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

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February 10, 2026

Goals for Today's Talk

1. **Toy Model: Is the Focus Right?**
   - Does the simple framework clearly capture the behavior I can measure (tank closures)?
   - Thoughts on how to sharpen the premium $\rightarrow$ closure mechanism?
2. **Structural Model: What's Missing?**
   - Is the DDC setup complete, or are key state variables/parameters omitted?
   - **Specific question:** How do I incorporate Marcus (2021) health externalities without estimating damages myself? Just use their estimates as inputs?
   - Best ways to push this forward?

Motivation: Mispricing Environmental Risk

The Environmental Problem

- USTs are the leading source of groundwater contamination (EPA, 2024); median cleanup cost $\sim \$150{,}000$ and mean costs $\sim \$420{,}000$

The Policy Paradox

- Federal law mandates strict liability insurance to internalize remediation costs.
- Strict liability works only when $P_i \propto Risk_i$ (Shavell, 1982), but uniform premiums $\bar{P}$ break this link.

The Technological Friction

- Single-walled tanks (riskiest types) persist: 73% of Texas stock as of 1999 and 49% in 2018, 75% of Control states in 1999 and 63% in 2018
- Double-walled replacement costs 60–90% more (GAO, 1987).

The "Texas Experiment" (1999)

- **Shock:** Petroleum Storage Tank (PST) Fund sunset forces 100% of owners into risk-rated private market.
- **Prediction:** Risk-based pricing should induce tank closures of high-risk facilities.

Research Question

Does replacing uniform-premium public insurance with risk-based private coverage induce firms to internalize environmental damages?

Two Behavioral Margins

1. **Tank Closures** (Optimal Stopping): Accelerated closure of aging, high-risk tanks
2. **Outcome**: Net change in Leaking Underground Storage Tank (LUST) reporting events

Modeling Strategy

- Dynamic discrete choice (DDC) framework (Rust, 1987): Owner chooses $\{Close, Continue\}$ each period. Insurance regime shift changes effective cost function.

Contribution

1. Identification: Correcting OVB in Prior Literature

- **Yin et al. (2011):** State-level aggregates $\rightarrow$ composition bias, regional shocks.
- **This Paper:** First facility-level panel with tank-specific covariates.
- **Gain:** Facility fixed effects isolate policy response from heterogeneity (location, geology).

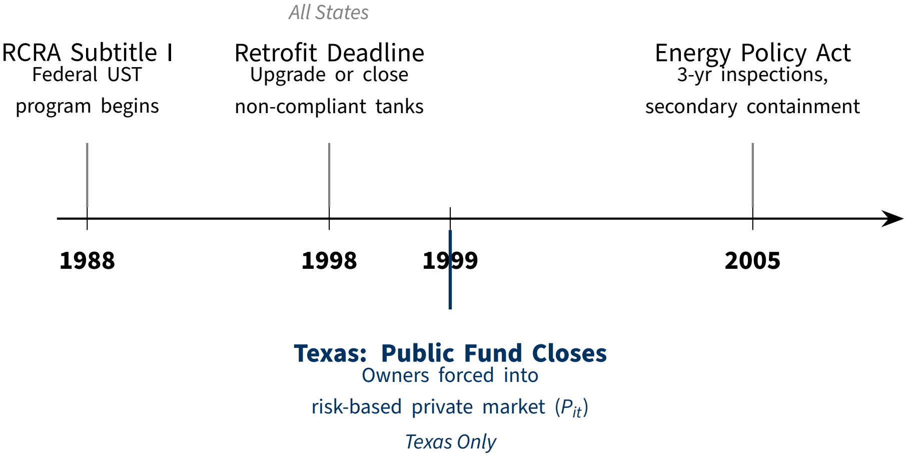
2. Mechanism: Structural Decomposition

- Tests whether insurance pricing affects ex-ante moral hazard (Einav et al., 2021).
- DDC model estimates optimal stopping rule $\rightarrow$ enables counterfactual policy analysis.

3. Policy: Pricing Design as Dynamic Lever

- Beyond bonding mandates (Boomhower, 2019): pricing structure within assurance matters.
- Links closure behavior to LUST outcomes and health externalities (Marcus, 2021; Kellogg & Reguant, 2021).

