects and changing tank technical standards), which renders it unclear what distribution standard survival curves are estimating.

Table 10
Decomposition of Absolute Risk Reduction by Facility Duration Status, 1990–2003

	All	Attritants	Stayers	Entrants	Unknown
Absolute risk reduction:[a]					
Michigan	−3.95	−4.63	−4.57	.31	−2.98
Illinois	−2.42	−3.19	−2.55	.06	−1.18
Indiana	−1.77	−1.70	−2.20	.17	−2.49
Contribution of each group:[b]					
Michigan	−3.95	−2.70	−1.21	.01	−.05
Illinois	−2.42	−1.91	−.42	.00	−.08
Indiana	−1.77	−1.03	−.30	.01	−.43
Share of excess absolute risk reduction (%):					
Michigan − Illinois		51	51	−1	−2
Michigan − Indiana		76	42	0	−17

Note. Unknown facilities are those operational in 2004 that cannot be definitively classified as entrants or as stayers from 1990 to 2003 because of missing installation year data. These facilities include 2 percent (Michigan), 7 percent (Illinois), and 17 percent (Indiana) of each state's total (active and closed) facilities.
[a] Conditional release rate changes $\Delta P(R_{ft} \mid \text{group})$.
[b] Share-weighted changes $s^{\text{group}} \times \Delta P(R_{ft} \mid \text{group})$.

The remaining half is attributable to a greater reduction in release rates at attriting facilities.

Table 10 steps through the detailed calculations. We include an additional group of unknown facilities that are operational in 2004 but have missing entry or installation dates (and thus cannot be unambiguously categorized as entrants or stayers). The declines in absolute risk reductions are broadly similar for both attritants and stayers, although there is some variation between states.

The attritants' conditional release rates in the first three rows of Table 10 are decreasing (negative absolute risk reductions), yet in Table 9 they are increasing over time. They measure different things: Table 9 estimates $P(R_{ft} \mid A_{ft}, \sim A_{f,2004})$, while Table 10 shows changes in $P(R_{ft} \mid \sim A_{f,2004})$. Empirically,

$$P(R_{ft} \mid \sim A_{f,2004}) = \alpha_t P(R_{ft} | A_{ft}, \sim A_{f,2004}) + \text{negligible terms},$$

where α_t is the proportion of facilities closing by 2004 that are still active at $t < 2004$. Over time, α_t decreases faster than $P(R_{ft} \mid A_{ft}, \sim A_{f,2004})$ rises, and particularly faster in Michigan. Michigan shuttered its comparatively more leak-prone facilities faster after 1995 than adjacent states—which results in its greater post-transition risk reduction among attritants.

The central panel of Table 10 presents each group's conditional release rate reduction weighted by its population share, corresponding to the product's terms on the right-hand side in equation (5). The share-weighted reduction in the attritants' release rates exceeds that of the continuously operated facilities for each state and by a factor of 2 or more. This is not unexpected insofar as approximately two-thirds of all facilities are attritants (Figure 2).

In Table 10, the bottom two rows show the result of subtracting each group's contribution and expressing the difference as a percentage of Michigan's overall excess risk reduction. This reveals that half of Michigan's excess absolute risk reduction over Illinois is attributable to the greater risk reduction at continuously operated facilities in Table 7. The balance is attributable to the fact that facilities that ultimately closed in Michigan had higher historical release rates than did closing facilities in Illinois. The proportions for Indiana are somewhat greater for attritants and smaller for stayers. (Combining Indiana's "unknown" group with the stayers they may represent reduces the stayers' contribution to about one-quarter). As noted earlier, we view the comparisons to Indiana as generally indicative, but less reliable, than results based on the higher quality data from Illinois and Michigan.

We conclude that not only did ongoing establishments make greater risk-reducing efforts in Michigan than in other states after 1995, but tank owners in Michigan tended to permanently close facilities that had a higher propensity to leak. Note that this second selective-attrition mechanism is not based on overall facility closure rates, which the data indicate were similar in each state (Section 6.3). Rather, it attributes part of the differential change in total release rates between Michigan and neighboring states to which facilities were closed. Greater sorting of leak-prone tanks into closure in Michigan than in neighboring states seems to be a particularly plausible result of the switch to private-market insurance, since tank attributes that predict future accidental releases (such as tank age) are a major determinant of commercial insurance premiums.

