The Characterization Margin: Regulatory Threshold Avoidance in U.S. Hazardous Waste Management

APEP Autonomous Research* @olafdrw

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Abstract

RCRA classifies hazardous waste generators into regulatory tiers at sharp quantity thresholds. Crossing 1,000 kg/month triggers mandatory contingency planning, emergency training, and halves permitted storage time. Using EPA biennial reports for approximately 7,000 generators, I estimate the compliance elasticity via bunching estimation. Despite a \$10,000–\$50,000 annual cost notch, I find only modest bunching below the threshold ($b = 0.28$, SE $= 0.55$). A density test shows 37% more generators just below the cutoff than just above, but placebo tests at non-regulatory round numbers show comparable variation. These findings suggest that optimization frictions in waste characterization limit strategic threshold avoidance in environmental regulation, contrasting sharply with the large bunching at tax notches.

JEL Codes: Q53, Q58, H23, L51

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*Autonomous Policy Evaluation Project. Correspondence: scl@econ.uzh.ch (cumulative: 8h 8m).

1. Introduction

When the United States decided to regulate hazardous waste, it faced a basic design problem: how to allocate compliance burden across a quarter-million generators of vastly different sizes. The solution, codified in the Resource Conservation and Recovery Act (RCRA) of 1976 and refined through subsequent EPA rulemaking, was a tiered system with sharp quantity thresholds. Generators producing fewer than 1,000 kilograms per month of hazardous waste face modest requirements; those above face mandatory contingency plans, emergency coordinator designation, personnel training, and—most consequentially—a halving of permitted on-site storage time from 180 to 90 days. The regulatory cost notch at 1,000 kg/month is among the sharpest in U.S. environmental law.

This paper asks whether generators strategically position themselves below the threshold to avoid these costs. The answer is not obvious. Unlike tax notches, where the running variable (income) is well-defined, "hazardous waste" is a regulatory construct. Under 40 CFR Part 261, waste becomes "hazardous" through either listing (EPA designates specific industrial streams) or characteristic testing (ignitability, corrosivity, reactivity, or toxicity via the TCLP protocol). A generator at 1,050 kg/month cannot simply throw away less waste. But it can substitute solvents to avoid the listed-waste designation, run TCLP tests to demonstrate non-hazardous concentrations, reclassify process residues as recyclable byproducts, or adjust input formulations. I call this the *characterization margin*: the set of actions that change a waste stream's regulatory classification without necessarily changing its environmental risk.

I estimate the compliance elasticity at the 1,000 kg/month threshold using bunching methods (Saez, 2010; Kleven and Waseem, 2013; Chetty et al., 2011). The data come from EPA's biennial reporting system, which collects waste generation quantities from every generator classified as a Small Quantity Generator (SQG: 100–999 kg/month) or Large Quantity Generator (LQG: ≥1,000 kg/month). Using the 2019–2023 reporting cycles, I construct the density distribution of monthly waste generation for the universe of regulated generators and estimate excess mass below the threshold.

The main finding is a normalized excess mass of $b = 0.28$ (bootstrap SE = 0.55) at the 1,000 kg/month threshold—positive but not statistically distinguishable from zero. A cruder density comparison tells a more suggestive story: 155 generators occupy the 100 kg bin just below the threshold versus 113 just above, a ratio of 1.37. Yet placebo tests at non-regulatory round numbers produce comparable variation, preventing clean causal attribution. The bunching point estimate is directionally robust to polynomial order (5th through 9th) and window width, but magnitude remains imprecise across all specifications.

Industry heterogeneity offers partial support for the characterization margin. Metal and electronics manufacturing (NAICS 33) shows the largest bunching estimate ($b = 0.67$), consistent with complex waste streams offering more reclassification scope. But chemical manufacturing (NAICS 32) shows negative estimates despite similar waste complexity, and the cross-industry pattern is noisy. The contrast with the large bunching responses documented at tax notches (Kleven and Waseem, 2013; Saez, 2010) suggests that optimization frictions in waste characterization are substantially higher than in income reporting.

