Internalizing Environmental Risk: Insurance Design and Firm Behavior in Hazardous Industries

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Abstract

Public trust funds in thirty-eight U.S. states insure underground storage tank (UST) leaks at a uniform flat fee, even though leak risk varies widely with observable traits such as tank age and wall construction. This paper quantifies how replacing flat-fee pooling with actuarially priced coverage changes firm behavior and environmental outcomes. I exploit Texas's 1999 closure of its trust fund, which forced all owners into a private market that sets premiums according to facility risk. A facility-year panel covering 1990–2021 links EPA inventories with administrative microdata for Texas and eighteen control states that retained public funds. Difference-in-differences and event-study estimates show that, among single-wall tanks installed before 1999, risk-rated premiums increased annual closure rates by two to three percentage points, shifted closures from market exit to on-site replacement with safer equipment, and reduced the probability of a reported leak by about one percentage point, nearly the entire pre-policy baseline for this high-risk group. The findings provide the first causal micro-evidence that cost-based environmental liability insurance can internalize pollution risk more effectively than uniform public pooling, offering clear guidance for states that are reconsidering the structure of UST insurance programs.

Introduction

Underground storage tanks holding motor fuels and other hazardous liquids sit beneath about half a million U.S. facilities, and leaks from these tanks are the leading documented source of groundwater contamination EPA (?). Cleanup is costly; median remediation expenses exceed \$100 000 per site Marcus (?), and the probability of a release rises sharply with observable characteristics such as tank age and whether the walls are single or double. Despite these predictable differences, thirty-eight states finance remediation through public trust funds that charge every facility the same premium, diluting incentives to invest in safer technology and crowding out private insurers ASTSWMO (?).

Economic theory predicts that tying premiums to expected damages should induce firms to internalize environmental risk Shavell (?); Polinsky (?), yet empirical tests of this mechanism for USTs are scarce. Michigan's mid-1990s shift toward private, risk-rated coverage suggested large gains but relied on aggregate counts that could not isolate facility-level responses Yin, Pfaff, and Kunreuther (?); Yin, Kunreuther, and White (?). Whether actuarial pricing disciplines high-risk owners without simply driving them out of the market therefore remains unresolved.

Texas provides a clean natural experiment. In 1999 the state closed its public fund overnight and required all owners to purchase private coverage whose premiums vary with observable risk. I assemble a new facility-year panel covering 1990 to 2021 that links EPA inventories with administrative microdata from the Texas Commission on Environmental Quality and comparable data from eighteen control states that retained trust funds. A difference-in-differences design compares Texas with these fund states, and an event-study variant confirms parallel pre-trends.

Three main results emerge. First, among single-wall tanks installed before 1999, risk-based pricing raised annual closure probabilities by roughly two to three percentage points and shifted closures from outright exit to on-site replacement with safer equipment. Second, the probability of a reported leak fell by about one percentage point, nearly the entire pre-policy baseline for this high-risk group. Third, the effect on leak rates is concentrated among facilities that were already high-risk before the policy change, suggesting that cost-based pricing effectively targets riskier firms. By providing the first causal micro-evidence that actuarially priced environmental liability insurance changes firm behavior in hazardous industries, the paper speaks directly to current policy debates over the future of state UST funds.

Related Literature

A well-established body of theoretical work suggests that strict liability rules can be an effective policy instrument for environmental risks, particularly when paired with insurance contracts that align a firm's private incentives with social costs (Shavell (?), Shavell (?), Shavell (?), Polinsky (?), Boyd and Kunreuther (?), Shavell (?)). A crucial condition for this alignment is the insurer's ability to accurately price the risk of environmental harm. This paper provides the first empirical test of this principle in the context of environmental liability, offering causal estimates of how firms respond to a transition from flat-fee to more efficient, cost-based insurance contracts.

The challenge of pricing environmental risk connects this study to the broader economics literature on insurance and selection markets. Specifically, this paper builds on work examining the effects of cost-based pricing and contract design on market outcomes and participant behavior (Janvry, McIntosh, and Sadoulet (?), McWilliams, Hsu, and Newhouse (?), Einav, Jenkins, and Levin (?), Einav, Jenkins, and Levin (?), Brown et al. (?), Liberman et al. (?), Nelson (?), Einav, Finkelstein, and Mahoney (?)). By studying the transition to risk-based premiums for environmental liability, this research contributes new evidence on how mispriced insurance can distort markets, particularly in hazardous industries where the social costs of pollution are significant.

