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Not All Waste Trades Alike: Material Archetypes in the Gravity of Global Waste Flows*

Stefano Bolatto† Filippo Santi‡ Maria Tremuli§

May 26, 2026

Abstract

International trade in waste and scrap has expanded rapidly, yet it remains underexplored in quantitative trade economics. This paper analyzes the determinants of waste flows across five major material categories (plastics, paper, glass, iron & steel, aluminum) using a gravity model enriched with bilateral tariff and non-tariff measures. Leveraging HS6 bilateral customs data for 2001–2022, we compare trade elasticities between waste and non-waste products within the same HS2 sectors to assess whether differences in trade patterns are material-specific. The results —robust to dynamic lead-lag specifications assessing systematic anticipation, and to heterogeneity analyses by income level— are consistent with three distinct archetypes: *information-sensitive* materials (plastics, aluminum), where technical NTMs display a pattern suggestive of certification mechanisms; *complementarity-driven* materials (paper), which exhibit inverted tariff elasticities reflecting technological lock-in in specialized recycling infrastructure; and *commodity-like* materials (glass, iron/steel), where trade responds conventionally to policy and geographic frictions. Our findings point to the value of tailoring trade and circular-economy measures to material characteristics, given the systematic differences observed across archetypes.

JEL Codes: F14, F18, Q53, C23.

Keywords: International trade, Waste and scrap, Gravity model, Tariff and non-tariff barriers, Circular economy, Trade and environmental policy.

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1 Introduction

International trade in waste and scrap represents a major challenge for the green transition. As governments pursue circular economy and decarbonization objectives, the role of cross-border shipments of secondary materials has become increasingly contentious: while recycling reduces virgin resource extraction and associated emissions, long-distance waste shipments generate transport emissions and raise concerns for environmental justice. Despite these tensions, global trade in waste and secondary materials has continued to expand, surpassing 200 billion USD annually (WTO, 2022). This reflects the emergence of a new economic geography in which waste management has shifted from a local public service into a transnational commercial activity (Zeng et al., 2022; Minter, 2013). Still, we know surprisingly little about whether trade in waste and secondary materials conforms to standard models of international trade.[1]

The circular economy agenda reinforces this tension.[2] While it calls for reducing waste generation and keeping materials in localized loops, global trade patterns instead reveal rising geographical concentration of recycling and treatment capacities, with developing economies often absorbing waste originating from high-income countries (Li and Whalley, 2012; Yamaguchi, 2020). This mismatch complicates the governance of cross-border waste flows.[3] The Basel Convention's notification-and-consent procedures interact with standard trade instruments but struggle to keep pace with fast-evolving recycling markets, ambiguous material classifications, and expanding illegal circuits (OECD, 2020). Regulatory asymmetries further encourage relocation of waste-intensive activities or export of waste toward jurisdictions with weaker environmental and enforcement standards, raising issues at the intersection of trade policy, environmental justice, and sustainability.[4] These forces jointly shape international waste trade in ways that are often counterintuitive to circular economy objectives (Kellenberg and Levinson, 2014).

Contemporary policy agendas must confront these contradictions. The EU's *Circular Economy Action Plan*, China's *dual circulation strategy*, and emerging critical raw materials policies all grapple with two fundamental questions: under what conditions should waste and secondary materials move globally rather than locally, and what trade-offs arise between economic efficiency, environmental objectives, and industrial strategy? Limited theoretical and empirical understanding of the economics of waste trade risks undermining efforts to design coherent green-transition policies (Baggs, 2009). In particular, policy instruments such as tariffs and non-tariff measures may have heterogeneous effects depending on material characteristics, potentially leading to unintended shifts in trade patterns rather than uniform reductions in waste shipments.

[1] See Head and Mayer (2014); Yotov (2024) for an overview of key facts from the gravity literature.

[2] The Ellen MacArthur Foundation defines the circular economy as pursuing three objectives: eliminating waste and pollution, circulating products and materials, and regenerating natural systems.

[3] To keep the text concise, "waste" will be used any time there is no need to differentiate waste and scraps from secondary raw materials.

[4] See Zalasiewicz et al. (2019), Pellow (2007), and Clapp (2001).

This paper contributes to this debate by providing a first comprehensive empirical assessment of the main drivers of global trade in waste and scrap. Empirical trade research has traditionally omitted waste categories due to data limitations and classification ambiguities, leaving policy debates with limited evidence on when cross-border recycling flows are socially beneficial and when they may facilitate harmful displacement. We address two core questions with direct implications for green transition policy design. First, *do waste and scrap materials follow systematically different trade patterns compared to conventional products within the same sectors?* Second, *are these differences uniform across material categories or inherently sector-specific?*

Three gaps in the existing literature motivate our approach. First, no study to our knowledge compares waste and non-waste products *within* narrowly defined material sectors: existing work either analyzes waste in isolation or relies on aggregate flows. Second, the role of non-tariff measures in waste trade remains underexplored, and the theoretical distinction between their *certification* and *restriction* functions has not been empirically tested. Third, prior research offers no systematic framework linking regulatory barriers to trade patterns across different waste categories.

Understanding how these dimensions interact is essential for calibrating effective policy interventions: uniform 'one-size-fits-all' approaches may prove ineffective, or even counterproductive, if different materials exhibit fundamentally distinct responses to trade costs, regulatory instruments, and geographic frictions. More broadly, our results suggest that the effectiveness of circular economy policies depends critically on material-specific trade elasticities, which should be taken into account when designing international regulatory coordination mechanisms.

To address our research questions, we combine bilateral, product-specific trade data at the HS6 level (2001–2022) from the CEPII BACI dataset (Gaulier and Zignago, 2010) with tariff information from CEPII's MAcMap-HS6 (Guimbard et al., 2012) and non-tariff measures from UNCTAD's TRAINS database. We focus on five major material sectors (plastics, pulp of wood/paper, glass, iron & steel, and aluminum) central to circular economy debates. Each corresponds to an HS2 chapter and contains heterogeneous HS6 subheadings with distinct technological, material, and regulatory characteristics. This heterogeneity provides the variation required to identify material-specific archetypes relevant for green-transition policy.