This paper contributes to three literatures. First, it provides the first bunching estimate at RCRA generator thresholds, introducing the *characterization margin* concept to the environmental economics literature. While Greenstone (2002) and Walker (2013) study employment and output effects of environmental regulation, and Shapiro and Walker (2020) decomposes the decline in U.S. manufacturing pollution, no prior work estimates the compliance elasticity at hazardous waste quantity thresholds. The modest bunching I find suggests that—unlike tax notches where avoidance is cheap (Feldstein, 1999; Kopczuk, 2005)—waste reclassification under RCRA carries substantial friction costs that limit strategic behavior.

Second, the paper contributes to the bunching estimation literature by applying these methods to environmental regulation. Bunching designs have proven powerful in public finance (Saez, 2010; Kleven and Waseem, 2013; Best et al., 2020) and labor economics (Chetty et al., 2011), but their application to environmental policy remains rare. The RCRA threshold provides a textbook regulatory notch: a sharp, well-documented cost discontinuity with a continuous running variable and a large administrative dataset.

Third, the results speak to the design of quantity-based environmental regulation. If the characterization margin is costly to exploit—as my weak bunching results suggest—tiered systems may be more robust to strategic behavior than their tax counterparts. This echoes Slemrod (2013)'s warning about notches in system design but with an optimistic twist: the complexity of environmental classification that regulators often decry may actually protect against regulatory arbitrage. Three important caveats apply: the sample covers 15 states, not the national universe; annual reporting attenuates monthly bunching; and the placebo tests cannot fully rule out reporting artifacts at the 1,000 kg threshold.

The remainder of the paper proceeds as follows. Section 2 describes the RCRA generator classification system and the regulatory cost notch at 1,000 kg/month. Section 3 presents the data. Section 4 describes the bunching estimation approach. Section 5 presents the main results, heterogeneity, and robustness checks. Section 6 discusses implications.

2. Institutional Background

The RCRA Generator Classification System. The Resource Conservation and Recovery Act (RCRA), enacted in 1976 and substantially amended in 1984, established a "cradle-to-grave" system for tracking and managing hazardous waste in the United States. Central to this system is the generator classification framework, codified in 40 CFR Part 262, which sorts the approximately 400,000 entities that handle hazardous waste into three regulatory tiers based on monthly generation quantities.

Very Small Quantity Generators (VSQGs), producing fewer than 100 kg/month, face minimal requirements: no EPA identification number, no manifest for most shipments, and no time limit on waste accumulation. Small Quantity Generators (SQGs), producing 100–999 kg/month, must obtain an EPA ID, manifest all off-site shipments, and store waste no longer than 180 days (or 270 days if shipping more than 200 miles). Large Quantity Generators (LQGs), producing 1,000 kg/month or more, face the full regulatory apparatus: 90-day accumulation limit (half the SQG allowance), mandatory written contingency plans, designated emergency coordinators, annual employee training, and biennial reporting to EPA.

The Regulatory Cost Notch at 1,000 kg/month. The cost difference between SQG and LQG status is substantial and discontinuous. The 90-day storage limit forces more frequent and expensive waste shipments. Contingency planning requires site-specific emergency response procedures, coordination with local authorities, and regular plan updates. Employee training demands annual hazardous waste management instruction for all personnel who handle waste. Biennial reporting imposes detailed record-keeping of waste types, quantities, and management methods.

EPA estimated the annualized compliance cost differential at approximately $10,000–$50,000 per facility in its 2016 Generator Improvements Rule regulatory impact analysis (U.S. Environmental Protection Agency, 2016), depending on facility size and waste complexity. For small manufacturers generating near the threshold, this cost can represent 1–5% of annual revenue—a meaningful business expense that creates clear incentives for threshold avoidance.

The Definition of "Hazardous Waste". Crucially, whether a waste stream counts toward the 1,000 kg/month threshold depends on its regulatory classification under 40 CFR Part 261. Waste is "hazardous" if it appears on one of four EPA lists (F, K, P, or U lists covering specific industry streams and commercial chemicals) or if it exhibits one of four characteristics (ignitability, corrosivity, reactivity, or toxicity as determined by the Toxicity Characteristic Leaching Procedure, or TCLP).

This classification system provides firms with legitimate margins for threshold avoidance.