This paper also contributes to the literature on U.S. UST policy. While much of the existing work focuses on estimating the marginal damages of pollution from leaks (Marcus (?), Zabel and Guignet (?), Guignet (?), Guignet and Martinez-Cruz (?), Guignet et al. (?), Walsh and Mui (?), Guignet (?)), this study is complementary, examining the design of management policies intended to prevent those damages.

This research is most closely related to studies of a similar insurance market reform in Michigan by Yin, Pfaff, and Kunreuther (?), Yin, Kunreuther, and White (?), and Yin, Kunreuther, and White

(?). That body of work finds that transitioning to risk-based insurance reduced the number of small firms and reported leaks. However, those analyses relied on aggregate or cross-sectional data, which cannot control for unobserved facility-level heterogeneity and may be susceptible to omitted variable bias.This research is most closely related to studies of a similar insurance market reform in Michigan by Yin, Pfaff, and Kunreuther (?), Yin, Kunreuther, and White (?), and Yin, Kunreuther, and White (?). That body of work finds that transitioning to risk-based insurance reduced the number of small firms and reported leaks. However, those analyses relied on aggregate or cross-sectional data, which cannot control for unobserved facility-level heterogeneity and may be susceptible to omitted variable bias. This paper advances on prior work by adopting an empirical strategy similar to other modern studies of environmental liability (Boomhower (?)). By using a rich, facility-level panel dataset, I can implement difference-in-differences models that control for unobserved facility characteristics and common time shocks, providing more credible causal estimates of how firms adjust their technology, replacement, and exit decisions in response to cost-based pricing.

Setting and Data

The Policy and Technical Landscape of U.S. Underground Storage Tanks

An underground storage tank (UST) is defined by the U.S. Environmental Protection Agency as any tank, including its connected underground piping, with at least 10% of its volume below ground (EPA (?)). Most UST facilities house multiple tanks on a single site and typically contain hazardous substances like petroleum. Importantly, the majority of these facilities are retail gas stations. In Texas, for example, an annual average of 75% of active facilities during the sample period are retail gas stations. The next largest category is fleet refueling firms (20%), with the remainder comprising airports, marinas, industrial plants, and municipal properties. These shares are consistent with national averages, where retail gas stations account for approximately 75% of all UST facilities (EPA (?)).

The primary technical distinction between USTs is their construction: either single-walled or double-walled. This initial technology choice is critical because, in practice, facility owners rarely invest in incremental upgrades once a tank is operational. Comprehensive data on such improvements are sparse, but evidence from Texas, where pricing incentives to upgrade have been strongest, is telling. From 1998 to 2021, only 0.003% of facilities ever upgraded their tanks. Instead, investment decisions are concentrated at two points: initial installation and subsequent closure with tank replacement, or complete exit from the market. This resistance to midlife retrofits underscores their high cost and reflects the perverse incentives created by vintage-differentiated minimum performance standards, which often grandfather in older, less safe technologies.[1]

A facility's choice of UST construction carries significant economic and environmental consequences. Single-walled tanks are markedly cheaper to build but leak far more often than double-walled designs. Retail catalogues and direct correspondence with a major manufacturer indicate that single-walled fiberglass tanks sell for roughly one-half to one-third the price of comparable double-walled units.[2]

[1] For example, 30 Tex. Admin. Code §334.45(d)(E)(i) requires that new tanks and piping (installed on or after Jan. 1, 2009) "must incorporate secondary containment". In other words, only newly installed UST systems must have dual containment, whereas older tanks (installed before that date) are not retroactively required to do so. Furthermore, the Texas code defines a new UST system as one whose installation "commenced after December 22, 1988." Every state has similar language, effectively grandfathering in older tanks and creating a vintage-differentiated regulation that discourages retrofits Gruenspecht (?)

