Good Intentions, Informal Outcomes: The Formalization Trap in Global E-Waste Markets

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January 23, 2026

Motivation

- E-waste is the fastest-growing waste stream globally.
- Informal processing dominates in many low- and middle-income countries.
- Informal recycling generates severe health and environmental externalities.
- Despite international treaties, subsidies, and integration schemes, formalization remains limited.

Policy Puzzle

- Why does informal recycling persist despite extensive policy effort?
- What role do international e-waste flows play?

Core Argument

- Formalization hinges on access to sufficient high-value throughput.
- International trade alters scale and composition of ewaste streams in receiving countries simultaneously, and dilutes any domestic subsidy.
- Global routing decisions and local cost asymmetries jointly prevent formal facilities from securing sufficient high-value throughput to operate at competitively.

Model Overview

- Two countries: exporter R (high-income) and receiver P (lower-income).
- In each period, country i generates W_i units of e-waste, all of which is processed within that period, either through formal or informal recycling channels.
- Each unit of e-waste has value $v \in [0, 1]$.
- Formal recycling or exports in R
- Formal and informal recycling coexist in P.
- Brokers allocate waste based on relative bids.

Recycling Technologies

- Formal recycling: recovery rate α_F, variable cost c_F^P, fixed cost K_F^P.
- Informal recycling: recovery rate $\alpha_I < \alpha_F$, cost c_I^P.
- Formal average cost: $c_F^P + \frac{K_F^P}{Q_P^F}$.

Export decision in R

- In country R, an EPR system finances treatment. A broker allocates e-waste across treatment options.
- For each unit of value v, the broker compares net domestic treatment costs with export to P.
- Export occurs whenever

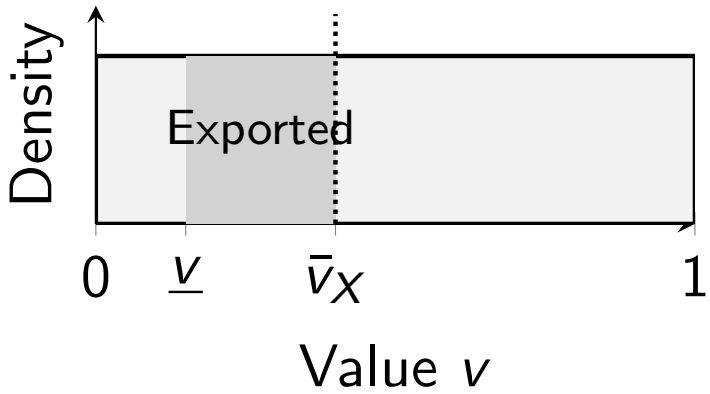
$$f - s_P(v) < c_F^R - p\alpha_F v,$$

which defines an export cutoff $\bar{v}_X$.

- Aggregate exports from R to P satisfy

$$X_{R\to P} = \Pr(\underline{v} \le v \le \bar{v}_X)\, W_R.$$

Uniform values and low-value exports (schematic)



Allocation in P: Formal vs. Informal

- Formal and informal recyclers compete for e-waste by bidding their net processing surplus.
- The broker in P observes both bids and sells to the sector offering the higher price:

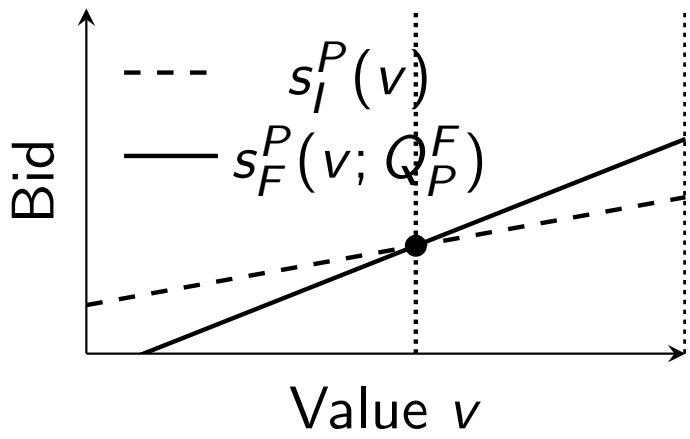
$$s_P(v) = \max\{s_F^P(v; Q_P^F),\ s_I^P(v)\}.$$