Underground Storage Tank (UST) Regulatory Context



All federal technical mandates apply identically to Texas and control states. Only the insurance regime diverges.

A Dynamic Model of Tank Closure

The Agent's Decision

The Choice

Each period t, the facility chooses: $d_t \in \{\text{Maintain}, \text{Close}\}$

The Trade-off

- **Maintain:** Earn net revenue, pay insurance premiums.
- **Close:** Exit market and recover scrap value κ (liquidity of land).

Flow Utility (Maintain)

$$u(a) = \underbrace{R}_{\text{Net Revenue}} - \underbrace{C_j(a)}_{\text{Insurance Premium}}$$

Simplifying Assumption: Full Coverage

Firms face environmental risk solely as an *ex-ante* cost (premium), not an *ex-post* shock (deductible).

The Dynamic Problem

The Bellman Equation

$$V(a) = \max \left\{ \underbrace{u(a) + \beta \mathbb{E}[V(a') \mid a]}_{\text{Value of Maintaining}}, \quad \underbrace{\kappa}_{\text{Scrap Value}} \right\}$$

The Continuation Value (V_{cont}) The value of keeping the tank active today to preserve the option of operating tomorrow:

$$V_{cont}(a) = u(a) + \beta \mathbb{E}[V(a') \mid a]$$

Optimal Stopping Rule

$$\text{Close if} \quad V_{cont}(a) < \kappa$$

The Policy Lever: Insurance Regimes

1. Uniform Premium Pooling (*F*)

- **Premium:** Constant $\bar{P}$.
- **Incentive:** Zero marginal cost of aging.

$$\frac{\partial C}{\partial \text{Age}} = 0$$

2. Risk-Based Pricing (*RB*)

- **Premium:** Rises with leak hazard $h(a)$, the instantaneous probability of a leak, strictly increasing in age.
- **Incentive:** Positive marginal cost of aging.

$$\frac{\partial C}{\partial \text{Age}} > 0$$

What's the First Best?

Social Planner's Objective

Internalize remediation costs (L) *and* health externalities (E):

$$u_{SOC}(a) = R - h(a) \cdot (\underbrace{L}_{\text{Remediation}} + \underbrace{E}_{\text{Health}})$$

Why Risk-Based Pricing Falls Short

- Actuarial premiums reflect *insurer claims data* $\rightarrow$ only remediation costs (L).
- Health damages (E) generate no third-party claims: contamination is unobservable (Marcus, 2021).
- $\Rightarrow$ Even fair risk-based pricing leaves E externalized.

Implication

$$V_{RB}(a) > V_{SOC}(a) \quad \text{because} \quad h(a) \cdot L < h(a)(L + E)$$

Risk-based pricing induces *some* closures, but not enough.

The Three Facts to Keep in Mind

1. Asset Depreciation

Rising leak risk causes tank value to strictly decrease in age ($V'(a) < 0$).

- *Economic Friction:* The regime determines if private incentives align with this social decay.

2. Inefficient Retention (Uniform Premium)

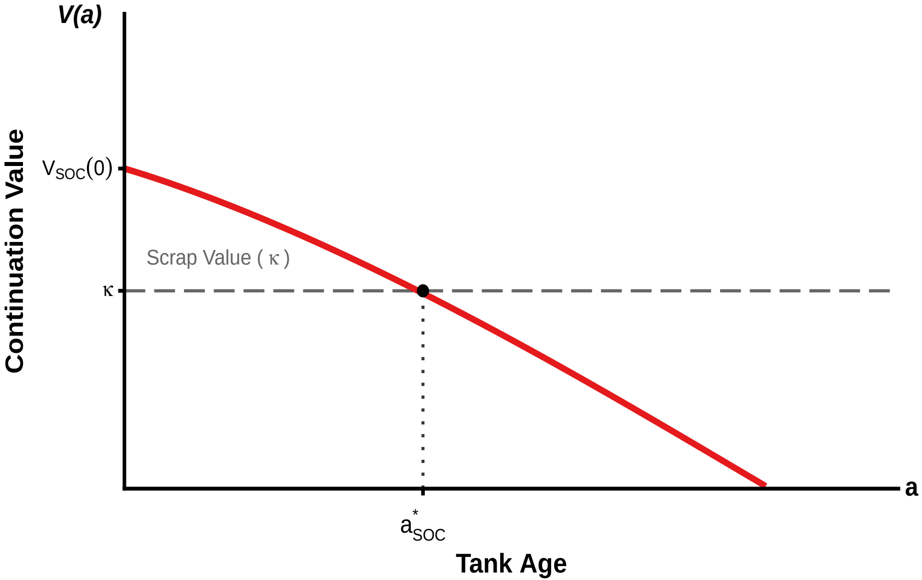
- **Mechanism:** Static costs ($\bar{P}$) $\implies$ Zero marginal cost of aging.
- **Result:** Firm ignores risk; retains asset longest (a^*_{UP}).