7. Conclusions

This study shows that after Michigan's transition to private-market environmental liability insurance, overall accidental release rates from underground fuel storage tank systems declined by more than 20 percent, or by about 1.5 releases per 100 facilities, more than in adjacent states. This is a substantial change, amounting to 3,000–4,000 fewer accidental releases over the following 8-year period. At an average cleanup cost of approximately $125,000 per release, this corresponds to aggregate avoided cleanup costs exceeding $400 million in that state. Those are the direct costs of cleaning up affected sites and do not include business interruption costs associated with cleanup activities. More important, it also excludes the cost of any adverse health effects resulting from contaminated water supplies. This is not because the public health consequences are apt to be negligible but because studies of their magnitude remain few and their representativeness is highly uncertain (see Jenkins, Kopits, and Simpson 2006).[27]

Are Michigan's policy change and the adoption of risk-based insurance pricing the only causes of Michigan's greater decline in accidental release rates? We believe that the best case, and one that may be particularly valuable given the

[27] Simons, Bowen, and Sementeilli (1999) estimate that a leaking (commercial) underground storage tank reduces the price of residential property within 1 block by 17 percent and reduces the price of commercial property by 28–42 percent. Their study uses detailed data for 10 leaking gas station sites in one Ohio county.

policy implications, would be achieved by replication of these findings elsewhere. Specifically, nine states have since followed Michigan's lead in closing their state fund assurance programs to new claims.[28] Since federal financial responsibility requirements are obligatory, this forces tank system owners to switch to commercial environmental liability contracts like those in Michigan. If the main findings that we report are confirmed independently for other states undertaking similar insurance reforms, the policy ramifications would be compelling.

With the desirability of replication in mind, we proffer these policy ramifications. According to the *State Financial Assurance Funds Survey* (ASTSWMO 2007), eight states' underground storage tank financial assurance funds are insolvent, with outstanding liabilities totaling $2 billion. Moreover, the EPA estimates that 6,300 new underground fuel tank releases occur annually (EPA 2010, p. 5). Adopting risk-based pricing structures similar to those studied here may reduce the frequency of accidental releases and alleviate these ongoing solvency crises. The potential is significant: a 20 percent reduction in release rates nationally would reduce future cleanup expenses on the order of $1.5 billion over the next decade.

We would be remiss not to observe parallels with other government assurance programs, such as deposit insurance and pension benefit guaranty programs. The fact that these programs are commonly subsidized with general tax revenue and exclude risk-based pricing mechanisms can lead to two adverse outcomes. First, moral hazard becomes a prominent concern. With pension benefit guaranty funds, for example, Cooper and Ross (1999) argue that unions and firms may have an incentive to agree to more lucrative employee retirement benefit packages if the government will cover pension liabilities in the event of bankruptcy. Similarly, banks and other financial intermediaries may take greater financial risks than they would be willing to hold in the absence of federal deposit insurance (see Kareken and Wallace 1978; Wheelock and Wilson 1995; but see Akerlof and Romer 1993).[29] The second shortcoming is that because participation in government assurance programs is usually subsidized, its existence may preclude the development of private insurance markets that may identify more efficient risk-reduction practices.

Several related questions remain for future research. First, this paper focuses on an ex ante moral hazard problem, that is, whether a tank owner takes extra risk-reduction efforts in response to risk-based pricing. There is also an ex post moral hazard problem wherein a tank system owner has an incentive to exaggerate losses when making an insurance claim. Since a small but significant share

[28] These states (and assurance fund discontinuation dates) are Wisconsin (1996), Texas (1998), Florida (1999), West Virginia (2000), Iowa (2000), Delaware (2001), Alaska (2004), Arizona (2006), and Maryland (2007).

[29] One early policy change proposed to address moral hazard in this setting was to condition federal deposit insurance premiums (paid by banks) on a measure of portfolio risk (Meltzer 1967). According to this principle, the 1991 Federal Deposit Insurance Corporation Improvement Act (Pub. L. No. 102–242, 105 Stat. 2236 [1991]) required the Federal Deposit Insurance Corporation to implement a system in which each bank's premium reflects the risk it poses to the insurance fund.

of tank systems are self-insured under the private-market regime but few to none are self-insured if a state assurance fund is available, it would be useful to determine whether the ex post moral hazard problem is more severe with government assurance funds.