Following standard practice in international trade, we estimate Poisson Pseudo-Maximum Likelihood (PPML) gravity models with comprehensive fixed effects capturing multilateral resistance and unobserved heterogeneity. Interaction-based specifications allow us to test whether waste-designated HS6 products exhibit systematically different sensitivities to trade costs relative to non-waste products in the same HS2 chapter.[5] We incorporate both tariffs and non-tariff

[5]For example, within HS2 category 39 "Plastics and articles thereof", the following HS6 product codes are explicitly designated as waste: 391510 (waste, parings and scrap, of polymers of ethylene), 391520 (of polymers of styrene), 391530 (of polymers of vinyl chloride), and 391590 (of other plastics, n.e.s.). See `https://wits.worldbank.org/trade/country-byhs6product.aspx?lang=en`.

measures, distinguishing technical NTBs (e.g., SPS/TBT requirements, conformity assessments) from non-technical ones (e.g., licensing, quantitative restrictions), and interact each class with a waste indicator to examine their differential effects.

Our results uncover three consistent material archetypes. *Information-sensitive materials* such as Plastics and Aluminum exhibit strong certification effects: technical NTBs are positively associated with waste trade relative to conventional products, consistent with standards functioning as quality signals that mitigate adverse selection when buyers cannot verify the composition, contamination level, or processing history of waste shipments prior to purchase. *Complementarity-driven materials* such as Pulp of wood/paper display inverted tariff elasticities rooted in technological lock-in: specialized mills rely on recycled fiber, and both high switching costs and structural input–output complementarities limit substitutability with virgin pulp. As a result, recycled-fibre demand remains relatively inelastic with respect to tariffs on virgin alternatives. *Commodity-like materials* such as Glass and Iron & steel show limited differential effects, with waste behaving similarly to conventional goods. Standard trade policies therefore remain appropriate. These archetypes appear plausibly rooted in the underlying material characteristics, including quality heterogeneity, substitutability with virgin inputs, and value-to-weight ratios, which shape distance sensitivities and regulatory responses.[6]

Beyond addressing these policy debates, our analysis advances the empirical literature on trade and the circular economy transition in three main ways. First, it provides the first within-sector comparison of trade elasticities for waste versus non-waste products. Second, it shows that sectoral characteristics —rather than waste status *per se*— drive departures from conventional gravity predictions. Third, it offers new evidence on the dual role of non-tariff measures, which can simultaneously facilitate trade through certification and restrict it through administrative burden, with effects that vary systematically across materials.

Our findings are supported by a series of robustness checks, including dynamic lead–lag specifications that assess whether the estimated NTB patterns reflect systematic regulatory anticipation or persistence; alternative fixed-effects structures; and multiple sample splits by income level, trade direction, and exposure to global waste trade. We also examine alternative definitions of waste versus secondary raw materials where the HS classification allows for cleaner separation, and obtain consistent qualitative results.

The remainder of the paper is organized as follows. Section 2 situates our contribution within the literature on waste trade, gravity models, and trade–environment linkages, and develops the conceptual foundations motivating our empirical approach. Section 3 presents the data. Section 4 discusses the empirical strategy. Section 5 reports the results, including robustness checks and heterogeneity analyses. Section 6 discusses policy implications. Section 7 concludes.

[6]Although untestable with available data, these patterns suggest that the feasibility of 'closing the loop' through localized recycling may vary systematically across materials, cautioning against uniform circular-economy prescriptions.

2 Background and Conceptual Framework

2.1 Literature foundations

Trade in waste and scrap occupies a relatively marginal position within the broader trade literature, but the strands that address it jointly highlight a set of recurring conceptual and empirical challenges. Rather than providing a comprehensive review, this section focuses on contributions that motivate three key elements of our empirical strategy: within-sector identification, the disaggregation of non-tariff measures (NTBs), and a material-level typology.

Gravity models and heterogeneous trade costs. The modern gravity literature provides the methodological foundation for empirical trade analysis. Structural gravity models (Anderson and van Wincoop, 2003), as synthesized by Head and Mayer (2014), emphasize multilateral resistance and motivate PPML estimation (Santos Silva and Tenreyro, 2006). These tools are particularly relevant in settings where policy and environmental frictions generate heterogeneous responses across goods.

Empirical work shows that trade costs affect sectors differently. Grether et al. (2005) find that pollution-intensive goods are more sensitive to trade costs, while Cantore and Cheng (2017) document heterogeneous responses of environmental goods to regulatory stringency. This literature establishes that heterogeneity in trade responses is pervasive, but does not identify whether such heterogeneity operates within narrowly defined material categories.

Classification issues and within-sector identification. A central empirical challenge is product classification. Sauvage (2014) highlight how aggregation biases can distort inference for environmental goods, an issue particularly relevant for waste and scrap, which are dispersed across HS categories and overlap with secondary raw materials.

Much of the existing literature compares environmental goods with aggregate trade flows, potentially conflating waste characteristics with broader sectoral differences. This paper addresses this issue by exploiting within-sector variation, comparing waste and non-waste HS6 products within the same HS2 chapter. This design isolates the effect of waste status while holding constant broader technological and material characteristics, providing a cleaner identification of waste-specific trade responses.

Trade–environment interactions and regulatory heterogeneity. Theoretical work by Copeland and Taylor (2003) shows how environmental regulation can shape trade patterns through comparative advantage effects. Empirical evidence is mixed: Levinson and Taylor (2008) document pollution-haven effects in U.S. manufacturing, while Cherniwchan et al. (2017) show substantial heterogeneity across sectors and regulatory instruments. In the context of waste and scrap, Kellenberg (2009) emphasize that regulatory differences interact with processing capacity and derived demand, complicating simple regulatory interpretations.

This paper does not revisit the pollution-haven hypothesis as a central object of analysis.

Instead, it uses this literature to motivate a more granular question: whether regulatory instruments have systematically different effects on waste versus non-waste products within the same sector once technological structure and demand conditions are held constant.

Distinctive empirical patterns in waste and scrap trade. A further strand of the literature highlights that waste and scrap exhibit trade patterns that differ from standard goods. Kellenberg (2012) emphasize the dual role of waste as both regulated material and economic input, generating determinants that differ from standard pollution-intensive goods. Higashida and Managi (2017) show that high-income countries are often net importers of recyclable waste, pointing to industrial specialization and processing capacity as key drivers.

