RISK-BASED PRICING AND RISK-REDUCING EFFORT: DOES THE PRIVATE INSURANCE MARKET REDUCE ENVIRONMENTAL ACCIDENTS?*

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Abstract. This paper examines whether risk-based pricing promotes risk-reducing effort. Such mechanisms are common in private insurance markets, but are rarely incorporated in government assurance programs. We analyze accidental underground fuel tank leaks—a source of environmental damage to water supplies—over a fourteen-year period, using disaggregate (facility-level) data and policy variation in financing the cleanup of tank leaks over time. The data suggest that eliminating a state-level government assurance program and switching to private insurance markets to finance cleanups reduced the frequency of costly underground fuel tank leaks by more than 20 percent. This corresponds to more than 3,000 avoided fuel-tank release accidents over eight years in one state alone, a benefit in avoided cleanup costs and environmental harm exceeding $400 million. These benefits arise because private insurers mitigate moral hazard by providing financial incentives for tank owners to close or replace leak-prone tanks prior to costly accidents.

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I. 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.[1] Instead, 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, raising 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. This 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 occurs when 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 they are financially capable of (*i*) cleaning up underground fuel leaks and (*ii*) 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 can have costly tank leaks and their consequential damages covered at state expense, while facing little program-related incentive to "take care" to prevent such leaks.

By the mid-1990s, Michigan's and Illinois' assurance funds became insolvent.

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[1] By *risk-based prices,* we mean insurance premia that (1) are based on an assessment of the insured party's risk of future losses, and (2) vary with the insured party's loss history (experience rating).

However, these states took radically different approaches to their insolvency crises. While Illinois raised 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 provides an opportunity to evaluate whether switching from a government assurance program to the private insurance market promotes risk-reducing activity and lowers the frequency of these adverse events.

Despite its importance, there are few studies that 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) found that banks that were members of the Kansas state deposit insurance system had a higher probability of failure than non-members. As they point out, however, it is unclear whether insurance attracted the most risk-prone banks (adverse selection), or banks tended to become more risk-taking 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 a state fund's cost is (largely) paid 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,

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[2] Empirical studies of private- versus public-sector insurance have proved more successful 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.

in which accident rates in Michigan would have declined (relative to surrounding states) even if that state had not switched to private market insurance. In fact, the evidence available indicates Michigan should—and did—expect to have a larger future tank cleanup problem than other states at the time it closed its public assurance program (PSC, 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 avoided fuel tank releases in Michigan over the following eight years. At an average cleanup cost of $125,000 per release (GAO 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 US Environmental Protection Agency estimates that 12,000 new underground fuel tank releases occur each year in the United States.[3] Gasoline and other petroleum products that leak underground tend to enter groundwater flows; if undetected, this can pose a public health hazard by contaminating public drinking water supplies, and require costly remediation. For the more than thirty states that presently operate state assurance fund programs, it would appear that adopting the risk-based pricing mechanisms used in private insurance markets may alleviate ongoing solvency crises and reduce the costly burden of future accidents.

II. TECHNOLOGY AND RISK-REDUCING ACTIVITY

To understand the effects of the government assurance programs 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.

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[3] US EPA Office of Underground Storage Tanks, *2006 Corrective Action Performance Measures Data.*

A. Technology

Most underground fuel tanks are located at retail gasoline stations. A small gas station typically has two tanks, a large station may have five or six. From a regulatory and an insurance standpoint, 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.[4]

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 1990's typical cleanup costs in these situations ranged from \$60,000 to \$100,000 (EID, 1993; Soesilo and Wilson, 1997). In contrast, a leak that remains unresolved will not stop on 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 acquisition of new water supplies.[5] For these reasons, investing in equipment and operating practices that can prevent accidental underground leaks—and detecting and remediating leaks with alacrity—is desirable to minimize the total social costs of underground fuel storage.

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

[5] Benzene and other compounds in gasoline are hemotoxic and neurotoxic to humans in high doses, and carcinogenic with long-term, low-exposure levels. See ASTDR (2005). Benton (1990) examines cleanup costs with groundwater contamination.

B. 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, near all underground fuel tanks were single-walled and constructed of bare steel that is prone to corrode. Two types of capital investments can greatly reduce this risk. The first, and most effective, is to replace a steel tank with one constructed of, or coated with, non-corroding material (such as reinforced fiberglass). Installing a double-walled tank will further reduce 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 will reduce the likelihood of underground tank leaks. Several anti-corrosion technologies are available, with more effective systems carrying higher installation and ongoing maintenance costs (see EPA, 2008, for details).

Tank system leaks can also be reduced, in severity and in likelihood, through assiduous operations and maintenance activities. These include regularly pressure testing 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 anti-corrosion devices, and the like. All of these activities are costly, and some require periodic closure of the station and attendant lost revenue.[6]

III. 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.

A. Federal Regulations and Owners' Responsibilities

In response to mounting scientific evidence and public concern over adverse health consequences of leaking underground fuel tanks, in 1984 Congress directed the US Environmental Protection Agency (EPA) to regulate public and private underground fuel storage

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[6] The technical literature on leak prevention practices is extensive; see, *e.g.*, Kreiger (2000) or Noyes (1992).

tanks.[7] 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 we examine.

Financial Responsibility Requirements. The EPA's financial responsibility requirements require tank system owners either to (*i*) 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 (*ii*) participate in a state-administered underground storage tank financial assurance program providing comparable coverage.[8] State and federal regulators believe that compliance with financial responsibility requirements is (essentially) universal.[9]

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 (*i*) administratively and socially costly relative to prophylactic regulation, and (*ii*) that the desired incentive effect of a pure liability rule for owners to "take care" to avoid leaks may be adversely tempered by the limited liability provisions of the bankruptcy code (Boyd, 1997).[10] 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.[11]

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[7] 40 CFR §280-281, implementing 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, the CBS program *60 Minutes* story "Check the Water" brought national attention to the health consequences of leaking underground gasoline storage.

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

[9] Email communications with Sammy Ng (US EPA Office of Underground Storage Tanks, 5/19/2006) and Kevin Wieber (Michigan Department of Environmental Quality, 6/15/2006).

[10] 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, for the reasons in §II.A. 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.

[11] Questions commonly arise regarding the allocation of liability between owner and operator at franchised gasoline stations. Effective liability varies, depending upon who holds title to the tank system and any provi-

Technical Requirements. Although changes in tank-system technical standards are not the focus of our analysis, they affect the data interpretation and merit brief discussion here. The EPA chose compliance deadlines for technical standards that differed for new versus 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 five years (by December 1993) and the corrosion-resistance requirement within ten 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 any state-level policy variation, we would expect the frequency of underground tank leaks to decrease over time as older, sub-standard tanks are closed or upgraded to meet the 1998 deadline.

Reporting and Corrective Action Requirements. The 1988 federal regulations stipulate prompt reporting of underground storage tank leaks in any detectable quantity to federal and/or state regulatory agencies, and specify required corrective actions in detail. Importantly for our purposes, the penalty for failing to report a suspected underground tank leak is extraordinarily high, at $11,000 *per day* (42 USC 6991(e)). We discuss this and other incentives facing owners to report and remediate tank leaks in Section IV.C below. It is useful first to summarize state policy responses to these federal regulations.

B. State Responses: Government Assurance Funds

The federal financial responsibility requirements generated a storm of political protest from gasoline retailers and small-business advocates. They argued many stations would not survive because private insurance was not widely available in the 1980s, and expensive

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sions regarding these contingencies in the specific franchise agreement.

when available.[12] 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 (1) pay a nominal registration fee (typically $100 per tank per annum); (2) comply with applicable technical standards for tank systems; and (3) promptly report (usually within 24 hours) any detected or suspected underground fuel leaks. Most state assurance fund programs were crafted so that participation enables tank owners to comply with their federal financial responsibility requirement.