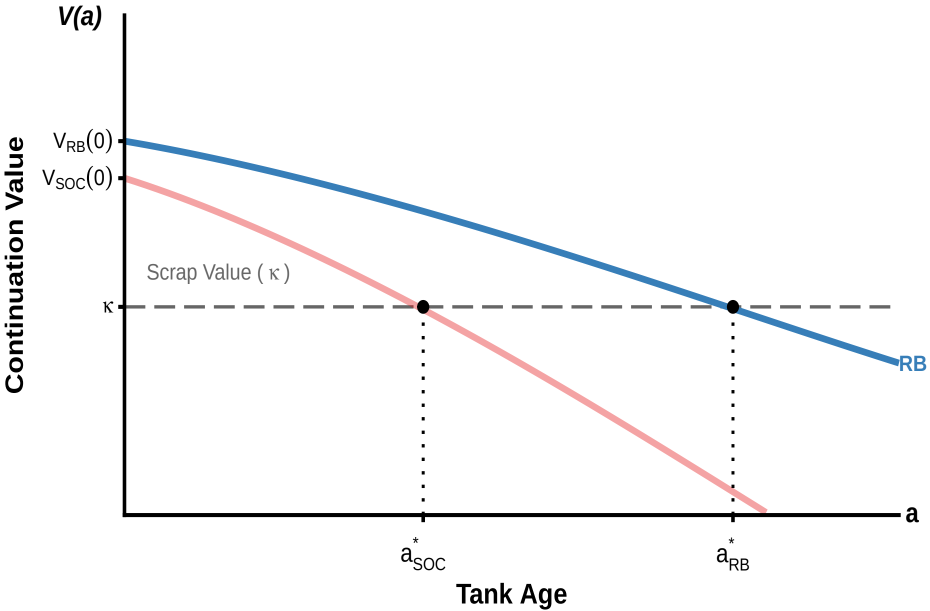
3. Partial Correction (Risk-Based)

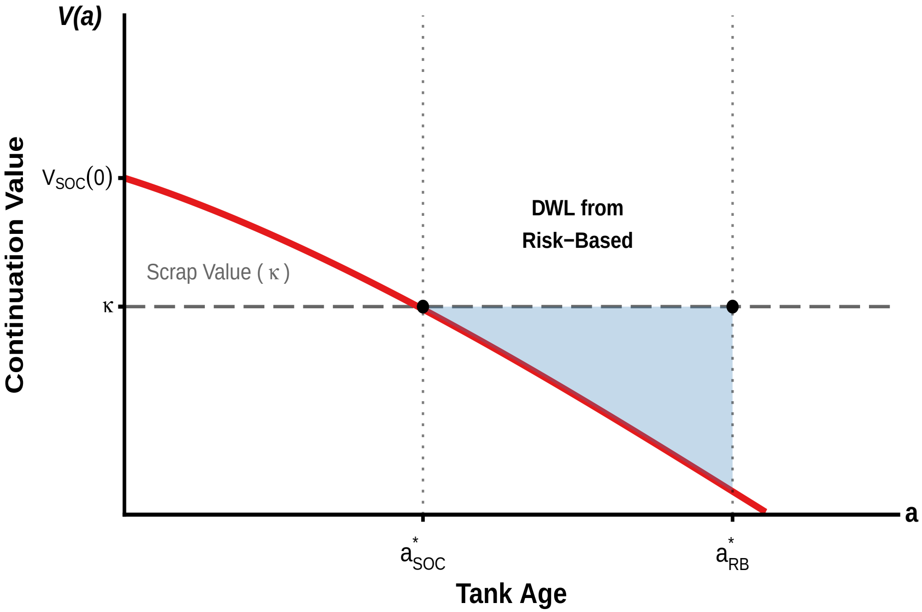
- **Mechanism:** Rising premiums ($h(a)L$) $\implies$ Positive marginal cost of aging.
- **Result:** Accelerated exit (a^*_{RB}), yet strictly $> a^*_{SOC}$ due to unpriced health costs.