Last, there are hybrid public-private reinsurance arrangements. For example, the state of Washington offers state-financed reinsurance at below-market prices to commercial tank insurers. The commercial insurers are required to pass this discount on to tank system owners. It would be desirable to know whether this public-private system is as effective at reducing risk as the private insurance market studied here.

Appendix

Installation and Closure Dates

This appendix summarizes the methods that we employ to address missing data on tank and facility installation and closure dates. Missing transition dates affect the calculation of release rates in equations (1) and (2) and the number of facilities and active facilities reported in Figure 2. Table A1 indicates the extent of missing installation and closure dates for each state. In general, if a tank's status (active or closed) is unknown, we estimate it with a probability of being active that varies by tank and by year.

A1. Number of Active Facilities

To determine the number of active facilities, let i index tanks and f index facilities. A tank is active between its installation year I_i and closure year C_i, inclusive:

$$T_{it} = \begin{cases} 1 & \text{if } I_i \leqslant t \leqslant C_i \\ 0 & \text{otherwise.} \end{cases}$$

A facility is active at t if it has at least one active tank:

$$A_{ft} = \begin{cases} 1 & \text{if } \max_{i\,\text{at}\,f}\{T_{it}\} = 1 \\ 0 & \text{otherwise.} \end{cases}$$

Figure 2 reports an estimate of

$$\text{total number of active facilities in year } t = \sum_f A_{ft}. \quad \text{(A1)}$$

Difficulties arise if either I_i or C_i is unobserved for a tank at facility f. For such facilities, we first estimate

$$\begin{aligned} \hat{A}_{ft} &= P(A_{ft} = 1|\Omega_f) \\ &= P(\max_{i\,\text{at}\,f}\{T_{it}\} = 1 \mid \Omega_f), \end{aligned}$$

Table A1
Prevalence of Missing Tank Installation and Closure Dates

	Michigan		Illinois		Indiana	
	N	%	*N*	%	*N*	%
Tanks active in 2004	24,002	27	20,125	24	16,537	30
Known installation date	22,582	25	16,499	19	10,728	19
Missing installation date	989	1	3,626	4	5,809	10
Tanks closed before 2004	66,006	73	65,201	76	39,518	71
Known installation and closure date	53,485	59	20,035	23	8,762	16
Known installation, missing closure date	32	0	3,909	5	398	1
Missing installation, known closure date	11,404	13	23,514	28	14,158	25
Missing installation and closure date	2	0	17,743	21	16,200	29
Observations	90,008	100	85,326	100	56,055	100

Note. Status in 2004 (active or closed) is known for all tanks. Data exclude tanks at facilities permanently closed before 1986, when reporting requirements commenced. Percentages may not total 100.0 because of independent rounding.

where Ω_f denotes information available to us about facility *f*. We then replace A_{ft} with $\hat{A}_{ft}$ in equation (A1).

A2. Estimating Active Status

For estimation of active status, let $i = 1, 2, \ldots, n_f$ be an (arbitrary) enumeration of all tanks, both active and closed, at facility *f*. Then

$$\hat{A}_{ft} = 1 - P(T_{1t} = 0,\ T_{2t} = 0, \ldots, T_{n_f t} = 0|\Omega_f)$$

$$= 1 - \prod_{i=2}^{n_f} P(T_{it} = 0|T_{i-1,t} = 0, \ldots, T_{1t} = 0,\ \Omega_f)$$

$$\times\ P(T_{1t} = 0|\Omega_f).$$

When T_{it} is unobserved, we estimate its conditional probability using a stratified matching procedure. Let $\mathcal{T}_{-it}$ be the event that all tanks with an index less than *i* are inactive at facility *f*, or

$$\mathcal{T}_{-it} = \{T_{i-1,t} = 0,\ T_{i-2,t} = 0, \ldots, T_{1t} = 0\}.$$

(If $i = 1$, let $\mathcal{T}_{-it} = \emptyset$.) For notational convenience, set

$$p_{it} = P(T_{it} = 0|\mathcal{T}_{-it}, \Omega_f)$$

so $\hat{A}_{ft} = 1 - p_{1t}p_{2t} \ldots p_{n_f t}$. To estimate an unobserved facility's status $\hat{A}_{ft}$, we require (an estimate of) p_{it} for each tank. Here, *t* runs from 1990 to 2003, in annual periods.