Overall, bilateral waste flows reflect a combination of technological constraints, recycling infrastructure, and resource-recovery incentives. This combination complicates interpretations based solely on regulatory stringency and reinforces the need for a framework that jointly accounts for material characteristics and trade costs.

Policy shocks and material heterogeneity. Recent institutional changes further highlight the sensitivity of waste flows to regulation. China's *National Sword* policy (Brooks et al., 2018) triggered a reconfiguration of global waste trade patterns, with increased intra-OECD flows and shifts in destination countries (Brown et al., 2023). Related evidence documents heterogeneous distributional and environmental effects across countries (Atalar et al., 2024).

Material-level studies reinforce this heterogeneity. Wang et al. (2019) show that technological complexity shapes e-waste trade, while Velis (2014) emphasize differences in recycling sector organization across materials. These shocks underscore that institutional and technological constraints interact in shaping secondary-material trade, suggesting that responses to policy changes are inherently material-specific.

Circular economy perspectives and persistent global flows. The circular economy literature provides a normative benchmark for evaluating waste trade, emphasizing localized material loops (Ghisellini et al., 2016). However, empirical evidence highlights persistent deviations from this benchmark due to structural constraints such as technological specialization, supply-chain lock-in, and concentration of recycling capacity (Korhonen et al., 2018; Stahel, 2016; Tisserant et al., 2017), as well as governance and enforcement frictions (Leipold and Petit-Boix, 2018; Hobson, 2016).

These constraints help explain why global waste flows persist despite strong policy narratives promoting circularity, reinforcing the importance of distinguishing between material types and regulatory functions.

Taken together, these strands point to three unresolved issues that motivate the empirical analysis. First, how to isolate the contribution of waste status within narrowly defined sectors. Second, how to distinguish between certification and restriction functions of non-tariff measures. Third, how to interpret heterogeneous patterns across secondary materials in a unified framework. These issues are addressed in the empirical analysis that follows.

2.2 Conceptual foundations

A first conceptual clarification concerns the interpretation of trade values for HS-classified waste and scrap. Although waste management in domestic settings can involve disposal costs, this logic does not translate to international trade statistics. The Harmonized System (HS) records cross-border flows of goods rather than services or disposal transactions (UNCTAD, 2019), and values follow standard FOB/CIF conventions. Waste and scrap appearing in trade data should therefore be interpreted as secondary materials with positive economic value, traded for recovery rather than disposal. This distinguishes them from residual waste streams with negative value, which are generally not observed in international trade statistics except indirectly through transport or handling costs. Observed flows are thus better interpreted as intermediate inputs whose value reflects material quality, composition, and expected recovery yields (Kellenberg, 2012).

A second clarification concerns the applicability of the gravity framework. While structural gravity models are typically derived under assumptions of product differentiation and monopolistic competition (Anderson and van Wincoop, 2003; Head and Mayer, 2014), these conditions also characterize waste and scrap trade. Secondary materials are intermediate inputs whose sourcing depends on relative costs, technological compatibility, and supply-chain integration. Waste streams are highly heterogeneous in composition, contamination, and processing requirements.[7] This heterogeneity supports treating waste as a differentiated input rather than a homogeneous commodity. Waste trade is also shaped by the same frictions that underpin gravity relationships—transport costs, informational asymmetries, and regulatory requirements such as Basel Convention procedures—and empirical evidence confirms the relevance of these determinants (Kellenberg, 2012).

This heterogeneity has a direct implication for how trade cost instruments operate. Technical NTBs —such as conformity assessments, contamination thresholds, and composition declarations— act on the *pre-transaction* margin by reducing informational frictions that would otherwise suppress high-quality waste due to adverse selection (Akerlof, 1970). Tariffs, by contrast, operate on the *post-certification* margin: once quality is verified, buyers can substitute between waste and virgin inputs in response to relative prices. High pre-transaction quality heterogeneity (which motivates the NTB certification channel) is therefore fully compatible with high post-certification input substitutability (which dampens tariff complementarity) because the two mechanisms operate at different stages of the transaction, a distinction that informs our empirical interpretation.

A further conceptual element concerns the construction of the indicator $dWaste_k$, defined at the HS6 level as equal to one for products classified as waste, scrap, parings, or recovered materials within each HS2 chapter. This design enables within-sector comparisons that isolate the role of waste status and mitigates concerns that results reflect sectoral composition rather

[7] For instance, plastic scrap varies by polymer type and contamination levels, while metal scrap differs in alloy composition and sorting quality.

than waste-specific features (Sauvage, 2014).

Finally, the HS classification does not consistently distinguish between "waste" and processed secondary raw materials. In the baseline specification both are included in $dWaste_k$, but in HS47 and HS72 —where the distinction is clearer— we separately analyze the two categories in Appendix D.3. While differences across sub-groups do not alter the main patterns, they provide additional insight into the mechanisms underlying trade in secondary materials, as regulatory scrutiny and contamination risks differ across these categories.

These clarifications establish the conceptual basis for the empirical framework and guide the modelling choices developed in the next section.

3 Data and summary statistics

3.1 Data sources

We combine product-level information on trade, tariffs, and non-tariff barriers (NTBs), harmonized at the HS6 level. Bilateral trade data come from the CEPII-BACI dataset (Gaulier and Zignago, 2010), which reports FOB values (current USD) for virtually all countries and product categories, ensuring broad coverage of both advanced and developing economies. Bilateral applied tariffs are taken from the MAcMap-HS6 database (Guimbard et al., 2012), a CEPII–ITC dataset reporting ad-valorem equivalents of MFN and preferential tariffs at the HS6 level. The data aggregate tariff-line information using trade weights and unit values from CEPII's Trade Unit Values dataset, incorporating preferential regimes and regional trade agreements, which is relevant for our setting, as waste and scrap often circulate within integrated recycling networks.

We focus on HS6 products within HS2 chapters 39, 47, 70, 72, and 76, together with all corresponding subheadings. Waste products are identified by classifying all HS6 subheadings explicitly listed as waste, parings, scrap, or recovered materials within these five HS2 chapters (Table 1). We define a binary indicator $dWaste_k$ equal to one for these codes. This construction follows Section 2.2 and supports within-sector comparisons that isolate waste-specific effects from broader material characteristics. All product codes are harmonized to HS2012 using official concordance tables, which ensures consistency with WITS classifications.[8] The harmonization process also guarantees that all product-year observations are strictly comparable across countries and over time, reducing potential noise from changes in nomenclature.