The Ordering

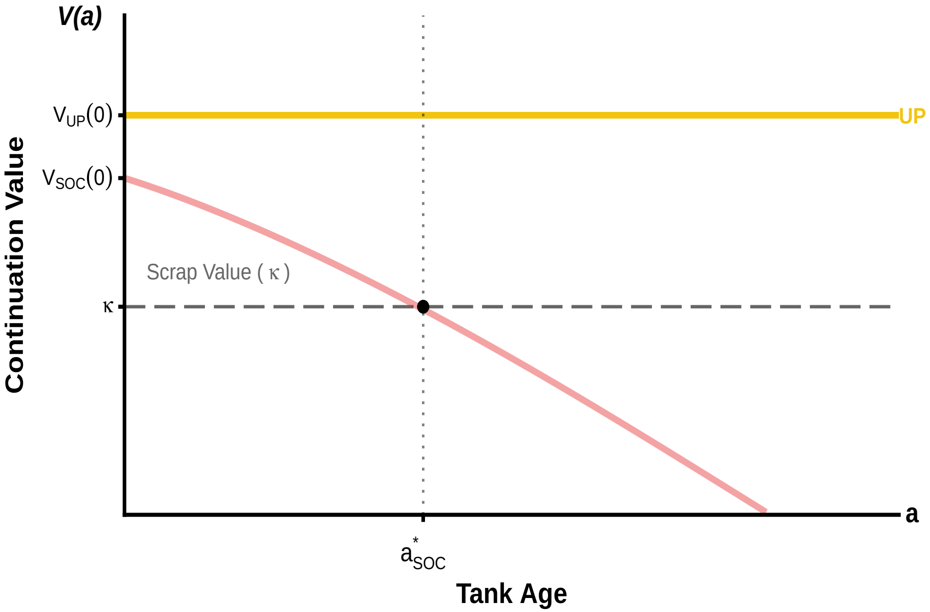
$$a^*_{SOC} < a^*_{RB} < a^*_{UP}$$


V(a)
Continuation Value
$V_{SOC}(0)$
Scrap Value (κ)
κ
a
a^*_{SOC}
Tank Age

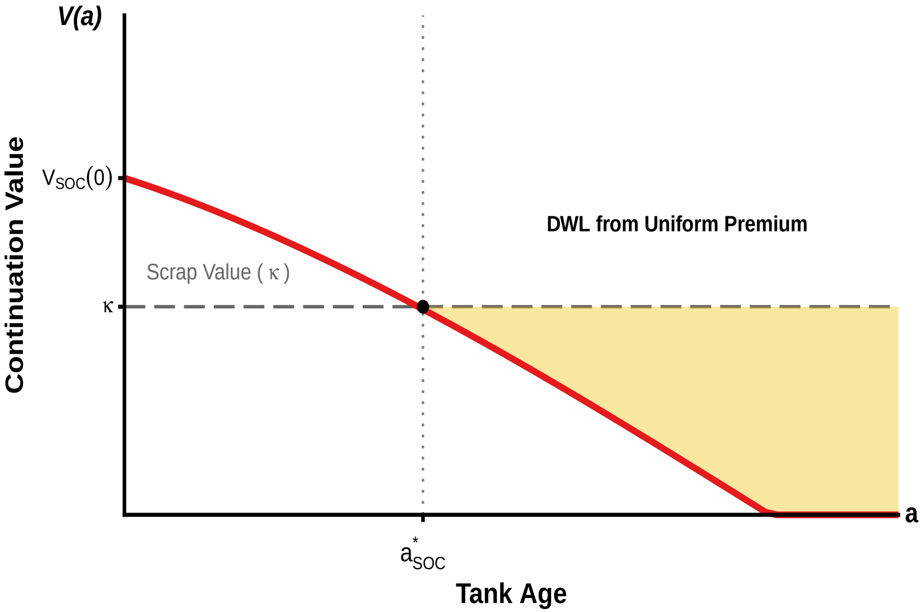

V(a)
Continuation Value
$V_{RB}(0)$
$V_{SOC}(0)$
Scrap Value (κ)
κ
RB
a
a^*_{SOC}
a^*_{RB}
Tank Age

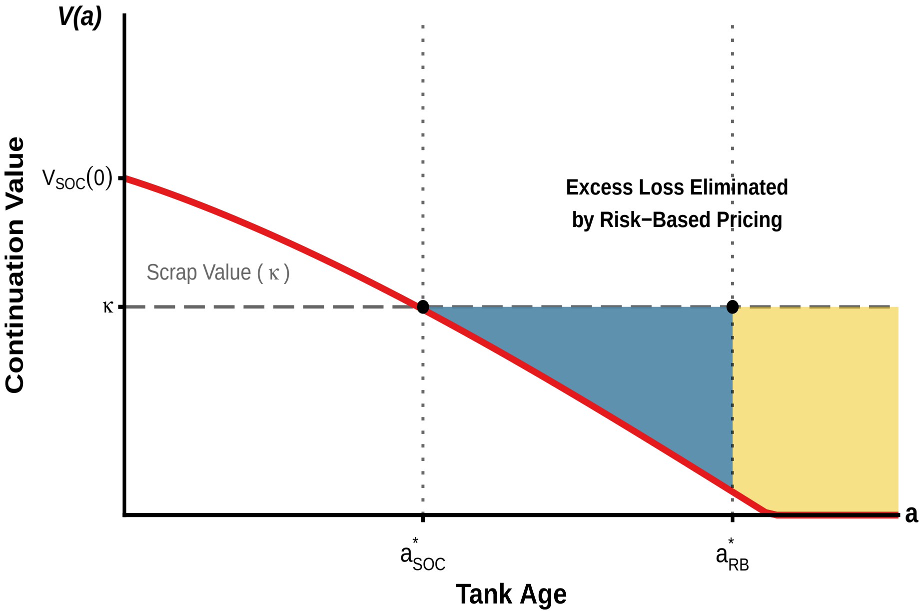


V(a)
Continuation Value
$V_{SOC}(0)$
DWL from
Risk−Based
Scrap Value (κ)
κ
a
a^*_{SOC}
a^*_{RB}
Tank Age



V(a)
$V_{UP}(0)$
UP
$V_{SOC}(0)$
Scrap Value (κ)
κ
a
a^*_{SOC}
Continuation Value
Tank Age


V(a)
Continuation Value
V_SOC(0)
κ
Scrap Value (κ)
DWL from Uniform Premium
a*_SOC
a
Tank Age


V(a)
Continuation Value
$V_{SOC}(0)$
Scrap Value (κ)
κ
Excess Loss Eliminated
by Risk−Based Pricing
a
a^*_{SOC}
a^*_{RB}
Tank Age

Structural Model [Simulated Data]

The Agent's Decision Problem

State Space $x = (A, w, \rho)$

- **Age (A):** 9 bins (0-5y ... 40y+).
- Risk $h(A)$ rises w/ age.
- **Wall (w):** Single vs. Double.
- **Regime (ρ):** Uniform Premium vs. Risk-Based.

Choice Set

1. **Maintain ($d = m$)**
   - Pay premium $p(x)$, face risk $h(x)$.
   - Next: $A \to A + 1$ (stochastic).
2. **Close ($d = c$)**
   - Permeanlty Close Tank.
   - Payoff: Scrap value κ.

Timing

1. Facility observes state x_t and shock ε_{it} (Type I EV).
2. Chooses d_{it} to maximize expected discounted value ($\beta = 0.95$).