In the data, we observe every tank's current (as of 2004) status. (Current status, which matters for enforcement purposes, is recorded in the data even if the installation and, if applicable, closure years are missing.) This implies that if I_i is recorded and either C_i is recorded or $C_i > 2004$ (a right-censored survival time), then p_{it} is known and either zero or one, a degenerate case:

Case 0. If I_i is observed, and either C_i is observed or $C_i > 2004$ (right censored), then

$$p_{it} = \begin{cases} 0 & \text{if } I_i \leqslant t \leqslant \min\{C_i, 2004\} \\ 1 & \text{otherwise.} \end{cases}$$

If a tank's status is not directly observable, then it must be estimated, and one of four mutually exclusive cases applies:

Case 1. If I_i is unobserved and C_i is observed (this implies that $C_i \leqslant 2004$), then

$$p_{it} = P(T_{it} = 0 | I_i \text{ unobserved}, C_i, n_f, \mathcal{T}_{-it})$$

$$= \begin{cases} P(I_i > t | I_i \text{ unobserved}, C_i, n_f, \mathcal{T}_{-it}), & t \leq C_i \\ 1, & t > C_i, \end{cases}$$

which we estimate with

$$\hat{p}_{it} = \begin{cases} \hat{F}(I_i > t \mid I_i \text{ observed}, C_i, n_f, \mathcal{T}_{-it}), & t \leqslant C_i \\ 1, & t > C_i, \end{cases}$$

where $\hat{F}(Y \mid X)$ denotes the observed relative frequency of tanks with attribute Y in set X. Thus, if tank i at (say) a three-tank facility has an observed closing year C_i but an unknown installation date, then we estimate i's probability of active status in year t with the observed relative frequency of active status for the ith tank at all three-tank facilities in which tank i's installation year is known, tank i's closure year is the same (C_i), and tanks 1 through $(i - 1)$ are known to be inactive in year t.

When a tank's closing date is unknown, the generalization is straightforward:

Case 2. If I_i is unobserved and $C_i > 2004$ (right censored), then, for $t \leqslant 2004$,

$$p_{it} = P(T_{it} = 0 | I_i \text{ unobserved}, C_i > 2004, n_f, \mathcal{T}_{-it})$$

$$= P(I_i > t | I_i \text{ unobserved}, C_i > 2004, n_f, \mathcal{T}_{-it}),$$

which we estimate with

$$\hat{p}_{it} = \hat{F}(I_i > t \mid I_i \text{ observed}, C_i > 2004, n_f, \mathcal{T}_{-it}).$$

Case 3. If I_i is observed, C_i is unobserved, and $C_i \leq 2004$ (not right censored), then

$$p_{it} = P(T_{it} = 0 | I_i, C_i \text{ unobserved}, C_i \leqslant 2004, n_f, \mathcal{T}_{-it})$$

$$= \begin{cases} 1, & t < I_i \\ P(C_i < t | I_i, C_i \text{ unobserved}, C_i \leqslant 2004, n_f, \mathcal{T}_{-it}), & t \geqslant I_i, \end{cases}$$

which we estimate with

$$\hat{p}_{it} = \begin{cases} 1, & t < I_i \\ \hat{F}(C_i < t \mid I_i,\ C_i \leq 2004,\ n_f,\ \mathcal{T}_{-it}), & t \geqslant I_i. \end{cases}$$