Two features of these programs are important. First, most states' assurance funds are financed by an incremental excise tax on motor fuel (typically about one 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 same for everyone. It does not vary with respect to the age of the tank being insured, its capacity, prior leak history, groundwater proximity, whether or not the tank system has been retrofit with advanced corrosion protection equipment, whether or not it is single- or double-walled to contain a leak, or with 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 standards.

Indeed, it is possible that state assurance fund programs actually attenuate tank owners' incentives to comply with tank-system technical standards. Our discussions with regulatory officials indicated that while state assurance funds nominally require participants to comply with federal technical standards, that requirement is not well-enforced.

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[12] See GAO (1987) or Boyd and Kunreuther (1997). 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.

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 non-compliance 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.[13]

In practice, this perspective has a potential to create mal-aligned incentives for tank owners to comply with tank-system technical standards. Still, whether or not the absence of strong incentives to prevent accidental leaks among state assurance fund participants is manifest in more adverse outcomes is an empirical matter. We now turn to the policy variation that informs this question.

IV. STATE POLICY VARIATION AND MARKET INSURANCE

A. State Assurance Fund Changes

We examine three states for which comprehensive station- and tank-level data are available: Michigan, Illinois, and Indiana. All three 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-1990's.

In response, Illinois raised its (wholesale) motor fuels tax by 0.8 cents by gallon and continued to operate its state assurance fund. Studies performed in Michigan at the time concluded a similar increase in funding would be necessary to restore that state's fund

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[13] Email communication with William Foskett, US EPA, August 18, 2004.

solvency (PSC, 1995). Facing public opposition to further gasoline taxes, Michigan's legislature elected to close its state assurance fund program to new claims.[14] All tank owners operating in Michigan needed to obtain private-market insurance starting July 1, 1995.

B. 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 generally. A review of several 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. Premiums are also based on the number and types of leak detection systems in place, with lower premiums offered for more sophisticated detection systems.

Some evidence on the magnitudes involved is summarized in Tables 1 and 2. Table 1 lists several rate factors for one major commercial environmental liability insurer (the Zurich Company, N.A.).[15] Base premia vary with tank construction and age by a factor of *ten*, from $185 per annum (p.a.) for a new, double-walled tank to $1850 p.a. for a single-walled, 35+ year-old tank. Premiums are discounted by 10% each for installation of an advanced leak detection system, additional corrosion protection equipment, and other preventive measures that exceed federal technical standards. Table 2 shows insurance premia for several common three-tank system configurations of different vintages as of 1997, which is approximately the mid-point of our study period. Comparing the rows of Table 2 shows that premiums vary significantly: Lower premiums apply if owners invest in equipment that is less likely to corrode and leak, and that have better monitoring and in-

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[14] Michigan Public Act No. 451 of 1994 (Michigan Compiled Laws §324.21101 *et seq.*)

[15] Prices as of 2004. Discussions with Zurich indicate its premia during the mid-1990's were generally higher but structured similarly with respect to tank attributes. See also EPA (1997) and PSC (1995).

ventory control.

A second contrast to state assurance funds is that commercial insurance contracts provide incentives for tank owners to "take care" due to experience-rated pricing. For instance, the bottom row of Table 1 indicates that a prior accidental fuel release (a tank leak, or surface spill exceeding 25 gallons) will increase the premium per tank charged by this insurer by 10-to-20 percent 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.

Last, private market insurers engage in a variety of activities designed to promote risk-reducing activities by tank system owners. Some insurers issue newsletters that identify cost-effective technologies to prevent or detect leaks, which could conceivably reduce owners' costs of searching for and processing technical information. Insurers also offer premium discounts and rebates to tank owners who purchase leak detection and tank system maintenance services from specific third-party providers. For example, the American Insurance Group's Environmental Insurance unit provides premium discounts to tank system owners who purchase compliance management and monitoring services from Tanknology-NDE International, a firm that specializes in tank system engineering and monitoring equipment (NPN, 1998). Insurers view these third-party services as a means to reduce moral hazard in maintenance and operations activities by gasoline retailers.

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.

C. About Leak Disclosure Compliance

The data 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 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 under-reporting is more prevalent with private insurance than public insurance.

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

As to (1), there are two mechanisms at work: routine inspections and on-site testing when a tank is replaced, or a facility is closed. Routine facility inspections by state tank regulators occur every two to three years; their primary purpose is to detect previously unreported leaks. Furthermore, whenever 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—that is, highly unlikely to erroneously conclude a site is clean if a release has in fact occurred.

Regarding (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 wells). A facility that does not test clean becomes difficult, if not impossible, to sell and to insure 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.

The legal consequences if a tank owner fails to report an accidental release take two forms. 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 (RCRA Subtitle I §9006(d)2). Second, to renew commercial tank insurance a facility owner must make a detailed declaration of whether it experienced an accidental release in the past. Non-disclosure 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 that event, a tank system owner may well declare bankruptcy. 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 (3), even an insured facility owner bears some cost 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 business interruption losses during cleanup, and the cost of accelerated replacement of the tank system. Since the public insurance programs do not cover business interruption losses or replacement equipment, only the experience-rating and (possibly) deductible amounts differ between commercial and public insurance systems.

The totality of these considerations leaves both us and regulatory officials skeptical that tank owners with private insurance are systematically less likely to report an accidental release than owners participating in state assurance fund programs.[16] Nevertheless, hard data on the prevalence of unreported tank leaks remain elusive; we are aware (from EPA staff) of only two such incidents during our study period. EPA officials who oversee compliance policies nationally assert there is no evidence tank owners using state assurance funds and those using commercial insurance differ in reporting accidental releases.[17]

V. DATA AND MEASUREMENT

A. Data

We examine accidental release rates over a fourteen year period at all facilities in Michigan, Illinois, and Indiana. These states are informative for several reasons. 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

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[16] 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.

[17] Email communications with Sammy Ng (Director, US EPA Office of Underground Storage Tanks) and Mark Barolo (US EPA Office of Underground Storage Tanks), May 25, 2005.

underground fuel storage tanks and accidental releases in the state. These databases have been continuously updated for over twenty years as old tanks exit and new tanks enter service.[18] Third, each of these states' on-site inspections of tank facilities show a high rate of compliance with leak detection system installation requirements (GAO, 2000), indicating little difference among these states in tank owners' abilities to detect leaks that do occur. Last, these neighboring states have similar winter climates and precipitation levels, contributing long-term factors to tank system corrosion and failures.

Two databases are maintained by each state's environmental protection and tank regulatory agencies. One is the tank database, which reports each 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 clean-up progress.[19] 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.[20]

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 we examine began collecting comprehensive release data in 1990, upon implementation of their assurance funds programs.

Table 3 summaries various facility attributes and trends by state. Michigan and Il-

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[18] The US EPA also maintains a national *Corrective Action Database* of underground storage tanks and releases, based on data voluntarily supplied by state regulatory agencies. Couch and Young (2001, p. 18) report 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.

[19] In separate work, we are examining how releases and closure decisions vary with facility ownership and type (e.g., independent gas station s versus branded gas stations). Inferring ownership type is difficult, however, because owners are often listed as franchisees or individuals without further identification.

[20] The data (and state and federal tank insurance regulations) also include 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; these are not in our data.

linois 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 attributes. All three states exhibit similar growth rates (within one percentage point) on these dimensions over our fourteen-year study period. One noteworthy difference in Table 3 is that Michigan's tanks are slightly older than adjacent states. We come back to this in section VI.C.

A striking feature of the data is the dramatic facility exit rate in all three states. Sixty-five percent of the 25,253 active facilities in Michigan in 1990 closed permanently over the following 14 years. Entry (that is, *de novo* new facilities) was slight over this period, resulting in a *net* facility exit rate of 61% from 1990 through 2003. Net exit rates are similarly high in Illinois and Indiana over the same period (61 and 56 percent, respectively). There has also been a trend to larger stations: the mean tank capacity of active facilities increased steadily over time, by 4-to-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.