Bellman Equation & Flow Utility

Optimal Stopping Problem

$$V(x) = \max \left\{ \underbrace{u^m(x) + \beta \mathbb{E}[V(x')|x, m]}_{\textbf{Maintain (Continuation)}}, \quad \underbrace{\kappa}_{\textbf{Close (Scrap)}} \right\} + \sigma \varepsilon$$

Flow Utility (Normalized)

$$u^m(x) = \underbrace{1}_{\textbf{Revenue}} - \underbrace{\gamma_{\mathbf{p}} \cdot p(x)}_{\textbf{Premium}} - \underbrace{\gamma_{\mathbf{r}} \cdot h(x) \cdot L}_{\textbf{Liability}}$$

Scaling & Interpretation

- **Numeraire:** Annual net revenue is normalized to $\psi = 1$.
- **Unit Interpretation:** - Estimated parameters $\{\kappa, \gamma\}$ are expressed in **multiples of annual revenue**.
  - A value of $\gamma_{\mathbf{r}} = 0.5$ implies the marginal liability risk is equivalent to 6 months of revenue.

Identification of Parameters

Which Variation Identifies Which Parameter?

Parameter	Interpretation	Source of Variation
κ	Scrap Value	Average facility exit rate (Unconditional Levels)
$\gamma_{\mathbf{p}}$	Premium Sensitivity	Cross-sectional premium jumps across (A, w, ρ)
$\gamma_{\mathbf{r}}$	Liability Sensitivity	Variation in deductible sizes & coverage limits

Estimation Protocol

- **Algorithm:** Nested Pseudo-Likelihood (NPL) {(Aguirregabiria & Mira, 2007)}
- **Standard Errors:** Facility-level block bootstrap ($B = 999$).
- **Sample:** [Insert N] facilities observed quarterly (20XX-20XX).

Estimation Results [Simulated Data for Demonstration Only]

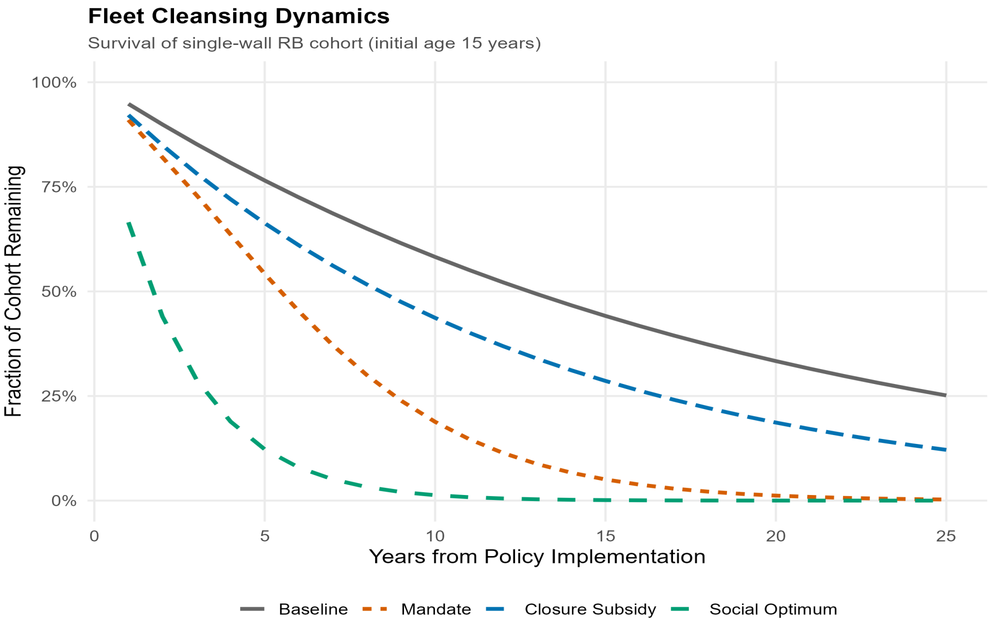
Parameter	Estimate	SE	Interpretation
$\hat{\kappa}$	6.25	(0.84)	Scrap value (annual revenue units)
$\hat{\gamma}_{price}$	−1.20	(0.31)	Firms dislike premiums (Price Elastic)
$\hat{\gamma}_{risk}$	1.00	(0.22)	Near-perfect private internalization

Interpretation

- **Price Sensitivity ($\gamma < 0$)** Firms respond strongly to premium hikes ($p < 0.01$).
- **Risk Neutrality ($\gamma \approx 1$)** Owners fully internalize *private* costs (deductibles), implying the remaining distortion is purely the **external** damage.