Case 4. If I_i is unobserved, C_i is unobserved, and $C_i \leq 2004$ (not right censored), then for $t \leq 2004$,

$$p_{it} = P(T_{it} = 0 | I_i \text{ unobserved, } C_i \text{ unobserved, } C_i \leqslant 2004,\ n_f,\ \mathcal{T}_{-it})$$

$$= 1 - P(I_i \leqslant t \leqslant C_i | I_i \text{ unobserved, } C_i \text{ unobserved, } C_i \leq 2004,\ n_f,\ \mathcal{T}_{-it}),$$

which we estimate with

$$\hat{p}_{it} = 1 - \hat{F}(I_i \leqslant t \leqslant C_i | I_i \text{ observed, } C_i \text{ observed, } C_i \leqslant 2004,\ n_f,\ \mathcal{T}_{-it}).$$

The *f*th summand in equation (A1) is then calculated as

$$\hat{A}_{ft} = 1 - \prod_{i=1}^{n_f} \hat{p}_{it}.$$

A3. Remark

As indicated in the main text, our procedure for estimating the number of active facilities and other statistics dependent on tank status is reasonable if the true (unknown) distribution of tanks' installation and/or closure dates, given current status (2004), is conditionally independent of whether the transition dates were recorded in the data. Some support for this assumption comes from our discussion with the database manager at the Illinois Office of the State Fire Marshall, who indicated that a major reason for missing data is that the missed information "may not have been processed yet."[30] This suggests that the distribution of true installation and closure dates, given tanks with identical current status (in 2004), may be similar regardless of whether it was recorded in our data.

However, our analysis of the Indiana data seems to suggest there are too few old tanks among the subgroup for which we have complete installation data. This makes statistics involving active release rates and facility status for Indiana suspect, and it is the reason that we are circumspect in reporting them in the text.

A4. Total Number of Facilities

In Figure 2, the total number of facilities reported by year is the cumulative number "born" on or before year *t*, or

$$N_t = \sum_f \mathbf{1}(\min_{i \text{ at } f}\{I_i\} \leqslant t), \tag{A2}$$

where $\mathbf{1}(\cdot)$ is the indicator function. The sum is over all facilities alive before *t*.

[30] Jan Spoor, database administrator, Illinois Office of State Fire Marshall, e-mail correspondence, May 19, 2005.

If the installation year I_i is unobserved for tank i at facility f, then we replace the fth summand in equation (A2) with an estimate of

$$P(\min_{i\,\text{at}\,f}\{I_i\} \leqslant t|\Omega_f) = 1 - \prod_{i=2}^{nf} P(I_i > t|\mathcal{I}_{-i}, \Omega_f)P(I_1 > t|\Omega_f),$$

where $\mathcal{I}_{-i}$ denotes the event that all tanks at facility f with an index less than i were installed after year t, or

$$\mathcal{I}_{-i} = \{I_{i-1} > t, I_{i-2} > t, \ldots, I_1 > t\}.$$

When tank i's installation year is unobserved, the matching procedure that we use to evaluate the installation conditional probabilities $q_i \equiv P(I_i > t|\mathcal{I}_{-i}, \Omega_f)$ here is analogous to the procedure for estimating tanks' active status probabilities. Specifically,

Case 1. Closure year C_i is observed. (This implies that $C_i \leqslant 2004$.) Then

$$P(I_i > t|\mathcal{I}_{-i}, \Omega_f) = P(I_i > t|I_i \text{ unobserved}, C_i, n_f, \mathcal{I}_{-i}),$$

which we estimate with

$$\hat{q}_i = \begin{cases} \hat{F}(I_i > t|I_i \text{ observed}, C_i, n_f, \mathcal{I}_{-i}), & t < C_i \\ 0, & t \geqslant C_i. \end{cases}$$

Case 2. If $C_i > 2004$ (right censored), then for $t < 2004$,

$$P(I_i > t|\mathcal{I}_{-i}, \Omega_f) = P(I_i > t|I_i \text{ unobserved}, C_i > 2004, n_f, \mathcal{I}_{-i}),$$

which we estimate with

$$\hat{q}_i = \hat{F}(I_i > t|I_i \text{ observed}, C_i > 2004, n_f, \mathcal{I}_{-i}).$$

Case 3. If C_i is unobserved and $C_i \leqslant 2004$ (not right censored), then

$$P(I_i > t|\mathcal{I}_{-i}, \Omega_f) = P(I_i > t|I_i \text{ unobserved}, C_i \text{ unobserved}, C_i \leqslant 2004, n_f, \mathcal{I}_{-i}),$$

which we estimate with

$$\hat{q}_i = \hat{F}(I_i > t|I_i \text{ observed}, C_i \text{ observed}, C_i \leqslant 2004, n_f, \mathcal{I}_{-i}).$$