B. Measuring Facility Release Risk

The empirical task is to measure whether accidental tank release rates changed differently across states after Michigan switched to private insurance. 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: An *active* tank stores fuel during the current (calendar) year, while a *closed* tank has been removed or rendered unusable *in situ*.[21] A facility is active if it has at least one active tank.

This distinction is 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 II.B, that reduce the chance of

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[21] Tanks that are *de facto* unused but have not been officially closed remain subject to technical regulations, reporting requirements, and insurance requirements.

a tank system leak. Such actions are not obligatory, however; a station owner might choose simply to pay higher insurance premiums and not undertake any risk-reducing activities. The second 'margin' 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 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 is manifest primarily through the closure of facilities. To be precise, some notation is needed. Let A_{ft} indicate if the status of facility f in year t is active, and R_{ft} indicate if an accidental release occurs.[22] A state's *total release rate* in year t is $\mathrm{P}(R_{ft})$, where the probability 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 $\mathrm{P}(R_{ft} \mid A_{ft})$, the chance 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:

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

and

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

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

$$\mathrm{P}(R_{ft}) = \mathrm{P}(R_{ft} \mid A_{ft})\, \mathrm{P}(A_{ft}) + \mathrm{P}(R_{ft} \cap {\sim}A_{ft}), \tag{3}$$

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

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[22] 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.

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, which enters the denominator of (1). The databases we employ contain reliable information (that is, a census of) tanks in the ground after 1986, when underground fuel tank reporting requirements were originally enacted (40 CFR §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, its closure year. Specifically, installation dates are missing for 14% of the tanks in Michigan, 53% in Illinois, and 64% in Indiana (see Appendix Table A). 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 was 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 same state that closed in the same year but with 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 within 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 the major reason for missing data is that installation dates are not considered essential to their enforcement activities and have not been completely coded into their databases.[23] 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 means data for Indiana relating to facility status and tank age should be interpreted cautiously. Overall we will place our primary emphasis on comparisons between Michigan and Illinois, with comparisons to Indiana serving as supplemental corroborative evidence.

VI. 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 adjacent states. The data also suggest that after the change, tank owners in Michigan tended to "take care" of their tanks more than in Illinois.

A. Changes in Total Release Rates

Table 4 summarizes the three states' average annual release rates before and after 1995, when Michigan's transition to private insurance occurred. It omits 1995 because Michigan's policy change took effect mid-year (we report 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 Illinois' by 31 percent. The relative risk reduction in Michigan exceeded Indiana's by a similar amount, 24 percent.

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[23] Interview with Jan Spoor, Database Administrator, Illinois Office of State Fire Marshall, May 19, 2005.

Reductions in environmental risks should also be considered in absolute terms. 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 a difference of 1.53 (or 3.95 – 2.42) releases per 100 facilities, which is 23% of Michigan's initial (1990-1994) average annual release rate.

In economic terms, is a reduction of 1.53 releases for every 100 facilities important? Yes. The number of facilities in Michigan after its policy change averages approximately 26,000 (see Figure 2). So 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 eight-year post-transition study period. Table 4 also indicates that Michigan's 'excess' absolute risk reduction (the difference-in-differences) is even greater compared to Indiana: 2.18 releases per 100 facilities annually. Taken together, these data suggest that Michigan had some three-to-four thousand *fewer* underground tank leaks over the eight years following its policy change than the number predicted by neighboring states' experience over the same time period. Given an average cleanup cost of $125,000 per release (GAO 2007), this represents an aggregate cleanup cost savings for that state on the order of $400 million over eight years.

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

Are these differences statistically significant? Since we have a census of the facilities in each state, errors in mean release rates arise from mis-measurement, not sampling variation. The standard error of the mean if binary outcomes are recorded with misclassification errors is a concave function of the misclassification probability. For our sample sizes, the standard errors of mean release rates due to misclassification error are bounded above by 0.0014. (This assumes independent errors across facilities). That means even with extraordinary measurement error in recording release events—e.g., a 50 percent error rate—differences in observed release rates larger than about 0.3 per 100 facilities are statistically significant. In administrative data like these, misclassification rates of 50% stretch credulity; the standard errors we report in Table 4 are based on a lower misclassification rate of 5%. Adjusting for within-facility correlation in release events over time (i.e., clustering on facility) yields *de minimus* changes in the standard errors, as few facilities have more than one release during the fourteen-year span of our data.

B. Mechanisms and Closure Rates

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

(*i*) *Greater facility closure rate*. Because releases at closed facilities are rare, shifting facilities from active to closed status will tend to reduce a state's overall release rate. A greater closure rate in Michigan—for any reason—would tend to reduce its total release rate more than neighboring states.

(*ii*) *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 other states even if overall facility exit rates are similar—that is, even if explanation (*i*) does not hold.

(*iii*) *Greater risk-reducing effort at active (surviving) facilities* in Michigan than in adjacent states. Tangibly, this means replacing or re-lining older tanks, improving maintenance practices, installing anti-corrosion equipment, and similar activities after Michigan's insurance policy change.

The first of these explanations is potentially problematic for conclusions about the role of insurance pricing. Conceivably, high closure rates of gas stations during the 1990's 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 (section III.B), the industry's trend to replace smaller stations with larger facilities that have higher-profit 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 (*ii*) and (*iii*) subsequently.

Facility Closings. Figure 2 displays the total number of facilities and the number of active facilities from 1986 to 2003 for Michigan and Illinois. A state's total and active facilities are the same in 1986, when record-keeping requirements began. In both states the total number of facilities (solid lines) grows incrementally over time, due to modest *de novo* entry by new gasoline stations. However, the number of active facilities (dashed lines) plummets in both states. The decline in Indiana's active facilities is substantively the same (see Table 3).

Figure 2 reveals several important points. First, the decline in the number of active facilities commences 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 after the "grandfathering" of existing facilities ends. We do not observe a similar decline in Michigan (more about this presently). Third, there is a slightly greater rate of *de novo* entry in Illinois than in Michigan. Since newly-installed tanks are unlikely to corrode and must meet federal tank-system technical standards upon installation (for corrosion resistance and leak prevention), this difference in entry rates should tend to *reduce* Illinois' overall release rate relative to Michigan's 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 importantly, 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, $\hat{P}(A_{it})$ in equation (1)—declined by essentially identical amounts in both states: 56 percentage points (from .90 to .34) in Michigan and 57 percentage points (from .88 to .34) in Illinois. The proportion of active facilities fell 69 percentage points (from .97 to .38) in Indiana over the same period, a greater closure rate than in Michigan.

These data support two intermediate conclusions: (*a*) The net exit of stations in Michigan over time was not induced by that state's private-market insurance requirement in 1995; and (*b*) The difference in absolute risk reductions 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 release rate changes 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 smaller yet than in Indiana. After all, the cost of operating a facility increased in Michigan when its state assurance program closed in mid-1995; there was no analogous fixed-cost increase in the two neighboring states. Why not greater exit after a cost shock? The likely explanation lies in the magnitudes. After Michigan's policy change, insurance costs for a typical three-tank facility that complies with the 1998 federal technical standards are in the range of $1,000 to 3,000 annually (Table 2, rows 1-3). These amounts may be too small to have a significant impact on facility exit rates among compliant facilities—which are apt to be better-managed, more-profitable establishments. The insurance cost increase at older, non-compliant facilities could be substantially higher, and perhaps high enough to drive out marginally-profitable establishments *ceteris paribus.* This may explain why Michigan's exit rate declines comparatively smoothly over the 1995-1999 period in Figure 2, but Illinois exhibits an abrupt drop in the number of active facilities from 1998 to 1999. Both states' non-compliant facilities could not operate after the federal "grandfathering" provision expired in 1998 (without costly upgrades), but in Illinois there was little incentive to close a non-compliant facility before 1998.