Counterfactual Policy Scenarios

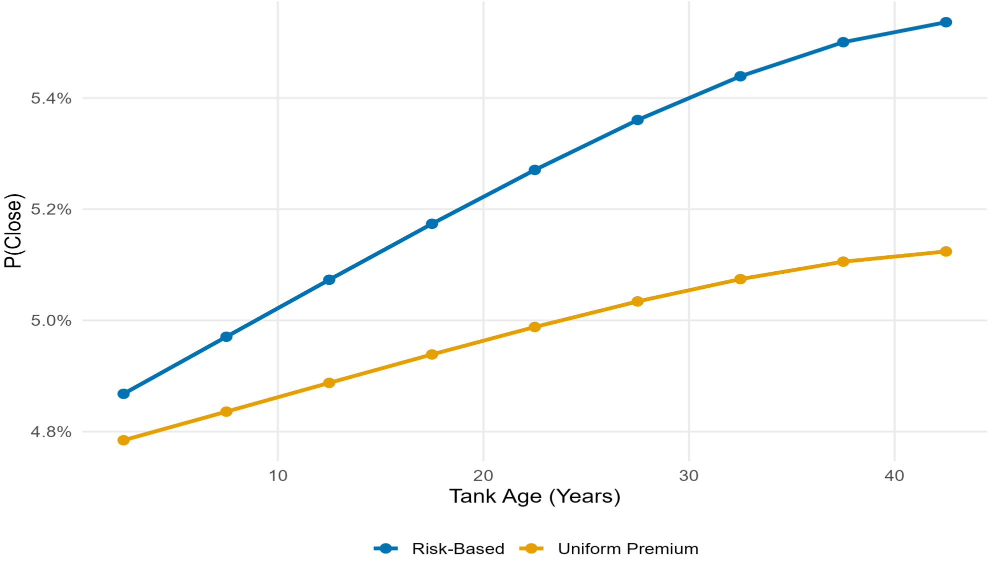
Scenario	Mechanism	Parameter Shift
1. Baseline	Status Quo (Estimated $\hat{\theta}$)	$\theta_{base} = \hat{\theta}$
2. Social Optimum	Internalize Externality (Pigouvian Tax)	$\gamma'_{risk} = \gamma_{risk} \times \xi_{ext}$
3. Closure Subsidy	Incentive Payment (Transfer)	$\kappa' = \kappa + \$10k$
4. Mandate	Command & Control (Targeted)	Force exit if $Age \geq 30$ & SW



Fleet Cleansing Dynamics
Survival of single-wall RB cohort (initial age 15 years)
Fraction of Cohort Remaining
100%
75%
50%
25%
0%
0
5
10
15
20
25
Years from Policy Implementation
Baseline
Mandate
Closure Subsidy
Social Optimum

Insurance Regime and Closure Incentives

Risk-based pricing increases exit incentives for high-risk tanks



Policy Impact Heterogeneity

Change in closure probability (pp) vs. baseline. Color capped at 15pp; bold = exceeds cap.

Mandate

	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5
SW, Uniform Premium	+0.7	+1.2	+2.2	+3.9	+7.8	**+19.3**	**+94.9**	**+94.9**	**+94.9**
SW, Risk-Based	+0.7	+1.2	+2.1	+3.8	+7.7	**+19.2**	**+94.6**	**+94.5**	**+94.5**
DW, Uniform Premium	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
DW, Risk-Based	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0