Last, we set $\hat{q}_i$ equal to either one or zero, as appropriate, if tank i's installation year is recorded in the data. The fth summand in equation (A2) is then calculated as

$$1 - \prod_{i=1}^{n_f} \hat{q}_i.$$

A5. Active Release Rates

To evaluate a state's active release rate using equation (2), the denominator requires the statistic in equation (A1), and the numerator requires the following:

$$\text{number of releases at active facilities in year } t = \sum_f \mathbf{1}(R_{ft} | A_{ft} = 1), \quad \text{(A3)}$$

where R_{ft} indicates a release at facility f in year t, and where $\mathbf{1}(\cdot)$ is the indicator function. If either I_i or C_i is unobserved for a tank at facility f, we replace the fth summand in equation (A3) with an estimate of $P(R_{ft} \mid A_{ft} = 1)$. Since A_{ft} is not directly observed in this case, we use Bayes's rule,

$$P(R_{ft}|A_{ft} = 1) = \frac{P(R_{ft})}{P(A_{ft})} P(A_{ft}|R_{ft} = 1),$$

which we evaluate using estimates of each term appearing on the right-hand side:

$$\hat{P}(R_{ft}|A_{ft} = 1) = \frac{R_{ft}}{\hat{A}_{ft}} \hat{A}_{R_{ft}},$$

where $\hat{A}_{ft}$ is the active status probability calculated earlier, R_{ft} is observed in the data (it is either zero or one), and $\hat{A}_{R_{ft}} = P(A_{ft}|R_{ft} = 1, \Omega_f)$. We calculate $\hat{A}_{R_{ft}}$ using the same procedure for $\hat{A}_{ft}$ described above, with one minor modification: the tank-level probabilities p_{it} in cases 0–4 are calculated among facilities with releases only—that is, conditional on $R_{ft} = 1$ at t.

References

Agency for Toxic Substances and Disease Registry. 2005. *Toxicological Profile for Benzene.* Atlanta: Agency for Toxic Substances and Disease Registry, U.S. Public Health Service.

Akerlof, George A., and Paul M. Romer. 1993. Looting: The Economic Underworld of Bankruptcy for Profit. *Brookings Papers on Economic Activity* 2:1–73.

ASTSWMO (Association of State and Territorial Solid Waste Management Officials). 2007. *State Financial Assurance Funds Survey 2007.* Washington, D.C.: Association of State and Territorial Solid Waste Management Officials. http://www.astswmo.org/Pages/Policies_and_Publications/Tanks.htm.

Benton, Charles L. 1990. Report of the Governor's Task Force on Underground Storage Tanks. Report No. Un55:2/B/990. Maryland State Law Library, Annapolis.

Boyd, James. 1997. "Green Money" in the Bank: Firm Responses to Environmental Financial Responsibility Rules. *Managerial and Decision Economics* 18:491–506.

Boyd, J., and H. C. Kunreuther. 1997. Retroactive Liability or the Public Purse? *Journal of Regulatory Economics* 11:79–90.

Brown, Jeffrey R. 2008. Guaranteed Trouble: The Economic Effects of the Pension Benefit Guaranty Corporation. *Journal of Economic Perspectives* 22(1):177–98.

Cooper, Russell, and Thomas W. Ross. 1998. Bank Runs: Liquidity Costs and Investment Distortions. *Journal of Monetary Economics* 41:27–38.

———. 1999. Public and Private Guarantee Funds with Market Fragility. *Journal of Risk and Insurance* 66:163–84.

Couch, Kevin, and Thomas Young. 2001. Leaking Underground Storage Tanks as Point

Sources of MTBE to Groundwater. Research report. University of California, Department of Civil and Environmental Engineering, Davis.

Environmental Information Digest. 1993. The Underground Storage Tank Market: Its Current Status and Future Challenges. August, p. 16.

EPA (Environmental Protection Agency). 1995. Musts for USTs. Report No. 510-K-95-002. Washington, D.C.: U.S. Environmental Protection Agency.