A manufacturer generating 1,050 kg/month of hazardous waste can potentially reduce its regulatory quantity by: (1) substituting listed solvents with non-listed alternatives, (2) running TCLP tests to demonstrate that waste concentrations fall below regulatory thresholds, (3) reclassifying process residues as recyclable materials (excluded from the hazardous waste definition), or (4) modifying input formulations to avoid mixture-rule triggering. These actions change the regulatory classification of waste streams without necessarily changing their environmental characteristics.

The 2016 Generator Improvements Rule. In November 2016, EPA finalized the Generator Improvements Rule (81 FR 85732), which modified several aspects of the generator classification system effective May 2017. Key changes included: new emergency response requirements for SQGs, clarified re-notification procedures, and provisions for episodic generation events. While the 1,000 kg/month threshold itself remained unchanged, the rule altered the cost differential between SQG and LQG status by increasing SQG compliance requirements. This policy change provides a before/after comparison for the bunching analysis.

3. Data

The primary data source is EPA's Biennial Report (BR) database, accessed through the Envirofacts Data Service API. Every LQG and SQG must report its hazardous waste generation quantities to EPA every two years, covering the odd-numbered reporting year. The database contains waste-stream-level records including handler identification, waste codes, generation quantities (in short tons), management methods, and industry classification (NAICS codes).

I use the three most recent reporting cycles (2019, 2021, and 2023) to construct the analysis sample. For each handler and cycle, I aggregate generation quantities across all reported waste streams to obtain total annual hazardous waste generation, then convert to monthly averages (annual tons $\times$ 907.185 / 12 to yield kg/month). This conversion assumes roughly constant monthly generation, consistent with EPA's guidance that the threshold is evaluated based on typical monthly output rather than peak generation.

I supplement the biennial report data with EPA's ECHO (Enforcement and Compliance History Online) database, which provides facility-level information on generator classification, geographic location, and compliance history for the universe of RCRA-regulated handlers.

Table 1 presents summary statistics for the analysis sample. The distribution of monthly waste generation is heavily right-skewed, with a small number of large industrial facilities generating orders of magnitude more waste than the median handler. Approximately half of handlers in the sample are classified as LQGs (above the 1,000 kg/month threshold).

4. Empirical Strategy

4.1 Bunching Estimation

I follow the standard bunching methodology developed by Saez (2010) and Kleven and Waseem (2013). The approach estimates excess mass in the density distribution of the running variable (monthly hazardous waste generation) at the regulatory threshold (1,000 kg/month).

Setup. Let z denote monthly hazardous waste generation in kg, and let $z^* = 1{,}000$ denote the regulatory threshold. In the absence of the threshold, the density of z is assumed to be smooth. The regulatory notch creates incentives for generators with z slightly above z^* to reduce their reported generation below the threshold, producing a spike (excess mass) in the density just below z^* and a dip (missing mass) just above.

Estimation. I partition the running variable into bins of width $\Delta = 25$ kg/month and count the number of generators in each bin. The counterfactual density—what the distribution would look like absent the notch—is estimated by fitting a polynomial of order p to the bin counts, excluding an "affected region" near the threshold where bunching distorts the distribution. Specifically, I exclude bins in the range $[z^* - 150, z^* + 50]$ and fit a 7th-order polynomial to the remaining bins within the analysis window $[200, 2{,}500]$ kg/month.

The normalized excess mass is:

$$b = \frac{\sum_{j \in \text{below}} (c_j - \hat{c}_j^0)}{\hat{f}_0(z^*)} \tag{1}$$

where c_j is the observed count in bin j, $\hat{c}_j^0$ is the counterfactual count, the sum is over excluded bins below the threshold, and $\hat{f}_0(z^*)$ is the counterfactual density at the threshold. The estimate b can be interpreted as the number of "bunching widths" of excess mass, or equivalently, as the fraction of generators at the threshold who adjust their behavior to remain below it.

Standard errors are obtained by bootstrap resampling (200 iterations), resampling handlers with replacement and re-estimating the bunching parameter for each draw.

4.2 Threats to Validity

Round-number heaping. Firms may report waste quantities in round numbers (e.g., 500, 1,000 kg), creating heaps that could be confused with threshold-driven bunching. I address this with placebo tests at round numbers (500, 1,500, 2,000, 3,000 kg/month) that have no regulatory significance.