Closure Subsidy

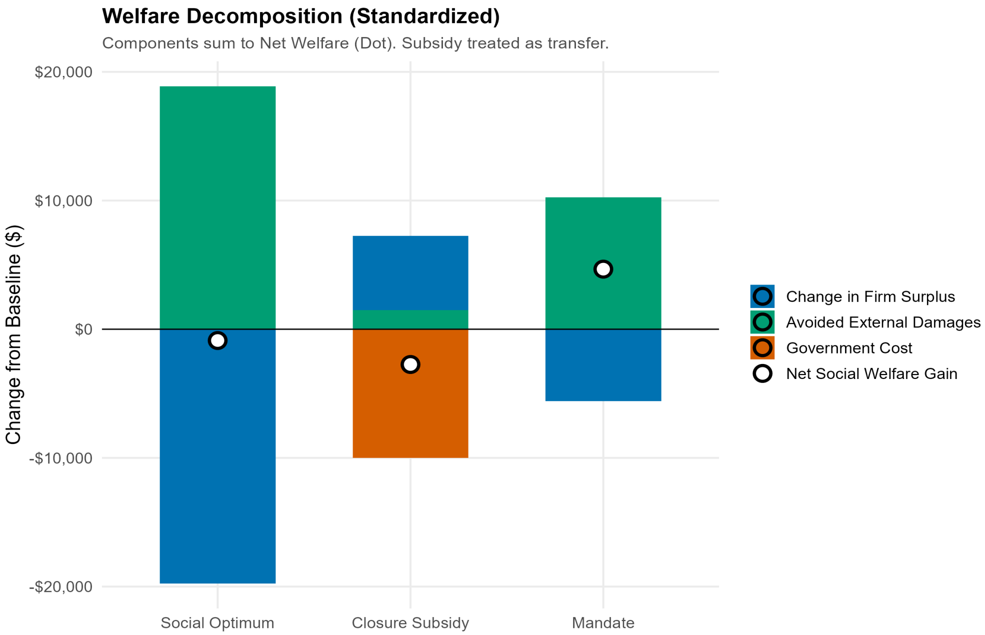
	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5
SW, Uniform Premium	+2.6	+2.6	+2.6	+2.6	+2.7	+2.7	+2.7	+2.7	+2.7
SW, Risk-Based	+2.6	+2.6	+2.6	+2.7	+2.7	+2.7	+2.7	+2.8	+2.8
DW, Uniform Premium	+2.6	+2.6	+2.6	+2.6	+2.6	+2.6	+2.6	+2.6	+2.7
DW, Risk-Based	+2.5	+2.5	+2.6	+2.6	+2.6	+2.6	+2.6	+2.7	+2.7

Social Optimum

	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5
SW, Uniform Premium	**+23.0**	**+24.7**	**+26.5**	**+28.3**	**+30.2**	**+32.0**	**+33.9**	**+35.7**	**+37.1**
SW, Risk-Based	**+22.9**	**+24.7**	**+26.5**	**+28.3**	**+30.1**	**+32.0**	**+33.9**	**+35.7**	**+37.2**
DW, Uniform Premium	**+16.4**	**+17.9**	**+19.5**	**+21.1**	**+22.8**	**+24.5**	**+26.2**	**+27.8**	**+29.1**
DW, Risk-Based	**+16.2**	**+17.8**	**+19.4**	**+21.0**	**+22.7**	**+24.4**	**+26.2**	**+27.8**	**+29.1**

Tank Age (Years)

Δ P(Close) (pp): 0, 5, 10, 15


Welfare Decomposition (Standardized)
Components sum to Net Welfare (Dot). Subsidy treated as transfer.
Change from Baseline ($)
$20,000
$10,000
$0
-$10,000
-$20,000
Social Optimum
Closure Subsidy
Mandate
Change in Firm Surplus
Avoided External Damages
Government Cost
Net Social Welfare Gain

Counterfactual Comparison

Table: Counterfactual Welfare Analysis (Model B)

Scenario	Closure Rate	Leak Risk	Firm Surplus	Social Welfare	Δ Welfare
Baseline	5.1%	17.93%	31.96	26.76	+0.000
Social Optimum Op	37.3%	11.62%	29.98	26.67	-0.088
Closure Subsidy	7.8%	17.42%	31.54	26.48	-0.274
Mandate	13.4%	15.40%	31.40	27.23	+0.467