[2] Direct correspondence with one of the largest UST manufacturers confirm that single-walled tank costs remains roughly one-half to two-thirds the price of an otherwise comparable double-walled tank. The sales team (speaking under a promise of anonymity) explained that they update list prices to reflect general input-cost inflation, i.e with general input costs, but the manufacturer deliberately keeps the percentage surcharge for secondary containment almost unchanged. Historical evidence echoes this pattern. An industry survey reported by the U.S. GAO priced a new 10 000-gallon fiberglass tank in 1987 at about $23 000 for single wall versus $39 000 for double wall, a 67 percent premium that has persisted for decades ("Hazardous Materials: Upgrading of Underground Storage Tanks Can Be Improved to Avoid Costly Cleanups" (?)). A January 2021 Containment Solutions guide lists double-walled fiberglass tanks from $162 270 (15 000 gal) to $462 425 (50 000 gal); although the catalogue no longer offers single-wall primaries, accessory pages show one-third lower prices for single-wall collars and sumps, implying a similar shell-level surcharge (Containment Solutions, Inc. (?)). A 2018 Xerxes list quotes single-wall prices of $19 382 (10 000 gal) and $174 690 (50 000 gal), while the matching double-wall prices are $47 497 and $326 671, confirming a 60–90 percent differential in that year (Xerxes Corporation (?)). All figures cover the tank itself; installation labour,

This cost-safety trade-off is borne out empirically. As shown in Figure **??**, facilities equipped with single-walled systems are significantly more likely to report releases than their double-walled peers at every age.

The evolution of the nation's UST stock has been heavily shaped by the 1998 federal deadline requiring the closure or upgrade of all non-compliant tanks. In the years leading up to this deadline, the average annual closure rate was a substantial 25.56% (SE = 9.91). Following this large-scale removal of older tanks, the turnover rate dropped dramatically; from 1999 onward, the average annual closure rate fell to just 3.29% (SE = 3.12). This slow post-deadline replacement cycle has led to a persistently old and high-risk tank population. In 1994, single-wall tanks constituted 56.2% of all active tanks, and while this share has declined, they still represented 47.8% of the active stock in 2019. This persistence is reflected in the age of the tanks, with the average age of an active tank steadily increasing from 13.3 years in 1994 to 30.7 years in 2019. Across the entire sample, single-wall tanks are significantly older, with an average age of 22.5 years, compared to 11.7 years for double-wall tanks. While the 1998 deadline removed a large cohort of the riskiest tanks, the subsequent low turnover rate has resulted in a significant and aging stock of high-risk USTs remaining in operation today.

Given the significant cleanup costs from leaks, federal regulations require UST owners to demonstrate financial responsibility, typically by securing $1 million in coverage. In the early 1990s, with the private insurance market for this risk still nascent, many states established UST Trust Funds to provide publicly managed insurance pools. However, unlike traditional insurance, these public funds typically operated on a flat-fee basis, charging uniform premiums regardless of facility-specific risk. While this approach ensures remediation costs are covered, it creates a significant price externality. By pooling diverse risks under one price, these funds distort incentives for risk mitigation and crowd out the private insurance market. In states with such funds, they consistently cover 90-100% of all facilities, an unsurprising outcome given that the subsidized, flat-fee contracts are difficult for any private, risk-based insurer to compete against.[3]

Six states have since transitioned away from this public model to private insurance markets, with Texas transitioning in 1999. This shift provides the setting for this paper's analysis. In Texas, from 2007 to 2021, an average of 89.8% of retail UST facilities met their financial responsibility requirements using private insurance. The remaining 10.2% relied on other mechanisms, predominantly self-insurance, a path available only to large owners who can meet stringent financial asset tests. Crucially, this private insurance market appears to incorporate facility risk. On average, 69.4% of these privately insured facilities were comprised of at least one single-wall tank. This indicates that higher-risk facilities are not excluded from the market but instead select into private insurance, where they face risk-adjusted premiums that reflect their specific operational characteristics.

In summary, the U.S. is managing a large and aging stock of underground storage tanks where construction type is a strong predictor of leak risk. The prevailing insurance regime, either a flat-fee public fund or a cost-based pricing private market, critically shapes the incentives for managing these risks. To empirically test how insurance design affects firm behavior, the following sections detail the data and causal methodology used to analyze Texas's transition to a private insurance market.

required release-detection equipment, and other site-specific costs are additional.

[3] Surveys from the Association of State and Territorial Solid Waste Management Officials (ASTSWMO (**?**)) show that between 2000 and 2021 consistently show that in states with public funds, these funds cover 90-100% of facilities. This holds true even in state fund states that permit owners to use private insurance, indicating the state fund is the dominant instrument.