———. 1997. State Funds in Transition: Models for Underground Storage Tank Assurance Funds. Report No. 510-B-97-002. Washington, D.C.: U.S. Environmental Protection Agency.

———. 2008. *Meeting Underground Storage Tank System Requirements.* Washington, D.C.: Office of Underground Storage Tanks, U.S. Environmental Protection Agency. http://www.epa.gov/oust/ustsystm/index.htm.

———. 2010. *Semiannual Report of UST Performance Measures, End of Fiscal Year 2010.* Washington, D.C.: U.S. Environmental Protection Agency. http://www.epa.gov/oust/cat/ca_10_34.pdf.

Freeman, Paul K., and Howard Kunreuther. 1997. *Managing Environmental Risk through Insurance.* Boston: Kluwer Academic Publishers.

Government Accounting Office. 1987. Availability of Insurance for Petroleum Underground Storage Tanks. Report GAO/T-RCED-88-9. Washington, D.C.: U.S. General Accounting Office.

———. 2000. *GAO Survey of the 50 States Financing Cleanups of Leaking Underground Storage Tanks.* Washington, D.C.: U.S. General Accounting Office.

———. 2007. Leaking Underground Storage Tanks. Report GAO-07–152. Washington, D.C.: U.S. General Accounting Office.

Hopkins, S., and M. Kidd. 1996. The Determinants of the Demand for Private Health Insurance under Medicare. *Applied Economics* 28:1623–32.

Jenkins, Robin, Elizabeth Kopits, and David Simpson. 2006. Measuring the Social Benefits of EPA Land Cleanup and Reuse Programs. Working Paper No. 06-03. U.S. Environmental Protection Agency, National Center for Environmental Economics, Washington, D.C.

Kareken, John H., and Neil Wallace. 1978. Deposit Insurance and Bank Regulation: A Partial-Equilibrium Exposition. *Journal of Business* 51:413–38.

Kreiger, Gary R. 2000. *Accident Prevention Manual: Environmental Management.* 2d ed. Chicago: National Safety Council.

Meltzer, Allan H. 1967. Major Issues in the Regulation of Financial Institutions. *Journal of Political Economy* 75:482–501.

Michigan Department of Natural Resources. 1995. *Causes of Underground Storage Tank Leaks and Recommendations.* Report to the Senate Committee on Natural Resources and Environmental Affairs and the House Committee on Conservation, Environment and Great Lakes Affairs. Lansing: Michigan Department of Natural Resources.

National Petroleum News. 1998. AIG Environmental Offers Reductions for Tanknology Customers. *National Petroleum News* 90(12):9.

Noyes, Robert, ed. 1992. *Handbook of Leak, Spill and Accidental Release Prevention.* Orlando, Fla.: William Andrew Publishers.

Public Sector Consultants. 1995. *An Analysis of the Michigan Underground Storage Tank Financial Assurance Program: Assessment of Solvency, Opportunities for Cost Containment, and Future Options.* Report to the Michigan Department of Environmental Quality. Public Sector Consultants, Lansing.

Sapelli, Claudio, and Arístides Torche. 2001. The Mandatory Health Insurance System in Chile: Explaining the Choice between Public and Private Insurance. *International Journal of Health Care Finance and Economics* 1:97–110.

Simons, Robert A., William M. Bowen, and Arthur J. Sementeilli. 1999. The Price and Liquidity Effects of UST Leaks from Contaminated Sites. *Appraisal Journal* 67:186–94.

Soesilo, Andy J., and Stephanie Wilson. 1997. *Site Remediation: Planning and Management.* Boca Raton, Fla.: CRC Press.

U.S. Department of Transportation. 1990. *Highway Statistics 1990.* Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration, Office of Highway Policy Information. http://www.fhwa.dot.gov/policyinformation/statistics.cfm.

———. 2003. *Highway Statistics 2003.* Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration, Office of Highway Policy Information. http://www.fhwa.dot.gov/policyinformation/statistics.cfm.

Wheelock, David C., and Paul W. Wilson. 1995. Explaining Bank Failures: Deposit Insurance, Regulation, and Efficiency. *Review of Economics and Statistics* 77:689–700.