Since tariff data are available at a triennial frequency, we retain eight benchmark years (2001, 2004, 2007, 2010, 2013, 2016, 2019, 2022), avoiding interpolation that would mechanically inflate the panel without adding information.[9] Focusing on benchmark tariff years preserves the integrity of the underlying policy variation and guarantees that all tariff observations correspond

[8]Additional details on concordance procedures are provided in Appendix A.
[9]Interpolating intermediate years would increase dimensionality without improving identification.

Table 1: HS2 chapters and HS6 subheadings for waste and scrap materials

HS2	**Chapter description**	**Tot. num. of HS6 codes**	**Waste-related HS6 codes**	**(Waste-related) Sub-heading description**
39.	Plastics and articles thereof	126	391510	Waste, parings and scrap of polymers of ethylene
			391520	Waste, parings and scrap of polymers of styrene
			391530	Waste, parings and scrap of polymers of vinyl chloride
			391590	Waste, parings and scrap of other plastics
47.	Pulp of wood or other fibrous cellulosic material; waste and scrap of paper or paperboard	21	470610	Pulps of fibres derived from recovered cotton linters
			470620	Pulps of fibres derived from recovered paper or paperboard
			470630	Pulps of fibres derived from recovered bamboo
			470691	Mechanical pulps from recovered paper or paperboard
			470692	Chemical pulps from recovered paper or paperboard
			470693	Pulps from combined mechanical and chemical processes
			470710	Waste and scrap of kraft or corrugated paper
			470720	Waste and scrap of bleached chemical paper or paperboard
			470730	Waste and scrap of mechanical pulp paper
			470790	Waste and scrap of paper or paperboard, n.e.s.
70.	Glass and glassware	64	700100	Cullet and other waste and scrap of glass
72.	Iron & steel	167	720410	Waste and scrap of iron or steel; remelting scrap ingots
			720421	Waste and scrap of stainless steel
			720429	Waste and scrap of iron or steel, n.e.s.
			720430	Waste and scrap of tinned iron or steel
			720441	Turnings, shavings, chips, and other processing scrap
			720449	Other waste and scrap of iron or steel
			720450	Remelting scrap ingots of iron or steel
76.	Aluminum and articles thereof	35	760200	Waste and scrap of aluminum

Source: World Bank WITS portal (HS2012 classification).

to actual updates of national tariff schedules.

Non-tariff barrier data come from UNCTAD's TRAINS database, developed jointly with

Table 2: UNCTAD TRAINS classification of non-tariff measures, by chapter

Technical measures	
A	Sanitary and phytosanitary measures
B	Technical barriers to trade
C	Pre-shipment inspection and other formalities
Non-technical measures	
D	Contingent trade-protective measures
E	Non-automatic import licensing, quotas, prohibitions, quantity-control measures
F	Price-control measures, including additional taxes and charges
G	Finance measures
H	Measures affecting competition
I	Trade-related investment measures
J	Distribution restrictions
K	Restrictions on post-sales services
L	Subsidies and other forms of support
M	Government procurement restrictions
N	Intellectual property
O	Rules of origin

Notes: Export-related measures (MAST P) are excluded from the analysis.
Source: UNCTAD TRAINS (UNCTAD, 2019).

FAO, WTO, ITC, OECD, IMF, and the World Bank. TRAINS reports HS6-level regulatory measures following the MAST classification of NTMs. The taxonomy includes 16 chapters (A–O for import measures; export measures in chapter P are excluded), as summarized in Table 2. We construct an importer–exporter–product–year panel by collapsing all NTB observations at the HS6 level. The baseline indicator equals one when at least one measure of a given type is active for a country pair and product-year. This procedure captures the presence of regulatory frictions without requiring strong assumptions on their intensity, which is consistent with the empirical literature using TRAINS data. Consistent with Section 2.1, we group NTBs into two categories:

(i) technical measures ($dNTBt$, chapters A–C), including SPS, TBT, and pre-shipment inspection;

(ii) non-technical measures ($dNTBn$, chapters D–O), including quotas, licensing, price controls, and trade remedies.

There are two caveats worth noting. First, export-related measures (chapter P) are excluded from our analysis, as they tend to reflect export-side industrial policies rather than the market-access restrictions relevant to our setting. Second, we rely on an aggregate classification of NTBs because many disaggregated categories are very sparsely observed within the fixed-effects structure of our empirical design, which would severely limit variation and identification.

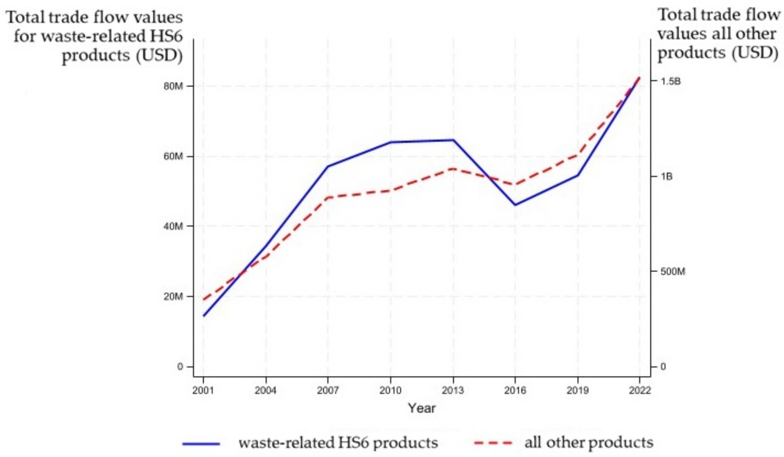
3.2 Descriptive statistics

We now document a few stylized facts on global trade in waste and scrap across our five focal sectors, focusing on differences between waste and non-waste products as well as their policy treatment. While these patterns carry no causal interpretation, they anticipate the material-specific heterogeneity formally estimated in Section 5.

Trade values and growth. *Waste-related trade flows have generally grown faster than those of non-waste products within the same sectors, with plastics representing the main exception.*

Figure 1 plots the evolution of waste and non-waste trade values aggregated across HS2 chapters. Waste-related trade expands steadily throughout the 2000s and typically outpaces the growth of non-waste flows. The 2007–2016 period features a pronounced slowdown—followed by a sharper contraction—that is more marked for waste, reflecting the global financial crisis and early regulatory tightening. After 2016, waste trade rebounds strongly, again growing faster than non-waste products despite heightened scrutiny such as China's 2018 National Sword policy.