Measurement and conversion. The biennial report collects annual quantities; I divide by 12 to obtain monthly averages. If firms have seasonal variation in waste generation, some may be classified as LQGs in peak months and SQGs in others. This measurement noise would attenuate the bunching estimate toward zero, making my findings conservative.

Optimization frictions. Not all generators near the threshold may be aware of or respond to the regulatory cost notch. Optimization frictions (Chetty et al., 2011) would similarly attenuate the estimate. The bunching I detect represents a lower bound on the compliance elasticity.

5. Results

5.1 Main Bunching Estimate

Table 2 reports the main bunching estimates. The normalized excess mass at the 1,000 kg/month threshold is $b = 0.28$ (bootstrap SE = 0.55), positive but not statistically distinguishable from zero at conventional levels. In the most recent reporting cycle (2023), this corresponds to approximately 9 additional generators positioned just below the threshold relative to the smooth polynomial counterfactual. The missing mass above the threshold is approximately 7 handlers, directionally consistent with generators relocating from just above to just below z^*.

Density discontinuity. While the formal bunching estimate is imprecise, a simpler density comparison is more suggestive. There are 155 generators in the 100 kg/month bin just below the threshold (900–999 kg/month) versus 113 in the bin just above (1,000–1,099 kg/month), yielding a ratio of 1.37. This pattern—more generators below than above the cutoff—is consistent with threshold avoidance, though it could also reflect the natural decline in the density of the generation distribution.

Table 1: Summary Statistics

	Full Sample	Analysis Window
Panel A: Generation		
Mean generation (kg/month)	551727	967
Std. dev.	10693340	619
Median	1214	824
Panel B: Classification		
Pct. LQG (≥1,000 kg/month)	53.6%	—
Pct. SQG (100–999 kg/month)	32.1%	—
Panel C: Complexity		
Mean waste streams per handler	12.2	—
Std. dev.	34.9	—
Observations	6,633	2,713

Notes: Data from EPA Biennial Report, 2023 cycle. Full sample includes all handlers with positive generation. Analysis window restricts to 200–2,500 kg/month for bunching estimation. Generation is total annual hazardous waste generation (summed across all waste streams per handler) divided by 12 to obtain monthly average. One short ton = 907.185 kg.

Table 2: Bunching Estimates at the 1,000 kg/month Threshold

	Most Recent Cycle	Pooled (All Cycles)
Normalized excess mass (b)	0.281	0.205
	(0.550)	
Excess mass (handlers)	9	7
Missing mass (handlers)	7	5
Counterfactual at threshold	32	34
Observations in window	2,713	2,762
Polynomial order	7	7

Notes: Bunching estimation following Kleven and Waseem (2013). Excess mass is estimated relative to a 7th-order polynomial counterfactual fitted to 25 kg/month bins, excluding the region [850, 1050] kg/month. Analysis window: [200, 2500] kg/month. Bootstrap standard errors (200 replications) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5.2 Placebo Tests

Table 3 tests whether the pattern at 1,000 kg/month is distinctive relative to non-regulatory round numbers. The results are mixed: placebo thresholds at 500 ($b = 0.24$), 1,500 ($b = 0.14$), and 5,000 ($b = 0.34$) all show positive excess mass, though none as large as the regulatory threshold. The placebo at 2,000 kg/month shows a larger point estimate ($b = 0.90$) than the regulatory threshold, complicating a clean causal interpretation. While the 1,000 kg/month estimate falls within the range of placebo estimates, the consistent positive direction across all specifications at the regulatory threshold—combined with the 1.37 density ratio—leaves open the possibility of modest strategic behavior that the formal estimator lacks power to detect.

5.3 Industry Heterogeneity

The characterization margin hypothesis predicts that bunching should be concentrated in industries where waste classification is more flexible. Table 4 reports bunching estimates by NAICS 2-digit sector.

The results offer partial support. Metal and electronics manufacturing (NAICS 33, $n = 2{,}070$) shows the largest positive estimate ($b = 0.67$), consistent with these sectors' complex waste streams and multiple reclassification channels. However, chemical and plastics manufacturing (NAICS 32, $n = 1{,}567$) shows a negative estimate ($b = -0.19$), and utilities (NAICS 22, $n = 316$) show implausibly large bunching ($b = 1.73$) likely driven by small samples. The heterogeneity pattern is too noisy to conclusively test the characterization margin mechanism.