Setting, Data, and Institutional Background

The Technical and Regulatory Landscape of U.S. Underground Storage Tanks

The physical setting of this analysis concerns the U.S. Environmental Protection Agency (EPA) definition of an underground storage tank (UST) system: any tank and connected underground piping with at least 10% of its volume beneath the surface (EPA (**?**)). These facilities are predominantly retail gas stations, which account for approximately 75% of active sites in both the national average and the Texas-specific sample. The remainder comprises fleet refueling depots (20%) and a mix of industrial, aviation, and municipal facilities.

The primary source of heterogeneity in this capital stock is the tank construction technology. The critical distinction lies between single-walled systems—essentially bare steel or fiberglass shells—and double-walled systems, which incorporate an interstitial space for leak detection. This initial technology choice is economically critical because facility owners rarely invest in incremental upgrades once a tank is operational. From 1998 to 2021, only 0.003% of Texas facilities ever retrofitted their tanks prior to a terminal closure event. Investment decisions are consequently concentrated at the extensive margin of entry and exit. This resistance to midlife retrofits reflects high switching costs and the perverse incentives created by vintage-differentiated standards. State regulations typically grandfather in older systems, requiring secondary containment only for new installations initiated after specific cutoff dates, such as December 1988 or January 2009.

The construction type dictates the environmental risk profile. Single-walled tanks are significantly cheaper to install but exhibit higher failure rates. Historical industry data indicates a persistent price differential; a 1987 GAO survey priced single-walled units at approximately \$23,000 compared to \$39,000 for double-walled equivalents, a 67% premium. Federal regulation explicitly targets this risk through the 1984 Hazardous and Solid Waste Amendments (HSWA), which culminated in a 1998 deadline requiring the closure or upgrade of non-compliant tanks. While the years preceding this deadline saw annual closure rates averaging 25.56% (SE = 9.91), the post-deadline turnover dropped precipitously to 3.29% (SE = 3.12). This collapse in capital turnover resulted in an aging legacy fleet. In 2019, single-walled tanks still constituted 47.8% of the active stock, with an average age of 22.5 years compared to 11.7 years for double-walled units.

Financial Responsibility and the Insurance Regime

To mitigate the liability associated with these environmental risks, the EPA's 1988 Financial Responsibility Rule (40 CFR Part 280, Subpart H) mandates that owners secure coverage for corrective action and third-party liability, typically \$1 million per occurrence. In the late 1980s, the immaturity of the private environmental insurance market led many states to establish public trust funds. These funds typically operate on a flat-fee basis, charging uniform premiums regardless of facility-specific risk. While effective at ensuring solvency, this pooling mechanism creates a price externality that distorts incentives for risk mitigation. In states retaining such funds, they consistently cover 90% to 100% of facilities.

Texas initially utilized a public fund model but diverged in 1998 following the passage of House Bill 2587. Facing actuarial insolvency, the legislature sunset the Texas Petroleum Storage Tank Remediation Fund, forcing the entire facility population to migrate to the private market or self-insure by 1999. This sharp policy discontinuity serves as the central identification strategy. In the post-transition period (2007–2021), 89.8% of Texas retail facilities met their obligations through private insurance, with the remainder relying on self-insurance mechanisms available only to highly capitalized firms.

Conceptual Framework: Insurance Design and Optimal Stopping

The facility owner's decision is modeled as a single-agent dynamic discrete choice problem following the optimal stopping literature (Rust, 1987). In an infinite horizon setting with time indexed by