C. Changes in Active Release Rates

Explanations (*ii*) and (*iii*) above point to the possibility of changes in release rates at active facilities as a result of insurance reform. Table 5 summarizes each state's active facility release rate, or $\hat{P}(R_{ft} | A_{ft} = 1)$, calculated using equation (2). Note 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, from 8.81 to 5.78 per 100 active facilities. By contrast, Illinois' release rate declines by slightly more than 1 percentage point and Indiana's falls by less than one. 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.

The active facility release rate changes and the total release rate changes in Table 4 are mechanically related: A greater decline in the total release rate in Michigan than other states implies a greater decline in the 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 3 and Figure 2), and changes in releases reported at *closed* facilities are empirically negligible.[24]) Thus, the new information content in Table 5 lies not in the magnitudes but in their interpretation.

Because the set of active facilities is declining 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. This is the earlier explanation (*iii*), and 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 the latter mechanism would reduce active release rates, as measured in Table 5, *even if* firms made no efforts at all to reduce release risks at ongoing establishments.

Which of these mechanisms accounts for the larger reduction in release rates in Michigan, relative to the other states, after its policy change? Ideally, the most compelling

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[24] In the data, the release rate at closed facilities in Michigan during 1990-1994 is 0.0027 and during 1996-2003 is 0.0018, a decrease of 9 releases for every 10,000 closed facilities. The decrease in the release rate at closed facilities in Illinois is <1 per 10,000 closed facilities, and there is a small increase for Indiana of 9 releases for every 10,000 closed facilities. For all three states, the changes in release rates at closed facilities are two orders of magnitude smaller than the changes in the total and active release rates—far too small to help explain the overall decline in either.

data to address this question would be information on facility-level investments in specific risk-reducing technologies before and after 1995 (such as cathodic anti-corrosion protection equipment, tank re-linings, maintenance logs showing more frequent pressure testing, and so on). To our knowledge such data have not been systematically collected, and we are skeptical they could now be assembled reliably in retrospect. Nevertheless, we can draw some useful inferences about whether or not these activities must have occurred by examining surviving and attriting facilities separately.

Risk-Reducing Activity. The majority of the facilities active at the end of our study period were active since (at least) 1990. Table 6 summarizes the average annual release rates for these continuously-operated facilities.[25] The average annual release rate in Michigan decreases by 4.57 releases per 100 facilities after 1995 (from 8.08 to 3.51). In contrast, the rate in Illinois falls by about half as much: 2.55 per 100 facilities (from 6.27 to 3.72). The situation in Indiana is similar, with a decline of only 2.20 per 100 facilities (from 6.04 to 3.84). In absolute terms, the reduction in Michigan's release risk exceeds that in Illinois and in Indiana by 2.02 and 2.37 per 100 facilities, respectively, and the relative risk falls 39 percent and 55 percent more in Michigan than the adjacent states. These magnitudes are substantial, exceeding the excess absolute risk reduction and etiologic ratios for the facility population overall (see Table 4).[26]

The facilities in Table 6 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 or replacement tanks and equipment, for many years before and after Michigan's policy changed. It leaves three possible explanations for Michigan's substantially greater decline in release rates among the three states' continuously-operated facilities:

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[25] Tables 6 and 7 omit facilities operating in 2004 for which operational status in 1990 is unknown due to missing tank installation year data. Similar calculations (not shown here) treating these facilities as continuously-operated do not materially change these results. Information on the prevalence of missing installation years is provided in Appendix Table A.

[26] 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 (section III.A).

(a) Greater direct risk-reducing activity among facilities in Michigan, whether through closing or replacing old tanks, re-lining existing tanks, installing anti-corrosion equipment, improving maintenance practices, or similar efforts;

(b) Greater non-disclosure of releases that do occur in Michigan after 1995, financial penalties and insurer monitoring efforts notwithstanding; or

(c) A change in the rate at which steel tanks corrode underground in Michigan relative to other Midwest states, for some other reason.

Some additional evidence favors explanation (a), as noted presently. Although we cannot completely rule out (b), we find it difficult to support for the reasons discussed in section IV.C: The facilities in Table 6 are long-term operators at (presumably) profitable locations, and therefore should have high opportunity costs of violating federal reporting requirements—including the substantial civil penalties for non-disclosure and loss of commercial insurance coverage. We can identify no evidence (nor reason) to support explanation (c), which would seem to require a heretofore-undocumented change in Michigan's geology—and in the same year as its insurance policy reform.

Tank closure data offer further, albeit narrow, supporting evidence for explanation (a). Table 7 Panel A shows that after 1995, the number of tanks in service at continuously-operated facilities in Michigan falls 16 percent (from 3.6 to 3.1). In contrast, the corresponding changes are close to zero in Illinois and in Indiana (2.9 to 2.9 and 3.0 to 3.1, respectively). 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, Panel B shows the number of older tanks in service (per facility) at continuously-operated facilities. Column (4) indicates that prior to 1995, facilities in Michigan had nearly twice as many tanks over 20 years old in service (per facility) as Illinois. Michigan had 70 percent more than Indiana. The greater prevalence of older tanks in service helps explain Michigan's higher initial release rate, as noted in Tables 4, 5, and 6.[27]

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[27] The reasons tank age is a statistically useful predictor of leaks are two. First, corrosion takes time (years) to develop. Second, regulatory changes after 1989 required new tanks to meet higher leak resistance standards. This means there is a pure vintage effect that results in most leaks occurring at older tank installations. On these points, the evidence in the technical literature is unequivocal: A detailed engineering study of the caus-

The final row in Panel B reveals that after 1995, this ratio declines 23 percent (from 1.9 to 1.5) relative to Illinois and 13 percent (from 1.7 to 1.5) 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—ostensibly more leak-prone—tanks than Illinois and Indiana.

Interestingly, the proportion of active tanks over 20 years old increases in both Illinois and Indiana, but not in Michigan. This seems consistent with (*i*) increases in new tank installation costs during the 1990s (section III.A), and (*ii*) the limited incentive to replace old tanks under a public insurance system, relative to the incentives to replace old tanks (Tables 1 and 2) under the commercial insurance system adopted in Michigan in 1995.

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:

$$\mathrm{P}_{MI}(R_{ft} \mid A_{ft}\,,\ \sim\! A_{f,2004}) \;>\; \mathrm{P}_{OtherState}(R_{ft} \mid A_{ft}\,,\ \sim\! A_{f,2004})\,, \quad t < 2004\,. \tag{4}$$

Table 8 tabulates empirical frequencies that address (4). It reveals that the facilities that ultimately closed in Michigan had significantly higher historical release rates: Over 6 percentage points higher than Illinois (18.11 versus 10.07 releases per 100 facilities), and 4.5 percentage points higher than Indiana (18.11 versus 13.67 releases per 100 facilities).

Note these frequencies do not say how much selective attrition may have occurred among facilities that closed before 1995, nor how much this contributed to the overall absolute risk reduction in Tables 4 and 5. For this we require a more detailed decomposition of the relative magnitudes.[28]

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es of accidental tank leaks at several hundred facilities in California indicated that over 75% of all leaks occurred in tanks (or piping systems) over 15 years old (Couch and Young, 2001). An independent study conducted for the Michigan Department of Environmental Quality in 1995 reached similar conclusions, finding that tanks over 20 years old or with unknown age accounted for a disproportionate 64% of accidental tank releases (DEQ 1995).