- Allocation is determined by a cutoff v_c at which bids are equal:

$$s_F^P(v_c) = s_I^P(v_c).$$

- Units with $v \geq v_c$ are processed formally; and informally otherwise.

Formal vs. informal bids



Formalization Trap

- Formal throughput: $Q_P^F = [W_P + X_{R\to P}][1 - v_c]$.

$$v_c(Q_P^F) = \frac{c_F^P + \frac{K_F^P}{Q_P^F} - c_I^P - \bar{\tau}_F^P}{p\,[\alpha_F - \alpha_I]}, \qquad \Delta\alpha \equiv \alpha_F - \alpha_I > 0.$$

- Define

$$A \equiv 1 - \frac{c_F^P - c_I^P - \bar{\tau}_F^P}{p\,\Delta\alpha}, \qquad B \equiv \frac{K_F^P}{p\,\Delta\alpha}.$$

- Fixed costs create non-linear feedback:

$$Q_P^F = \widetilde{W}_P A - \widetilde{W}_P \frac{B}{Q_P^F}.$$

- Multiple equilibria: no-formal, low-formal, and high-formal states.

Why Imports Matter

- **Scale effect**: more total throughput.
- **Subsidy dilution**: EPR applies only to domestic units.
- **Quality composition**: imports are lower-value.

Subsidy dilution

- Subsidy lowers marginal formal cost.
- Effective subsidy diluted by imports:

$$\bar{\tau}_F^P = \tau_F^P \frac{W_P}{W_P + X_{R \to P}}$$

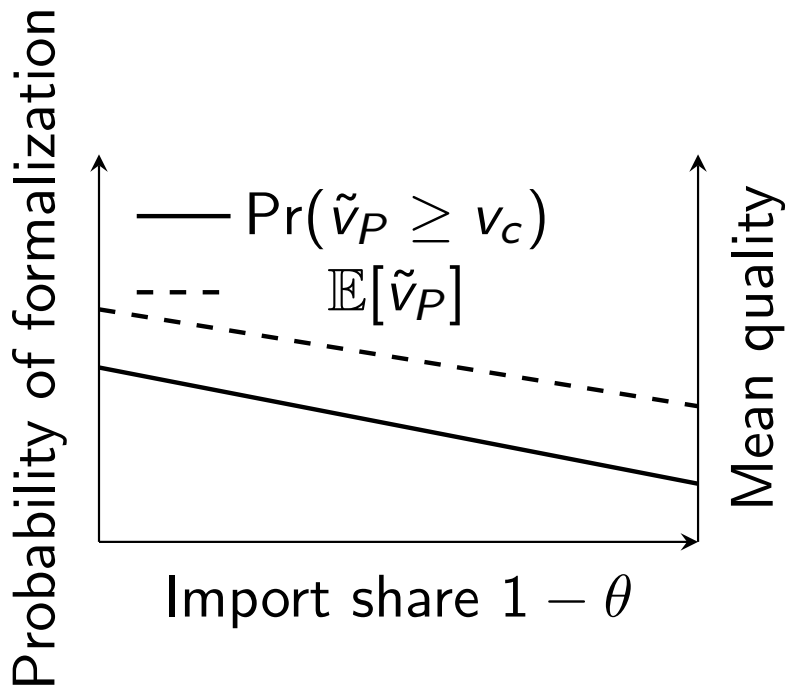
- EPR payments are financed by domestic producer obligations and capped by the domestic fee pool, not by the volume of waste treated.
- Imported units may still be processed formally to utilize capacity, but because they do not generate additional EPR revenue, they dilute the subsidy per unit of formal throughput.