Figure 1: Global trade values of waste and non-waste products, 2001–2022 (aggregated across five HS chapters)



Source: Authors' elaboration on CEPII BACI data.

Table 3 confirms these patterns at the HS2 level, highlighting substantial cross-sector heterogeneity. Plastics (HS 39) constitute the main exception: waste grows at 5.71% annually over 2001–2022, below the 7.60% rate for non-waste plastics. In all other material categories, waste trade grows faster —for instance, 6.43% versus 5.30% in pulp of wood/paper (HS 47)— reinforcing the need for a disaggregated empirical approach.

Table 3: World trade values (billions USD) for selected years, by HS2 chapter and waste vs. non-waste HS6 categories

HS2 Chapter		Years 2001	2007	2010	2016	2022	Av. annual growth rate
39 – Plastics and articles thereof	Waste-related HS6	0.50	2.351	3.167	2.357	1.609	5.7%
	All other products	150.891	360.437	410.745	468.645	703.271	7.6%
47 – Pulp of wood	Waste-related HS6	3.261	8.654	11.328	10.488	12.065	6.4%
	All other products	17.330	29.230	35.338	34.913	51.260	5.3%
70 – Glass and glassware	Waste-related HS6	0.132	0.248	0.292	0.387	0.469	6.2%
	All other products	25.611	49.636	54.109	61.753	76.501	5.4%
72 – Iron & steel	Waste-related HS6	7.056	35.307	38.562	22.491	46.764	9.4%
	All other products	98.305	319.404	300.590	256.819	454.605	7.6%
76 – Aluminum and articles thereof	Waste-related HS6	3.478	10.460	10.715	10.249	21.485	9.1%
	All other products	58.628	129.900	123.478	134.106	233.285	6.8%
TOTAL (across all selected chapters)	Waste-related HS6	14.429	57.021	64.063	45.973	82.393	8.6%
	All other products	350.765	888.606	924.261	956.235	1518.922	7.2%

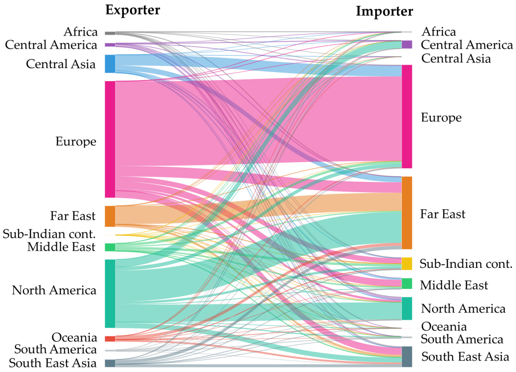
Source: Authors' elaborations on CEPII BACI data.

Geographical structure. *Waste trade exhibits a pronounced North–South orientation, with strong intra-regional clustering and a sharp post-2018 re-routing away from China.*

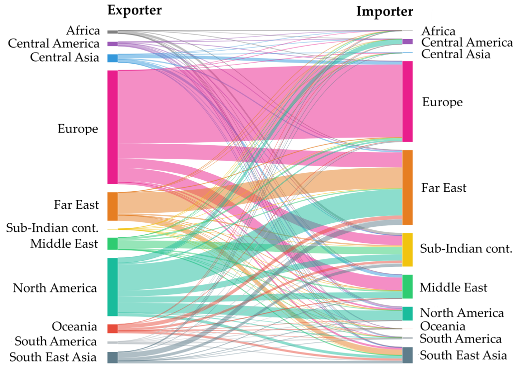
The Sankey diagrams in Figure 2 visualize waste flows between major regions in 2001, 2016, and 2022. Thick intra-regional flows, particularly within Europe, highlight the importance of geographical proximity. At the inter-regional level, waste trade displays a persistent North–South pattern, with high-income economies in Europe and North America predominantly exporting waste to developing regions. East Asia was the main destination until 2018, when China's National Sword policy sharply curtailed low-quality waste imports, forcing a reallocation of waste streams toward Southeast Asia, the Middle East, and the Indian subcontinent.[10]

[10] Prior to 2018, China was the world's main destination for recyclable materials. The National Sword policy tightened contamination thresholds, disrupting global waste markets and diverting flows toward

Figure 2: Gross trade flow values in waste-related HS6 products (aggregate level)



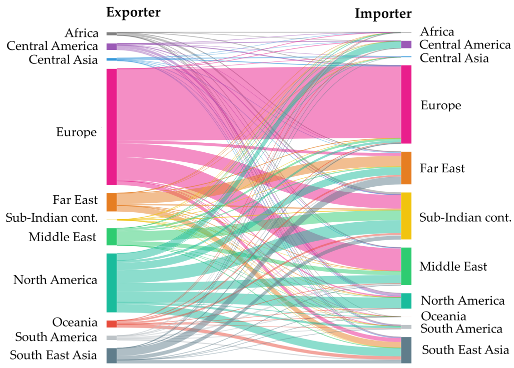
(a) 2001



(b) 2016

Note: The figures report aggregated bilateral flows across the five focal material sectors. Flows are expressed in USD millions. The structure highlights both intra-regional clustering and inter-regional asymmetries in global waste trade. China is included in the regional cluster labelled "Far East". Material-specific diagrams for Chapter 39 (Plastics) are reported in Figure B-1 in the Appendix, together with a list of countries included in each regional cluster. Higher-resolution diagrams for the remaining sectors are available in the dedicated OSF repository.

Source: Authors' elaboration on CEPII data.



(c) 2022

Tariff rates. *Waste and scrap materials face substantially lower average tariffs than non-waste products within the same sectors (by more than 40% over the full sample) and display far greater cross-country dispersion. Pulp of wood/paper represents the main exception.*

Table 4 reports *ad-valorem* tariff levels for waste and non-waste HS6 codes within the five HS chapters considered. On average, waste products are subject to noticeably lower tariffs. The difference is small and statistically insignificant in 2001 (about 1.5%), but increases over time, exceeding three percentage points in 2022 and becoming significant at conventional levels. Over the full sample, this gap amounts to more than 40% relative to the mean tariff level for non-waste products. Tariffs on waste also display systematically higher cross-country dispersion, as indicated by the coefficient of variation across years, likely reflecting differences in domestic

Southeast Asian economies (such as Malaysia, Vietnam, and Indonesia), which often lacked comparable processing capacity (Brooks et al., 2018; Sakai et al., 2014).

recycling capacity, environmental regulation, and the policy treatment of secondary materials.