[28] We have 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 transition probabilities vary with time-at-risk but are invariant with respect to calendar time. This stationarity as-

Relative Magnitudes. In principle, we can decompose a state's absolute risk reduction into the release rate changes at continuously-operated facilities (*stayers*), at facilities that ultimately close (*attritants*), and at new facilities (*entrants*), weighted by their population shares:

$$\Delta\mathrm{P}\,(R_{ft}) = s^{s} \times \Delta\mathrm{P}(R_{ft} \mid stayer\,) + s^{a} \times \Delta\mathrm{P}(R_{ft} \mid attrittant\,) + s^{e} \times \Delta\mathrm{P}(R_{ft} \mid entrant\,) \qquad (5)$$

Note that the facility 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 2004, a fixed denominator). The left-hand term is the change in a state's total release rate, as shown in Table 4.

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 (5) is negligible: There are few entrants and their release rates do not change much. The "stayer" share is $s^{s} \approx ⅓$ in each state (*c.f.* Figure 2), and Table 6 reports $\Delta\mathrm{P}(R_{ft} \mid stayer)$. It declines by 4.6 in Michigan versus only 2.5 and 2.2 in Illinois and Indiana (per 100 facilities). Thus the first term on the right in (5) accounts for an excess absolute risk reduction in Michigan over Illinois of about ⅓ × (4.6 – 2.5) = .7 per 100 facilities—which is half Michigan's excess absolute risk reduction (Table 4). The remaining half is attributable to a greater reduction in release rates at attriting facilities.

Table 9 steps through the detailed calculations. Here we include an additional group of "unknown" facilities that are operational in 2004 but have missing entry/installation data (thus cannot be unambiguously categorized as entrants or stayers). Panel A shows the conditional release rate changes for each group, on an average annual basis, before v. after 1995. The declines are broadly similar for both attritants and stayers, although there is some variation between the states.

The attritants' release rates in Panel A are decreasing, yet in Table 8 are increasing over time. They measure different things: Table 8 estimates $\mathrm{P}(R_{ft} \mid A_{ft}\ , \sim A_{f,2004})$, while Panel A of Table 9 (in column 2) shows changes in $\mathrm{P}(R_{ft} \mid \sim A_{f,2004})$. Empirically,

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sumption does not hold here (due to vintage effects and changing tank technical standards), which renders it unclear what distribution standard survival curves are estimating.

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

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

Panel B weights each group's conditional release rate reduction by its population share, corresponding to the products terms on the right 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 two or more. This is not unexpected insofar as approximately two-thirds of all facilities are attritants (Figure 2).

Subtracting the rows in Panel B and expressing the difference by group as a percentage of Michigan's overall excess risk reduction gives the decomposition in Panel C. It shows that half of Michigan's excess absolute risk reduction over Illinois is attributable to the greater risk reduction at continuously-operated facilities in Table 6. 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 the "unknown" group with the stayers they most likely represent would with lower the stayer 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 this second, selective attrition mechanism is not based on overall facility closure rates—which the data indicate were similar in each state (section VI.B). 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 neighboring states seems a particularly plausible outcome of the switch to private-market insurance in that state, since tank attributes that predict future accidental releases (such as tank age) are a major determinant of commercial insurance premiums (Tables 1 and 2).

VII. ALTERNATIVE EXPLANATIONS

Observational studies of policy changes confront two fundamental questions: Did outcomes of interest change significantly after the policy did, and was the policy change the (only) cause? The data appear to answer the first question unequivocally. By any measure, the fraction of establishments that reported an accidental fuel tank release declined dramatically in Michigan relative to surrounding states after 1995. As a consequence, the number of costly accidental release cleanups in that state declined by thousands in subsequent years. The second question is more difficult to answer conclusively, however. Our preferred explanation—the adoption of risk-based insurance pricing in Michigan—stems from its theoretical appeal and ability to explain the empirical evidence assembled here. Still, there are some other potential explanations for these changes and some perspective on these is worthwhile.

A. Michigan Expected Less of a Tank Problem

Is it possible that the Michigan legislature made its policy change because it expected to have less of a problem with tank releases after 1995, and therefore believed its state assurance fund program was no longer needed? If so, then Michigan's decline in accidental releases (relative to other states) after its policy change may not be attributable to the switch to risk-based insurance pricing. That is, perhaps cause and effect are reversed.

State-projected tank release claims in Michigan during the mid-1990s are not especially supportive of this interpretation. The impetus for Michigan's policy change was the fact that its state assurance fund was insolvent. Documents prepared for the state's regulatory enforcement agency at the time indicated that "the current MUSTFA [Michigan Underground Storage Tank Financial Assurance Fund] is already insolvent, with an expected shortfall of $235.34 million to meet expected costs for existing claims." (PSC, 1995).

More importantly, actuarial estimates of future liabilities predicted more than 3000 additional claims for reimbursement between March 1995 and December 1998. This is nearly the same number as during the state fund program's operations in 1993 and 1994, and is a higher projected release rate after 1995 than actually occurred in Michigan—or even in Illinois, for that matter.

In sum, we find no basis to conclude that Michigan expected to have fewer releases in the future, or that it closed its public assurance fund because it believed claims would have declined in any event. The record indicates Michigan closed its assurance fund because the program was insolvent, its actuaries forecasted a growing net liability under the status quo, and its legislature elected not to fund the escalating public subsidy.

B. Michigan Enforced Technical Standards

Tank system anti-corrosion requirements can help reduce tank releases. Conceivably, an alternative explanation for greater decline in release rates in Michigan is that its regulatory authorities made greater efforts to enforce tank engineering and maintenance standards, especially after 1995.

In 2000, the U.S. Government Accountability Office (GAO) conducted a survey of state underground storage tank inspection programs. As summarized in Table 10, this survey showed that Michigan, Illinois and Indiana made similar efforts to enforce technical standards. Facilities in all three states exhibited similar compliance rates with the installation of required leak detection equipment, ranging from 91 to 95 percent. With regard to nominal inspection frequency, a tank is inspected by the state every two years in Illinois, but every three years in Michigan and Indiana. In practice, the GAO found that Michigan inspected between 30 and 40 percent of facilities in the state annually, and a similar percentage for Illinois. Indiana inspected fewer than either of the other states during the late 1990s (less than 20 percent). Although the quantitative evidence on inspections and enforcement activity is limited, there appears to be little basis for attributing Michigan's greater decline in release rates to the conjecture that it may do a better job enforcing technical standards.

IX. 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 over 20 percent, or about 1.5 releases per 100 facilities, more than adjacent states. This is a substantial change, amounting to three-to-four thousand fewer accidental releases over the following eight-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 importantly, it also excludes the cost of any adverse health effects of 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 highly uncertain (see Jenkins, Kopits, and Simpson (2006) for a review).[29]

Is Michigan's policy change and the adoption of risk-based insurance pricing the cause of Michigan's greater decline in accidental release rates? The evidence on causality is necessarily imperfect; there is no true element of randomization in our study design. Still, it seems difficult to identify any other theory capable of explaining all of the available evidence. We believe the most compelling case, and one that may be particularly valuable given the policy implications at stake, 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.[30] 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 we report are confirmed independently for other states undertaking similar insurance reforms, the policy ramifications would be difficult to ignore.

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[29] Simons, *et al.* (1999) estimate that a leaking (commercial) underground storage tank reduces the price of residential property within one block by 17%, and reduces the price of commercial property by 28-42%. Their study uses detailed data for ten leaking gas station sites in one Ohio county.

[30] 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).

With the desirability of replication in mind, we tentatively proffer some of these policy ramifications. According to the *State Financial Assurance Funds Survey* 2007, eight states' underground storage tank financial assurance funds are insolvent with outstanding liabilities totaling $2 billion. Moreover, the US EPA estimates that 12,000 new underground fuel tank releases occur annually.[31] It would appear that adopting risk-based pricing structures similar to those studied here may alleviate these ongoing solvency crises, and reduce the frequency of costly release accidents.