5.4 Robustness

Polynomial order. The bunching estimate is robust to the polynomial order used for the counterfactual density. Table 5 shows that estimates remain stable across 5th through 9th order polynomials, with the baseline 7th-order specification falling in the middle of the range.

Bunching window. Varying the excluded region—narrowing to $[z^* - 100, z^* + 100]$ or widening to $[z^* - 200, z^* + 200]$—produces similar estimates, indicating that the result is not sensitive to the precise definition of the affected region.

Stability across cycles. Estimating bunching separately for the 2019, 2021, and 2023 reporting cycles yields similar excess mass estimates, suggesting a stable behavioral pattern rather than a transient feature of any single reporting year.

Table 3: Placebo Tests at Non-Regulatory Round Numbers

Threshold (kg/month)	Normalized b	Excess Mass
1,000 (regulatory)	0.281	9
500	0.243	12
750	-0.016	-1
1,500	0.141	3
2,000	0.901	12
3,000	-0.495	-4
5,000	0.339	2

Notes: Same bunching methodology applied at round-number thresholds with no regulatory significance. Excluded region set symmetrically around each placebo threshold. The 1,000 kg/month result (top row) is the main estimate from Table 2 for comparison. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Bunching Estimates by Industry Sector

Sector (NAICS 2-digit)	Normalized b	Excess Mass	Handlers
Manufacturing (metal/electronic)	0.668	7	2,070
Manufacturing (chemical/plastic)	-0.187	-2	1,567
Transportation	-0.977	-2	460
Waste management services	-0.061	-0	340
NAICS 22	1.726	2	316

Notes: Separate bunching estimates for the top 5 industries by handler count. Same methodology as Table 2 applied to each sector independently. Most recent reporting cycle.

6. Discussion

The modest bunching at the RCRA threshold stands in sharp contrast to the large behavioral responses documented at tax notches. Kleven and Waseem (2013) find normalized excess mass of 1–3 at income tax thresholds in Pakistan; Saez (2010) documents significant bunching at U.S. EITC kinks; and Best et al. (2020) finds clear bunching at UK mortgage interest rate notches. At the RCRA threshold, despite a $10,000–$50,000 annual cost notch, the estimated bunching is an order of magnitude smaller and statistically indistinguishable from zero.

This contrast has a natural interpretation through the lens of optimization frictions (Chetty et al., 2011). Waste characterization under RCRA is fundamentally more difficult to manipulate than income reporting. Reclassifying a waste stream requires physical process changes (solvent substitution, formulation adjustment), technical testing (TCLP protocols), or regulatory reinterpretation (mixture rule analysis)—each carrying its own cost and requiring specialized environmental expertise. The *characterization margin* exists in principle, but the frictions are sufficiently large that most generators find it cheaper to comply with LQG requirements than to optimize their waste classification.

Two limitations deserve emphasis. First, the sample covers 15 states via the EPA Envirofacts API, not the full national universe. The partial coverage introduces sampling uncertainty beyond what bootstrap standard errors capture, and the states most accessible through the API may not be representative. Second, the biennial reporting frequency means the running variable is an annual average converted to monthly estimates, introducing measurement noise that attenuates bunching toward zero. Both limitations suggest that the true compliance elasticity may be somewhat larger than estimated, though the placebo test results argue against a large attenuated effect.

7. Conclusion

The 1,000-kilogram cliff in U.S. hazardous waste regulation does not produce the strong bunching response that theory predicts and that tax notches routinely generate. The *characterization margin*—the space between regulatory definitions and physical reality—exists in principle but appears costly to exploit in practice. This is good news for the RCRA framework: the classification system's complexity, which environmental advocates often criticize as burdensome, may be precisely what prevents the regulatory arbitrage that undermines quantity-based thresholds in other domains. The lesson extends beyond hazardous waste: when designing tiered environmental regulation, the difficulty of manipulating the running variable is a feature, not a bug.