The only partial exception is HS 47 (Pulp of wood/paper), where the tariff gap between waste and non-waste products is comparatively small (and even reversed in 2001), and dispersion is higher for non-waste products. This pattern aligns with the complementarity mechanism discussed in Section 5: in sectors where recycled inputs are essential for downstream production, tariff policy may generate more nuanced competitive effects.[11]

Table 4: Tariffs for waste and non-waste products across selected years (full sample)

	2001			2022			Full sample		
	Waste	Non-waste	Diff.	Waste	Non-waste	Diff.	Waste	Non-waste	Diff.
Panel A: Tariff statistics (cross-country averages)									
Mean (%)	6.72	8.25	-1.53	3.00	6.02	-3.01***	4.89	8.09	-3.20***
Median (%)	5.33	6.65	-1.32	1.23	5.11	-3.88	4.00	7.40	-3.40
Std. dev. (%)	6.24	6.66	-0.42	4.54	5.23	-0.69	5.60	6.20	-0.60
25th percentile (%)	2.33	2.37	-0.04	0.34	1.49	-1.14	0.30	3.10	-2.80
75th percentile (%)	9.73	11.89	-2.15	4.65	9.71	-5.06	6.50	12.10	-5.60
CV (%)	92.85	80.70	12.15	151.11	86.90	64.20	115.16	77.19	37.97
Panel B: Distributional properties									
Min (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max (%)	25.00	32.30	-7.30	39.02	37.64	1.37	38.20	36.50	1.70
IQR (P75-P25) (%)	7.41	9.51	-2.11	4.30	8.22	-3.92	6.20	9.00	-2.80
Panel C: Mean comparison tests									
t-test		$t = 1.42$			$t = 5.04$***			$t = 464.23$***	
CV ratio (W/NW)		1.15			1.74			1.49	

Notes: Ad-valorem tariffs for waste and non-waste products aggregated across Plastics (HS 39), Pulp of wood/paper (HS 47), Glass (HS 70), Iron & steel (HS 72), and Aluminum (HS 76). Statistics are computed as importer-country averages. The Diff. columns report absolute differences (Waste - Non-waste). *** $p < 0.001$. The full sample includes all years available in our dataset. For Chapter-specific comparisons, see Tables E5 to E9 in the online appendix.
Source: Authors' calculations based on CEPII MAcMap data.

Non-tariff barriers. *NTB incidence increased markedly over the last twenty-five years, with waste products systematically more exposed than non-waste goods. The composition of NTBs also shifted toward greater coexistence of technical and non-technical measures.*

Table 5 reports the incidence and composition of non-tariff barriers across all HS chapters, distinguishing between waste and non-waste products. The share of dyad-product-year observations subject to at least one NTB rose from 9.6% in 2001 to 36.2% by 2016, remaining broadly stable thereafter at around 38–39%. Waste-related products consistently exhibit higher exposure: NTB incidence in the waste subsample reaches 16.5% in 2001 and climbs to nearly 50% by 2016, systematically exceeding the full-sample rate. This pattern is consistent with a deliberate regulatory mix: the lower tariffs documented above reduce price barriers to importing secondary

[11] Chapter-specific versions of Table 4 are available in the online appendix and in the OSF repository.

materials, while the expanding use of non-tariff measures serves a complementary function of screening quality and managing environmental risks. The two instruments therefore move in opposite directions, jointly shaping the regulatory environment faced by waste trade.

Beyond incidence, NTB composition has also evolved. In the early 2000s, non-technical measures accounted for the majority of NTBs in both the full sample and the waste subsample (around 50% and 57% respectively in 2001). Their relative importance declines sharply over time, while joint adoption of technical and non-technical measures becomes dominant by 2022 (47% in the full sample; 54% in the waste subsample), reflecting a broader transition toward more complex, standards-based regulatory frameworks in international trade.

Table 5: Distribution of NTBs in waste and non-waste products, for selected years

	2001	**2007**	**2016**	**2022**
Panel A: full sample				
N. observations	14,825,822	14,877,230	15,235,487	15,250,683
N. $dNTB = 1$	1,421,407	2,410,472	5,510,182	5,889,825
% $dNTB = 1$ on total	9.6%	16.2%	36.2%	38.6%
$dNTBt = 1$ & $dNTBn = 0$	32.9%	33.9%	43.3%	35.7%
$dNTBt = 0$ & $dNTBn = 1$	50.0%	46.1%	18.6%	17.0%
$dNTBt = 1$ & $dNTBn = 1$	17.2%	20.0%	38.2%	47.0%
Total (%)	100.0%	100.0%	100.0%	100.0%
Panel B: waste-related subsample ($dWaste_k = 1$)				
N. observations	653,719	658,267	672,242	672,411
Subsample / Total (%)	4.4%	4.4%	4.4%	4.4%
N. $dNTB = 1$	107,973	219,108	335,529	352,920
% $dNTB = 1$ on subsample	16.5%	33.3%	49.9%	52.5%
$dNTBt = 1$ & $dNTBn = 0$	20.7%	19.3%	13.5%	13.4%
$dNTBt = 0$ & $dNTBn = 1$	57.0%	60.2%	35.7%	35.7%
$dNTBt = 1$ & $dNTBn = 1$	22.3%	20.5%	48.6%	53.9%
Total (%)	100.0%	100.0%	100.0%	100.0%

Notes: The table reports, for selected years, the incidence and composition of non-tariff barriers (NTBs) across all dyad–product–year observations (Panel A, full sample) and for the waste-related subsample (Panel B). $dNTBt$ denotes technical NTBs and $dNTBn$ non-technical NTBs; $dNTB = 1$ indicates the presence of at least one NTB of either type. Percentages in the lower blocks of each panel are computed relative to the set of observations with $dNTB = 1$. For Chapter-specific comparisons, see Tables E10 to E14 in the online appendix.
Source: Authors' elaboration on UN TRAINS.