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 (Kareken and Wallace, 1978; Wheelock and Wilson, 1995; but see Akerlof and Romer, 1993, for another perspective).[32] 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 focused 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 of tank systems are self-insured under the private-market regime but few-to-none are self-insured if a state assurance fund is availa-

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[31] US EPA Office of Underground Storage Tanks, *2006 Corrective Action Performance Measures Data.*

[32] 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 required the FDIC to implement a system where each bank's premium reflects the risk it poses to the insurance fund.

ble, it would be useful to determine whether the *ex post* moral hazard problem is more severe with government assurance funds. Last, there are also 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 in reducing accidental releases as the fully private insurance market studied here.

TECHNICAL APPENDIX

This appendix summarizes the methods 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. Appendix Table A 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.

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:

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

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

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

Figure 2 reports an estimate of

$$\textit{total \# active facilities in year } t = \textstyle\sum_f A_{ft} \tag{A-1}$$

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

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

where Ω_f denotes information available to us about facility f. We then replace A_{ft} with $\hat{A}_{ft}$ in (A-1).

Estimating Active Status. Let $i = 1, 2, \ldots, n_f$ be an (arbitrary) enumeration of all tanks, both active and closed, at facility f. Then

$$\begin{aligned} \hat{A}_{ft} &= 1 - \Pr(T_{1t} = 0, T_{2t} = 0, \ldots, T_{n_f t} = 0 | \Omega_f) \\ &= 1 - \prod_{i=2}^{n_f} \Pr(T_{it} = 0 | T_{i-1,t} = 0, \ldots, T_{1t} = 0, \Omega_f) \Pr(T_{1t} = 0 | \Omega_f) \end{aligned}$$

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

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

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

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

so $\hat{A}_{ft} = 1 - p_{1t} p_{2t} \cdots p_{n_f t}$. 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, 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 0 or 1, a degenerate case:

Case 0: I_i observed, and either C_i observed *or* $C_i > 2004$ (right censored). Then

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

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

Case 1: I_i unobserved, C_i observed. (This implies $C_i \leq 2004$). Then

$$\begin{aligned} p_{it} &= \Pr(T_{it} = 0 |\ I_i \ \textit{unobserved},\ C_i,\ n_f, \mathscr{T}_{-it}) \\ &= \begin{cases} \Pr(I_i > t |\ I_i \ \textit{unobserved},\ C_i,\ n_f, \mathscr{T}_{-it}) & ,\ t \leq C_i \\ 1 & ,\ t > C_i \end{cases} \end{aligned}$$

which we estimate with

$$\hat{p}_{it} = \begin{cases} \hat{F}(I_i > t |\ I_i \ \textit{observed},\ C_i,\ n_f, \mathscr{T}_{-it}) & ,\ t \leq C_i \\ 1 & ,\ t > C_i \ . \end{cases}$$

where $\hat{F}(Y|X)$ 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: I_i unobserved, $C_i > 2004$ (right-censored). Then, for $t \leq 2004$,

$$\begin{aligned} p_{it} &= \Pr(A_{it} = 0 |\ I_i \ \textit{unobserved},\ C_i > 2004,\ n_f, \mathscr{T}_{-it}) \\ &= \Pr(I_i > t |\ I_i \ \textit{unobserved},\ C_i > 2004,\ n_f, \mathscr{T}_{-it}) \end{aligned}$$

which we estimate with

$$\hat{p}_{it} = \hat{F}(I_i > t |\ I_i \ \textit{observed},\ C_i > 2004,\ n_f, \mathscr{T}_{-it}) \ .$$

Case 3: I_i observed, C_i unobserved, $C_i \leq 2004$ (not right-censored). Then

$$\begin{aligned} p_{it} &= \Pr(A_{it} = 0 |\ I_i,\ C_i \ \textit{unobserved},\ C_i \leq 2004,\ n_f, \mathscr{T}_{-it}) \\ &= \begin{cases} 1 & ,\ t < I_i \\ \Pr(C_i < t |\ I_i,\ C_i \ \textit{unobserved},\ C_i \leq 2004,\ n_f, \mathscr{T}_{-it}) & ,\ t \geq I_i \end{cases} \end{aligned}$$

which we estimate with

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

Case 4: I_i unobserved, C_i unobserved, $C_i \leq 2004$ (not right-censored). Then, for $t \leq 2004$,

$$\begin{aligned} p_{it} &= \Pr(A_{it} = 0 |\ I_i \ unobserved,\ C_i \ unobserved,\ C_i \leq 2004,\ n_f, \mathscr{T}_{-it}) \\ &= 1 - \Pr(I_i \leq t \leq C_i |\ I_i \ unobserved,\ C_i \ unobserved,\ C_i \leq 2004,\ n_f, \mathscr{T}_{-it}) \end{aligned}$$

which we estimate with

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

The fth summand in (A-1) is then calculated as $\hat{A}_{ft} = 1 - \prod_{i=1}^{n_f} \hat{p}_{it}$.

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 or not the transition dates were recorded in the data. Some support for this assumption comes from our interview with Jan Spoor, the database manager at the Illinois office of the State Fire Marshall, who indicated the major reason for missing date information is that her office is understaffed and the missed information is not considered essential (May 19, 2005). She also noted that when a tank owner or operator reports obviously wrong information (e.g., an installation year of 2040), her office codes it as missing. 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 is the reason we are circumspect in reporting them in the text.

Total Number of Facilities. The total number of facilities reported by year in Figure 2 and used in the denominator of equation (1) is the cumulative number "born" on or before year t, or

$$N_t = \sum\nolimits_f \mathbf{1}\left(\min_{i \text{ at} f}\{I_i\} \leq t\right) \tag{A-2}$$

where $\mathbf{1}(\cdot)$ denotes the indicator function. The sum is over all facilities ever alive before t. If the installation year I_i is unobserved for tank i at facility f, we replace the fth summand with

$$\Pr\left(\min_{i \text{ at} f}\{I_i\} \leq 1|\Omega_f\right) = 1 - \prod_{i=2}^{n_f} \Pr(I_i > t|\mathscr{I}_{-i}, \Omega_f)\Pr(I_1 > t|\Omega_f)$$

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

$$\mathscr{I}_{-i} = \{I_{i-1} > t,\ I_{i-2} > t,\ \ldots,\ I_1 > t = 0\}.$$

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

Case 1: C_i observed. (This implies $C_i \leq 2004$.) Then

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

which we estimate with

$$\hat{q}_i = \begin{cases} 1 & , t < C_i \\ \hat{F}(I_i > t |\ I_i \ observed,\ C_i,\ n_f, \mathscr{I}_{-i}) & , t \geq C_i \ . \end{cases}$$

Case 2: $C_i > 2004$ (right-censored). Then, for $t < 2004$,

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

which we estimate with

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

Case 3: C_i unobserved, $C_i \leq 2004$ (not right-censored). Then

$$\Pr(I_i > t | \mathscr{I}_{-i}, \Omega_f) = \Pr(I_i > t |\ I_i \ unobserved,\ C_i \ unobserved,\ C_i \leq 2004,\ n_f, \mathscr{I}_{-i}) \ .$$

which we estimate with

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

Last, we set $\hat{q}_i$ equal to either 1 or 0, as appropriate, if tank i's installation year is recorded in the data. This is common in the data for Michigan and Illinois, less common in Indiana (Table A). The fth summand in (A-2) is then calculated as

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

Active Release Rates. To evaluate a state's active release rate using equation (2), the denominator requires the statistic in equation (A-1) and the numerator requires

$$\textit{\# releases at active facilities in year } t = \sum\nolimits_f \mathbf{1}(R_{ft} | A_{ft} = 1) \tag{A-3}$$

where R_{ft} indicates a release a facility f in year t and $\mathbf{1}(\cdot)$ the indicator function. If either I_i or C_i is unobserved for a tank at facility f, we replace the fth summand in (A-3) with an estimate of $\Pr(R_{ft}|A_{ft} = 1)$. Since A_{ft} is not directly observed in this case, we use Bayes' rule,