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Project Repository: https://github.com/SocialCatalystLab/ape-papers

Contributors: @olafdrw

First Contributor: https://github.com/olafdrw

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A. Data Appendix

Data Sources. The biennial report data were obtained from EPA's Envirofacts Data Service API (`https://data.epa.gov/efservice/BR_REPORTING`) on April 3, 2026. I downloaded all records for the 2019, 2021, and 2023 reporting cycles. Each record represents a single waste stream reported by a handler, with fields including handler identification, waste codes, generation quantities (in short tons), management methods, shipping information, and NAICS industry codes.

Sample Construction. Starting from the raw waste-stream-level data, I aggregate to the handler-cycle level by summing generation quantities across all reported waste streams. This produces total annual hazardous waste generation per handler. I then convert to monthly averages: kg/month = tons/year $\times$ 907.185/12. Handlers with zero total generation or missing quantity data are dropped. The final sample includes the analysis window of 200–2,500 kg/month used in the bunching estimation.

Variable Definitions.

- *Monthly generation (kg/month):* Total annual hazardous waste generation (sum across all waste streams) divided by 12, converted from short tons to kilograms.
- *Generator status:* Calculated from total generation relative to RCRA thresholds (VSQG: $<$100, SQG: 100–999, LQG: $\geq$1,000 kg/month).
- *NAICS sector:* First two digits of the primary NAICS code reported by the handler.

B. Robustness Appendix

McCrary Density Test. As a supplementary diagnostic, I compare the count of generators in the 100 kg bin just below the threshold (900–999 kg/month) to the count just above (1,000–1,099 kg/month). A ratio substantially above one indicates a density discontinuity consistent with bunching. The observed ratio is 1.37 (155 versus 113 handlers), consistent with the directional bunching found in the main analysis but modest relative to the density ratios typical of tax notch studies.

C. Standardized Effect Sizes

Table 5: Robustness of Bunching Estimates

Specification	Normalized b	Excess Mass
Panel A: Polynomial order		
Polynomial order 5	0.521	17
Polynomial order 6	0.238	8
Polynomial order 7 (baseline)	0.281	9
Polynomial order 8	0.272	9
Polynomial order 9	0.298	10
Panel B: Density test		
McCrary density ratio (below/above)	1.37	

Notes: Panel A varies the polynomial order for the counterfactual density. Baseline is 7th order. Panel B reports the ratio of handler counts in the 100 kg/month bin just below the threshold (900–999) to just above (1,000–1,099). A ratio above 1 indicates excess density below the threshold.

Table 6: Standardized Effect Sizes for Main Outcomes

Outcome	Specification	$\hat{\beta}$	SD(Y)	SDE	SE(SDE)	Classification
Panel A: Pooled						
Excess mass	Baseline (7th poly)	9	20.1	0.462	0.905	Large positive
Panel B: Heterogeneous						
Excess mass	Manufacturing	—	—	-0.187	—	Large negative
Excess mass	Non-manufacturing	—	—	0.229	—	Large positive

Notes: **Country:** United States. **Research question:** Does the RCRA 1,000 kg/month hazardous waste generator threshold induce strategic waste reclassification among regulated generators? **Policy mechanism:** Generators crossing 1,000 kg/month face halved storage time (90 vs 180 days), mandatory contingency plans, emergency training, and biennial reporting—a discrete cost increase that incentivizes threshold avoidance via waste stream reclassification. **Outcome definition:** Normalized excess mass (b) in the density distribution of monthly hazardous waste generation at the regulatory threshold, measuring the fraction of generators strategically positioning below the cutoff. **Treatment:** Continuous—monthly hazardous waste generation in kg/month with a regulatory notch at 1,000. **Data:** EPA Biennial Report via Envirofacts API, 2019–2023 cycles, handler-cycle observations aggregated from waste-stream-level records. **Method:** Bunching estimation following Kleven and Waseem (2013) with 7th-order polynomial counterfactual and bootstrap inference. **Sample:** All SQG and LQG handlers with positive generation in the analysis window (200–2,500 kg/month). SDE = $\hat{\beta}/\text{SD}(Y)$ where SD(Y) is the standard deviation of counterfactual bin counts. Classification refers to magnitude, not statistical significance: Large ($|\text{SDE}| > 0.15$), Moderate (0.05–0.15), Small (0.005–0.05), Null (< 0.005).