Finally, the correlation between technical ($dNTB_t$) and non-technical ($dNTB_n$) non-tariff measures is consistently negative across all sectors. Table 6 reports these correlations by year and HS chapter, showing a gradual weakening of this negative association over time. Technical and non-technical measures therefore remain negatively related, but increasingly less so, indicating a shift away from strict mutual exclusivity toward greater coexistence in regulatory policy. The correlation ranges from about –0.20 in pulp of wood/paper (HS 47) to –0.33 in iron & steel (HS 72), suggesting persistent but declining specialization in regulatory instruments. Looking at individual MAST NTB categories, we do not find evidence of multicollinearity that would undermine the precision of our aggregate or disaggregated NTB variables. Yet, the extremely low prevalence of certain NTB types within our preferred gravity specification (see Section 4) still supports a simpler technical vs. non-technical NTB split (see Table B-3 in the Appendix).

Table 6: Correlation between technical and non-technical NTBs, by year and HS chapter

Year	HS39	HS47	HS70	HS72	HS76
2001	-0.532	-0.398	-0.393	-0.401	-0.490
2004	-0.498	-0.397	-0.389	-0.291	-0.438
2007	-0.609	-0.400	-0.401	-0.338	-0.422
2010	-0.297	-0.410	-0.325	-0.519	-0.355
2013	-0.315	-0.219	-0.337	-0.438	-0.327
2016	-0.196	-0.168	-0.190	-0.273	-0.121
2019	-0.161	-0.109	-0.154	-0.246	-0.101
2022	-0.125	-0.105	-0.119	-0.208	-0.090
Overall	-0.270	-0.204	-0.246	-0.332	-0.234

Source: Authors' elaborations on UN TRAINS data.

Summary. Taken together, these descriptive patterns reinforce the motivation for our empirical strategy: waste trade differs systematically from conventional trade in growth dynamics, geographical concentration, tariff treatment, and regulatory exposure. Notably, the lower tariffs and higher NTB incidence observed for waste products suggest that the two instruments serve complementary rather than substitutable functions in governing secondary-material flows. Whether these differences translate into distinct trade elasticities —and whether such elasticities vary systematically across materials— is the key question addressed in Section 5.

4 Empirical Strategy

We estimate a structural gravity model (Anderson and van Wincoop, 2003; Head and Mayer, 2014; Yotov et al., 2016) to study how trade costs and regulatory barriers affect bilateral trade in waste and non-waste products across sectors. Following Fontagné et al. (2022), we perform sector-specific estimations for HS2 chapters $s \in \{39, 47, 70, 72, 76\}$.

Baseline specification. Our *baseline gravity specification* is given by:

$$X_{ijkt} = \exp\Big[\theta_{it} + \theta_{jt} + \theta_{kt} + \beta \ln(Tariff_{ijkt}) + \\ + \gamma \ln(Dist_{ij}) + \lambda\, dNTB_{ijkt} + \delta Z_{ij} + \rho Z_{ijt}\Big] \cdot \varepsilon_{ijkt}, \quad (1)$$

where X_{ijkt} denotes the FOB value of exports from country i to country j of HS6 product k in year t. Trade costs are captured along three main dimensions. First, $\ln(Tariff_{ijkt})$ measures applied ad-valorem tariffs. Second, $\ln(Dist_{ij})$ captures bilateral geographic frictions and proxies for transport costs and broader trade resistance increasing in distance. Third, $dNTB_{ijkt}$ is a binary indicator equal to one when at least one import-side non-tariff measure applies to product k in the $i \rightarrow j$ flow at time t, thus capturing the extensive margin of regulatory restrictions. The vector Z_{ij} includes standard time-invariant dyadic controls—i.e., common language (*comlang*), colonial ties (*colony*), and territorial contiguity (*contig*)—while Z_{ijt} includes time-varying institutional variables in the form of dummies for joint WTO membership (WTO_{ijt}) and regional trade agreement participation (RTA_{ijt}).

A key feature of the specification is the inclusion of exporter-year (θ_{it}), importer-year (θ_{jt}), and product-year (θ_{kt}) fixed effects. Exporter-year effects absorb all time-varying characteristics of the exporting country, including macroeconomic conditions, production costs, policy shocks, and outward multilateral resistance. Importer-year effects capture analogous demand-side factors, as well as inward multilateral resistance and time-varying regulatory and macroeconomic conditions in the destination market. Product-year fixed effects control for global shocks common to all bilateral pairs within a given HS6 product and year, including commodity price cycles, technological change, and shifts in global demand for specific materials. This structure ensures that identification derives exclusively from bilateral variation in trade costs within narrowly defined exporter–importer–product–year cells, net of all country–time and product–time heterogeneity. It is particularly important in our context, where both trade costs and trade flows exhibit strong time-varying global and sectoral components.[12]

Interaction specification. We next estimate a *heterogeneous effects specification* that allows trade cost elasticities to differ between waste and non-waste goods:

$$\begin{aligned} X_{ijkt} = \exp\Big\{&\theta_{it} + \theta_{jt} + \theta_{kt} + \beta \ln(Tariff_{ijkt}) + \gamma \ln(Dist_{ij}) + \lambda dNTB_{ijkt} + \\ &+ [\mu \ln(Tariff_{ijkt}) + \upsilon \ln(Dist_{ij}) + \phi dNTB_{ijkt}] \times dWaste_k + \\ &+ \delta Z_{ij} + \rho Z_{ijt}\Big\} \cdot \varepsilon_{ijkt}, \end{aligned} \tag{2}$$

where $dWaste_k$ identifies waste-classified HS6 products within each HS2 chapter. All waste codes within a chapter are treated as homogeneous (see Table 1). The interaction terms capture whether waste products respond differently to trade costs relative to conventional goods. This is motivated by three channels: (i) the tariff treatment of waste as an industrial input and related

[12] While this high-dimensional fixed-effects structure removes the main sources of multilateral resistance and a large set of observable and unobservable confounders, it does not fully eliminate potential shocks operating at the country–pair–product–year level. Accordingly, the estimated coefficients should be interpreted as conditional correlations within a high-dimensional gravity framework rather than strictly causal effects.

reclassification incentives; (ii) complementarities between final goods and recyclable inputs; and (iii) heterogeneity in substitutability and domestic recycling capacity. The net effect is therefore theoretically ambiguous.