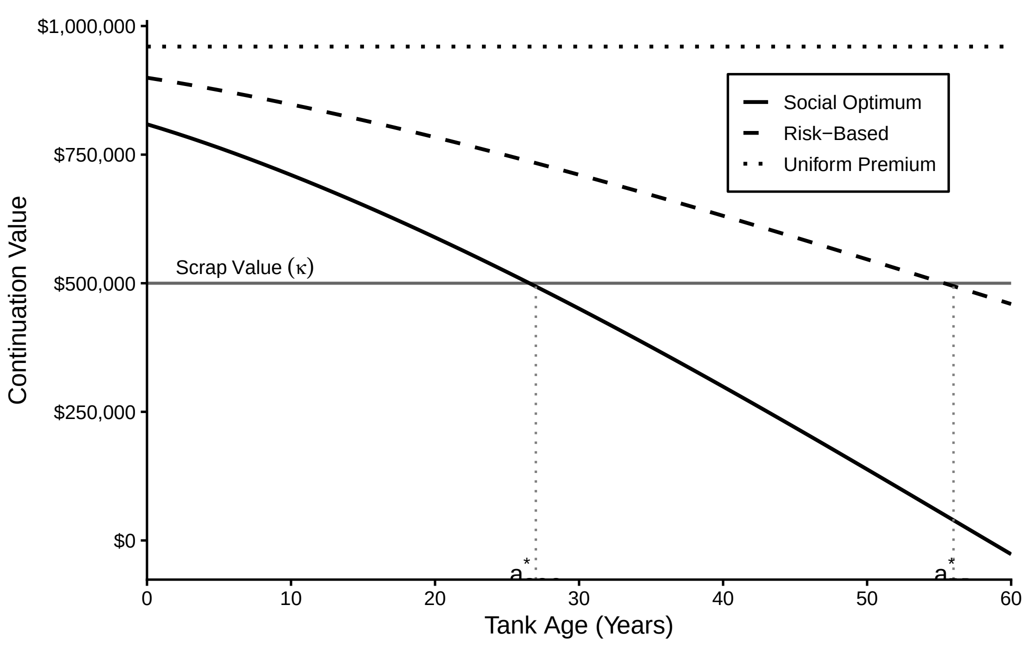
t, the agent operates a single underground storage tank (UST) and observes the state variable a_t, representing the tank's age. At the beginning of each period, the agent chooses a binary action $d_t \in \{\text{Maintain}, \text{Close}\}$ to maximize the expected present discounted value of future payoffs. If the agent chooses to close ($d_t = \text{Close}$), the facility exits the market permanently, receiving a terminal scrap value κ representing the liquidity of the land net of decommissioning costs. Conditional on maintenance ($d_t = \text{Maintain}$), the flow utility is specified as $u(a_t) = R - P_j(a_t)$, where R denotes the annual net revenue from operations less all non-insurance costs, and $P_j(a_t)$ is the insurance premium under regime j. While the structural estimation in Section 5 relaxes this assumption to incorporate deductibles and partial risk internalization, this simplified framework assumes full insurance coverage for tractability, treating environmental risk solely as an ex-ante premium cost rather than an ex-post liability shock. The agent's value function $V(a)$ satisfies the Bellman equation:

$$V(a) = \max\left\{R - P_j(a) + \beta\mathbb{E}[V(a') \mid a], \kappa\right\}$$

where $\beta \in (0, 1)$ is the discount factor and the expectation is taken over the stochastic evolution of tank age. The optimal stopping rule dictates that the firm closes the tank when the continuation value of operation falls below the scrap value κ.

The divergence in firm behavior across states is driven by the elasticity of the premium function $P_j(a)$ with respect to capital depreciation. Under the **Uniform Premium (Public Fund)** regime, the price is invariant to risk, such that $P(a) = \bar{P}$ and the marginal cost of aging is zero ($\frac{\partial P}{\partial a} = 0$). This flat pricing structure eliminates the financial incentive to retire aging capital, pivoting the continuation value curve upward and causing the firm to retain the asset until it is physically obsolete, defined as age a^*_{UP}. Conversely, under the **Risk-Based (Private Market)** regime, premiums are strictly increasing in the leak hazard rate $h(a)$, such that $\frac{\partial P}{\partial a} > 0$. This introduces a positive marginal cost of aging, pivoting the value function downward for older tanks and accelerating the optimal exit age to a^*_{RB}. Figure 1 illustrates this mechanism, demonstrating that the introduction of risk-based pricing strictly reduces the optimal tank lifespan relative to the uniform pricing baseline ($a^*_{RB} < a^*_{UP}$).

Figure 1: The Mechanism: Optimal Stopping under Alternative Insurance Regimes



While risk-based pricing improves allocative efficiency by penalizing higher failure rates, it does not achieve the first-best social optimum due to unpriced health externalities. The social planner's objective function includes both the remediation costs (L) covered by insurers and the health