Quality Composition Effect

- Domestic $v \sim U[0,1]$, imports $v_X \sim U[\underline{v}, \bar{v}_X]$.
- Mixed stream mean:

$$\mathbb{E}[\widetilde{v}_P] = \theta \cdot \frac{1}{2} + (1-\theta) \cdot \frac{\underline{v} + \bar{v}_X}{2}$$

- Probability of exceeding cutoff falls as import share rises.

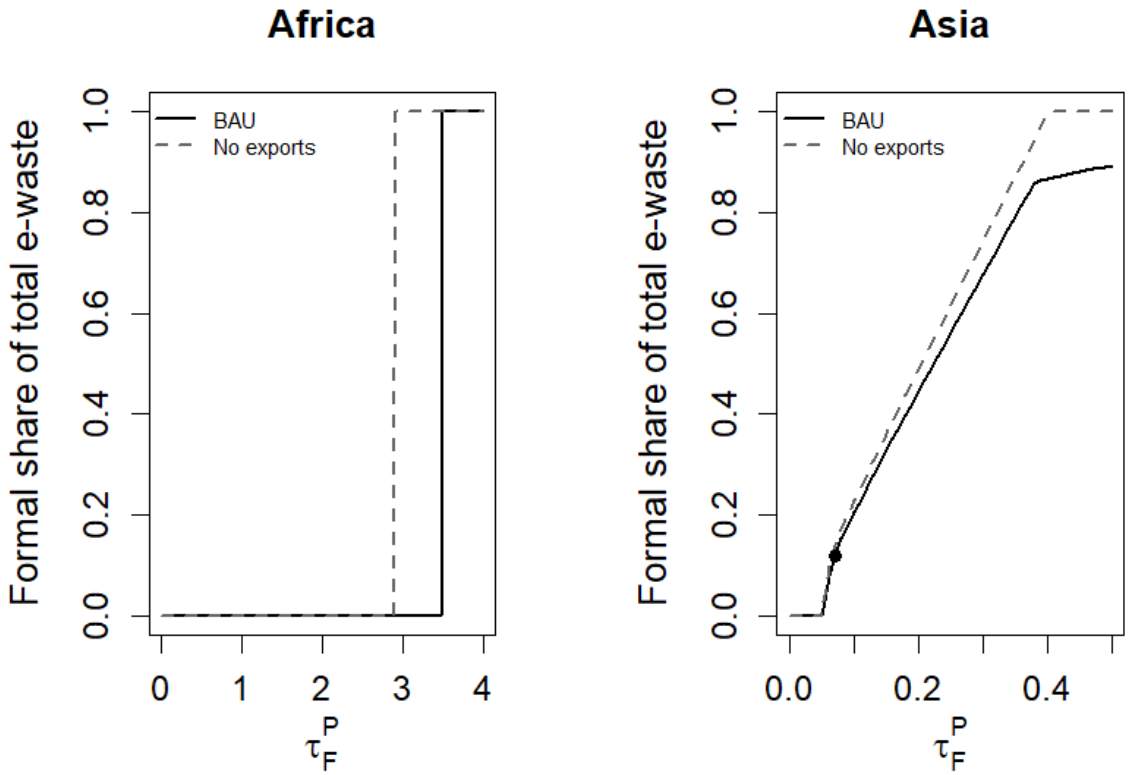


Calibration

- Europe as exporter R.
- Africa and Asia as receiving regions P.
- Parameters chosen to match:
  - observed waste volumes,
  - formalization rates,
  - export magnitudes.