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

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

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

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

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Figure 1. Difference in Overall Release Rates for Michigan – Illinois, 1990-2003

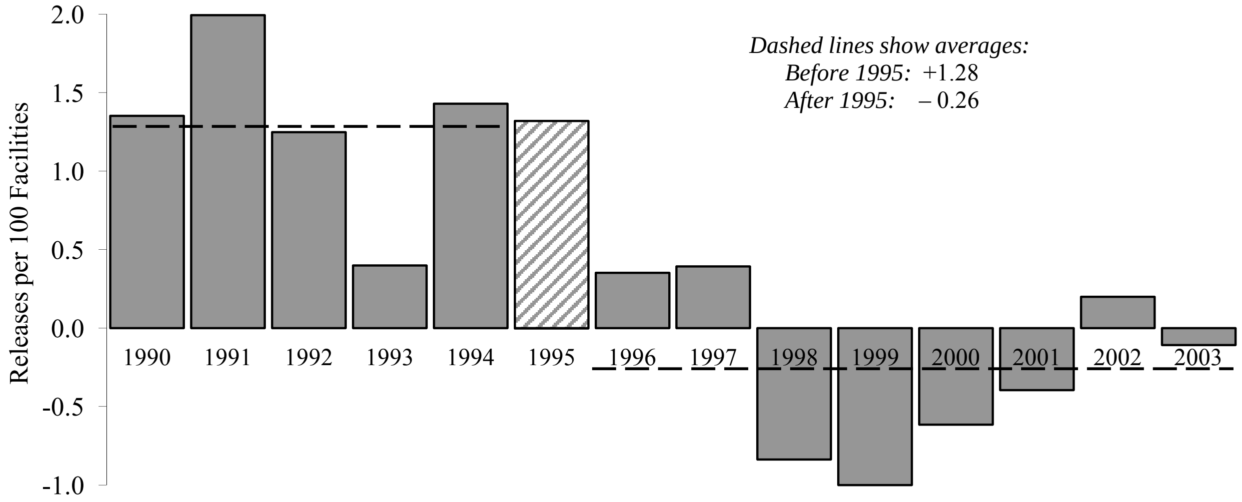

Figure 2. Number of Facilities and Active Facilities in Illinois and Michigan, 1986-2003

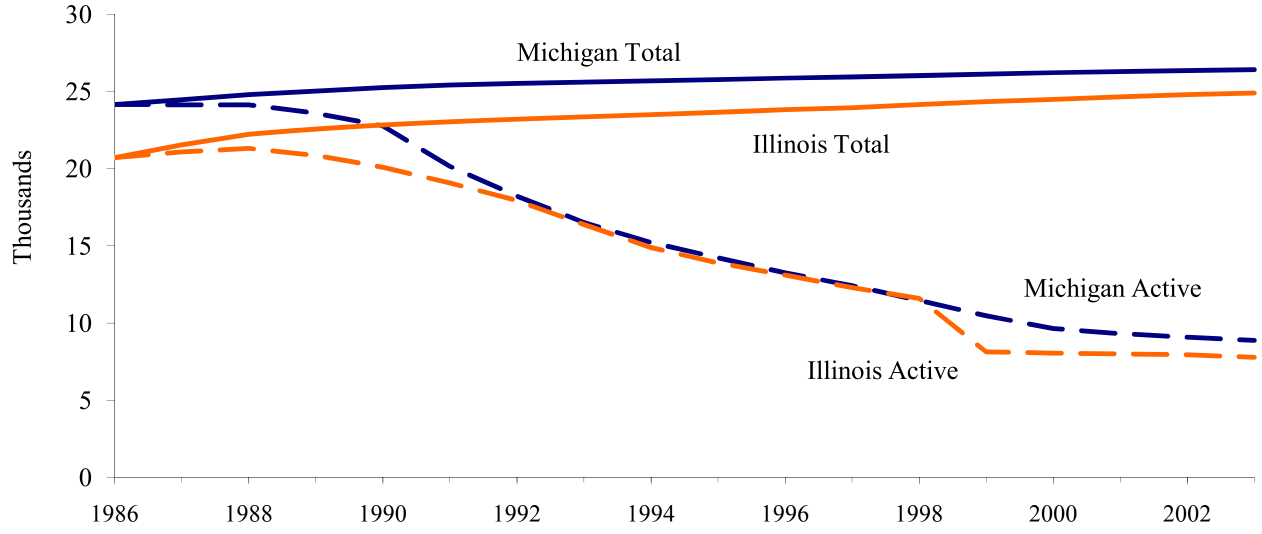

Table 1

Private Insurance Rate Factors and Base Premia
For Underground Fuel Tank Accidental Release Coverage

Panel A: Base Insurance Premium by Tank Type and Age (years). In dollars per tank, p.a.

	0 to 5	6 to 10	11 to 15	16 to 20	21 to 25	26 to 30	31 to 35	> 35 years
Single-Wall Construction	$284 - $339	$350 - $470	$500 - $700	$760 - $1030	$1100 - $1380	$1450 - $1690	$1,750	$1,850
Double-Wall Construction	$185 - $221	$228 - $302	$320 - $356	$365 - $426	$441 - $509	$441 - $509	$526 - $582	$620

Panel B: Impact of Preventive and Detective Equipment on Insurance Premia

	Yes	No	Unknown
Advanced Leak Detection	0%	+10%	+10%
Overfill Detection	0%	+10%	+10%
Supplemental Corrosion Protection System(s)	0%	+10%	+10%

Panel C: Impact of Prior Accidental Releases on Insurance Premia

	Yes, Claim Closed	Yes, Claim Open	No
Prior Release at Same Facility (adjustment per release)	+10%	+20%	0%

Notes. Table reports insurance premia information from Zurich N.A. for environmental liability and tank pollution insurance per $1 million coverage at a $5,000 deductible. This is a partial list of all rate factores used by this insurer. Data from 2004.
Sources: Zurich N.A., and the Michigan Office of Financial and Insurance Services.

Table 2

Variation in Private Insurance Premia in 1997 For Typical Tank System Configurations of Several Vintages

Tank System Attributes						*Insurance Premia for a 3-Tank System (1997 $)*		
Vintage	Tank Material	Piping Construction	Anti-Corrosion Equipment	Overfill Protection	Inventory Monitoring	Insurer A	Insurer B	Insurer C
1997	Reinforced Fiberglass	Double Wall	N/A	Yes	Automated	$1,350 ($5K ded.)	$825 ($5K ded.)	$1,320 ($10K ded.)
1991	Coated Steel	Single Wall	Yes	Yes	Automated	$1,500 ($5K ded.)	$1,250 ($5K ded.)	$1,320 ($10K ded.)
1985	Bare Steel	Single Wall	Yes	No	Manual	$3,500 ($10K ded.)	$1,500 ($5K ded.)	$2,563 ($10K ded.)
1975	Bare Steel	Single Wall	No	No	Manual	Decline Coverage	$3,800 ($5K ded.)	$5,610 ($10K ded.)

Notes. Minimum deductibles noted in parentheses (where K=1000). All tanks are single-walled construction. Anti-corrosion equipment (cathodic) applies only to steel tanks. *Source:* EPA (1997).

Table 3
Facility Statistics and Trends by State

	Michigan	Illinois	Indiana
Vehicle Miles Traveled (in billions), 1990	81.1	83.3	53.7
Growth Rate, 1990 to 2003 (p.a.)	2%	2%	2%
Number of Active Facilities, 1990	25,253	22,809	17,089
Growth Rate, 1990 to 2003 (p.a.)	-7%	-7%	-6%
Average No. Tanks per Facility, 1990	2.8	2.7	2.4
Growth Rate, 1990 to 2003 (p.a.)	-0.2%	0.8%	-0.4%
Average Tank Capacity (in gallons), 1990	4,428	4,732	4,248
Growth Rate, 1990 to 2003 (p.a.)	5%	4%	5%
Median Active Tank Age (in years)			
1990	14	11	10
2003	16	13	13

Notes. Growth rates are average annual compound rates from 1990 to 2003. Tank-level attributes are means for active facilities. *Sources.* Authors' calculations (see text) and *Highway Statistics* 1990, 2003, Table VM-2.