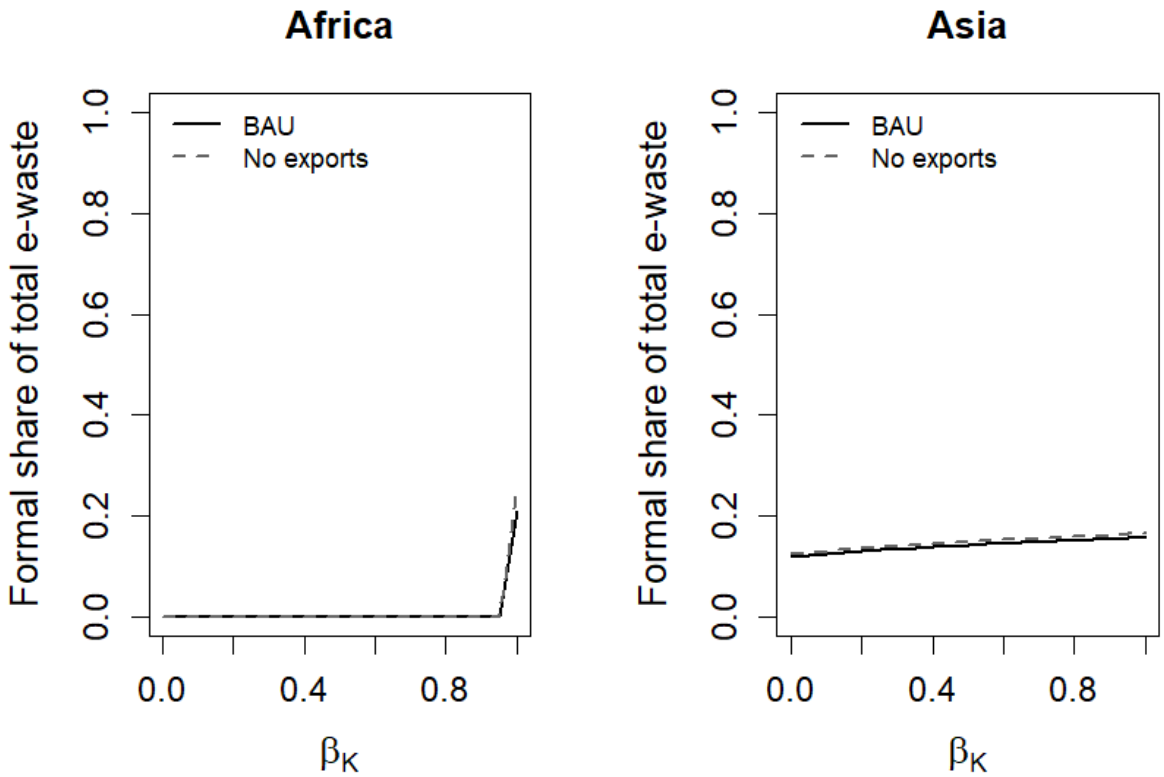
Policy 1: Per-Unit Subsidies

- Subsidy lowers marginal formal cost.
- Effective in Asia, ineffective in Africa.
- Effectiveness is reduced by cross-border e-waste trade.



Policy 2: Capital Support

- Reduces fixed cost K_F^P.
- Minimal interaction with cross-border ewaste trade.
- Cannot overcome marginal cost gap alone.



Policy: Integration of informal collectors

- Informal workers are encouraged to focus on collection and sell collected e-waste to formal recyclers, but informal dismantling remains weakly enforced.
- Formal recyclers must pay a regulated minimum purchase price to collectors, while informal dismantlers continue to operate at unchanged costs.
- The price floor raises formal input costs but does not bind informal buyers, shifting the formal–informal bid cutoff upward.
- In both Africa and Asia, integration reduces formalization: formal throughput falls, and informal processing expands.

Takeaways

- Formalization requires high-value throughput, not volume alone.
- Imports often weaken the effectiveness of the policy.
- Structural cost asymmetries dominate.
- Circular economy policies can shift hazards abroad. Low-value, high-cost, or hazardous-to-process material is sent abroad, even under EPR.