Table 4
Changes in Total Release Rates over Time by State

(Standard errors in parentheses)

	Releases per 100 Facilities		*Absolute Risk Reduction*		*Relative Risk Reduction* [a]	
State	Pre-transition (1990-1994)	Post-transition (1996-2003)	Post – Pre Difference	Contrast vs. MI	Post v. Pre (in percent)	Etiologic Ratio[b]
Michigan	6.51	2.56	-3.95		-60.6	
	(0.09)	(0.06)	(0.10)		(1.0)	
Illinois	5.23	2.82	-2.42	-1.53	-46.2	1.31
	(0.09)	(0.06)	(0.11)	(0.15)	(1.5)	(0.05)
Indiana	3.62	1.84	-1.77	-2.18	-49.0	1.24
	(0.09)	(0.06)	(0.11)	(0.15)	(2.2)	(0.06)

Notes. Standard errors assume a (symmetric) misclassification error rate of 5 percent (see text).

[a] Relative risk reduction is 100 × ($rate^{post} / rate^{pre} - 1$)

[b] The etiologic ratio is $RRR^{MICH} / RRR^{OtherState}$, where *RRR* is relative risk reduction

Table 5
Changes in Active Facility Release Rates over Time by State

(Standard errors in parentheses)

	Releases per 100 Facilities		*Absolute Risk Reduction*		*Relative Risk Reduction* [a]	
State	Pre-transition (1990-1994)	Post-transition (1996-2003)	Post – Pre Difference	Contrast vs. MI	Post v. Pre (in percent)	Etiologic Ratio[b]
Michigan	8.81	5.78	-3.03		-34.4	
	(0.11)	(0.10)	(0.15)		(1.4)	
Illinois	5.74	4.48	-1.25	-1.78	-21.8	1.58
	(0.10)	(0.10)	(0.14)	(0.21)	(2.3)	(0.18)
Indiana	4.20	3.26	-0.95	-2.09	-22.5	1.53
	(0.10)	(0.10)	(0.14)	(0.20)	(3.0)	(0.21)

Notes. Standard errors assume a (symmetric) misclassification error rate of 5 percent (see text).

[a] Relative risk reduction is 100 × ($rate^{post} / rate^{pre} - 1$)

[b] The etiologic ratio is $RRR^{MICH} / RRR^{OtherState}$, where *RRR* is relative risk reduction

Table 6
Release Rates at Continuously-Operated Facilities 1990-2003
(Standard errors in parentheses)

	Releases per 100 Facilities		*Absolute Risk Reduction*		*Relative Risk Reduction* [a]	
State	Pre-transition (1990-1994)	Post-transition (1996-2003)	Post – Pre Difference	Contrast vs. MI	Post v. Pre (in percent)	Etiologic Ratio[b]
Michigan	8.08	3.51	-4.57		-56.6	
n = 6985	(0.18)	(0.12)	(0.21)		(1.7)	
Illinois	6.27	3.72	-2.55	-2.02	-40.6	1.39
n = 4103	(0.22)	(0.15)	(0.26)	(0.34)	(3.2)	(0.12)
Indiana	6.04	3.84	-2.20	-2.37	-36.4	1.55
n = 2606	(0.27)	(0.19)	(0.33)	(0.42)	(4.3)	(0.19)

Notes. Standard errors assume a (symmetric) misclassification error rate of 5 percent (see text).

[a] Relative risk reduction is 100 × ($rate^{post}$ / $rate^{pre}$ – 1)

[b] The etiologic ratio is RRR^{MICH} / $RRR^{OtherState}$, where *RRR* is relative risk reduction

Table 7
Number of Tanks in Service at Continuously-Operated Facilities, 1990-2003

	Michigan (1)	Illinois (2)	Indiana (3)	MI / IL Ratio (4)	MI / IN Ratio (5)
			Panel A: Active Tanks per Facility		
Pre (1990-1994)	3.6	2.9	3.0	1.2	1.2
Post (1996-2003)	3.1	2.9	3.1	1.1	1.0
Percent change	-16%	-1%	3%	-15%	-18%
			Panel B: Active Tanks Over 20 Years Old per Facility		
Pre (1990-1994)	1.0	0.5	0.6	1.9	1.7
Post (1996-2003)	1.0	0.7	0.7	1.5	1.5
Percent change	0%	31%	15%	-23%	-13%

Notes. Figures are annual averages. Percentages calculated before rounding.

Table 8
Release Rates at Attriting Facilities
(Subsample of facilities closed by 2004. Releases per 100 active facilities)

	Michigan (1)	Illinois (2)	Indiana (3)	MI / IL ratio (4)	MI / IN ratio (5)
Overall Rate, 1990-2003	18.11	10.07	13.67	1.8	1.3
Pre-transition (1990-1994)	9.89	5.86	5.37	1.7	1.8
Post-transition (1996-2003)	24.25	13.41	19.59	1.8	1.2

Figures are annual averages for each period.

Table 10
Regulatory Compliance and Inspection Rates by State

	Michigan	Illinois	Indiana
Percent of active tanks with required leak detection equipment installed	91 - 95	91 - 95	91 - 95
Number of full-time employees that conduct field UST inspections	21	23	6
Frequency of state UST inspections (nominally)	Every 3 years	Every 2 years	Every 3 years
Fraction of tanks inspected annually (actual)	30 - 40%	30 - 40 %	10 - 20 %

Source: Government Accounting Office (2000)

Table 9
Decomposition of Absolute Risk Reduction by Facility Duration Status 1990-2003

	All (1)	Attritants (2)	Stayers (3)	Entrants (4)	Unknown[a] (5)
Panel A: Absolute Risk Reduction by Group, Post 1995 – Pre 1995. Rate per 100 facilities.					
Michigan	-3.95	-4.63	-4.57	0.31	-2.98
Illinois	-2.42	-3.19	-2.55	0.06	-1.18
Indiana	-1.77	-1.70	-2.20	0.17	-2.49
Panel B: Contribution of Each Group to Total Risk Reduction by State. Rate per 100 facilities.					
Michigan	-3.95	-2.70	-1.21	0.01	-0.05
Illinois	-2.42	-1.91	-0.42	0.00	-0.08
Indiana	-1.77	-1.03	-0.30	0.01	-0.43
Panel C: Decomposition of 'Excess' Absolute Risk Reduction in Michigan by Group					
Michigan – Illinois		51%	51%	-1%	-2%
Michigan – Indiana		76%	42%	0%	-17%

Notes. a. "Unknown" are facilities operational in 2004 but that cannot be definitively classified as entrants or as stayers from 1990-2003 due to missing installation year data. These are 2% (MI), 7% (IL), and 17% (IN) of each state's total (active and closed) facilities.

b. Panels A and B decompose equation (5) in the text: A reports conditional release rate changes $\Delta P(R_{ft} \mid group)$, and B reports share-weighted changes, $s^{group} \times \Delta P(R_{ft} \mid group)$.

Appendix Table A
Prevalence of Missing Tank Installation and Closure Dates

	Michigan		*Illinois*		*Indiana*	
Information Available	Number	Percent	Number	Percent	Number	Percent
A. 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
B. 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
Total Observations	90,008	100	85,326	100	56,055	100

Notes. Status in 2004 (active or closed) is known for all tanks. Data exclude tanks at facilities permanently closed prior to 1986, when reporting requirements commenced. Percentages may not sum to 100.0 due to independent rounding.