Specification choices and identification. In our preferred specification, we exclude the interaction between distance and waste status, focusing on tariff and NTB heterogeneity. This choice is motivated by two considerations. First, distance is time-invariant and its interaction is identified only from cross-sectional variation, which is relatively limited in a high-dimensional fixed-effects setting. Second, our main mechanisms of interest operate through policy instruments (tariffs and NTBs), for which there are clearer theoretical reasons to expect differential effects. We nonetheless estimate a fully extended specification that allows for all interaction terms, including distance interacted with $dWaste_k$, as a robustness check. Results are reported in Appendix C together with sector-by-sector tables. In the main text, we focus on the preferred specification and the baseline, which together provide core evidence on waste-specific trade elasticities.

Turning to non-tariff barriers, $dNTB_{ijkt}$ aggregates all import-side regulatory measures. We further distinguish between technical ($dNTB_t$) and non-technical ($dNTB_n$) measures following the MAST classification. This decomposition allows us to separate information- and certification-related channels from more restrictive market-access regulations. A potential concern is that NTBs may respond endogenously to trade flows. While the fixed-effects structure absorbs many confounding factors, residual policy endogeneity at the product level may persist, and instrumental-variable strategies are not feasible in our setting. Accordingly, NTB coefficients should be interpreted as conditional correlations within a high-dimensional gravity model.

The disaggregation of $dNTB_{ijkt}$ into technical and non-technical components has an important implication for sample composition that is worth stressing. Panel A of our results tables uses the aggregate indicator and therefore retains all country–product pairs with at least one period of NTB variation, regardless of the type of measure driving the change. Panel B, by contrast, relies on the disaggregated indicators and requires bilateral variation in *both* $dNTB_t$ and $dNTB_n$ within the same country–product pair over time. Because technical and non-technical measures are negatively correlated (Table 6) and often introduced in mutually exclusive regulatory contexts, many pairs that switch on one component never switch on the other, and are consequently dropped from Panel B.

The two panels are thus estimated on structurally distinct samples with different identification support. Panel A captures average NTB effects across the broad universe of bilateral trade relationships, including cases with limited or one-off regulatory activity. Panel B focuses instead on the subset of corridors where regulatory policy has been sufficiently active and multi-dimensional to generate simultaneous variation in both NTB categories. These tend to be the most intensively regulated and commercially significant corridors, where the distinction between certification-related and restriction-related mechanisms is likely to be empirically most informative. Divergences between Panel A and Panel B should therefore be interpreted as reflecting the different regulatory environments captured by the two samples rather than inconsistencies in the underlying model.

5 Results

5.1 Baseline estimates

Tables 7–8 report estimates from specifications (1) and (2). The fully extended specification including distance–waste interactions is reported in Appendix C. Each table displays results for all five HS2 chapters side by side, with Panel A using the aggregate NTB indicator and Panel B disaggregating into technical ($dNTBt$) and non-technical ($dNTBn$) measures. As discussed in Section 4, Panel B is estimated on a restricted subset of country–product pairs exhibiting bilateral variation in both NTB types, and therefore captures effects under stronger identification support than Panel A. Full-chapter tables including all gravity controls are in Appendix C.

We begin by examining the benchmark gravity specification in Table 7, which provides the reference point against which heterogeneous effects are evaluated. Coefficients are broadly consistent with standard gravity predictions. Tariffs are negatively associated with trade in four of the five chapters; distance is uniformly negative; and aggregate NTBs act as barriers for non-waste products in most sectors. The main exception is HS 76 (Aluminum), where the NTB level coefficient is positive, indicating that countries with more active regulatory frameworks tend to import more aluminum regardless of waste status. These baseline patterns already foreshadow the archetype structure developed in Section 6.

Turning to the heterogeneous-effects specification in Table 8, which is the main specification used for inference, two sets of interaction patterns emerge. The interaction $\ln(Tariff) \times dWaste_k$ is large and statistically significant only for HS 47 (+15.05) and HS 76 (+8.86) in Panel A, reversing the sign of the total tariff elasticity for waste in both chapters. For HS 39, HS 70, and HS 72, the interaction is small and not statistically distinguishable from zero, indicating that waste and non-waste products face broadly similar tariff responses within those sectors. The reversal for HS 47 is the largest and most precisely estimated result in the paper: it survives disaggregation in Panel B and the inclusion of the distance interaction in the fully extended specification (+11.22). A similar but somewhat smaller reversal is present for HS 76 and is stable across specifications.

The aggregate NTB interaction $dNTB \times dWaste_k$ is positive and significant for HS 39 (+1.67), HS 47 (+1.53), and HS 76 (+0.30), and negative for HS 72 (−0.29) and HS 70 (−0.32). Panel B reveals additional heterogeneity. For HS 39, both technical and non-technical interactions are positive and large (+2.54 and +2.69). For HS 76, the facilitation is concentrated in the technical component ($dNTBt \times dWaste_k = +1.11$; $dNTBn \times dWaste_k = +0.18$, not significant). For HS 47, both components are positive and significant, with the non-technical slightly larger.

Table 7: Baseline Gravity Specification

	HS 39 Plastics	HS 47 Paper	HS 70 Glass	HS 72 Iron & Steel	HS 76 Aluminum
Panel A — Aggregate NTB specification					
$\ln(Tariff)$	-7.134^{***}	5.302^{**}	0.010	-2.053^{***}	-6.518^{***}
	(0.228)	(2.289)	(0.477)	(0.386)	(0.600)
$\ln(Dist)$	-0.976^{***}	-1.066^{***}	-0.953^{***}	-1.089^{***}	-0.944^{***}
	(0.011)	(0.058)	(0.021)	(0.016)	(0.022)
$dNTB$	-0.224^{***}	0.157	-0.266^{***}	-0.182^{***}	0.296^{***}
	(0.031)	(0.139)	(0.049)	(0.041)	(0.055)
Panel B — Disaggregated NTB specification					
$\ln(Tariff)$	-9.518^{***}	6.020	-0.528	-5.323^{***}	-7.144^{***}
	(0.377)	(4.056)	(0.985)	(0.638)	(0.897)
$\ln(Dist)$	-0.874^{***}	-1.277^{***}	-1.014^{***}	-1.098^{***}	-0.971^{***}
	(0.019)	(0.101)	(0.042)	(0.030)	(0.039)
$dNTBt$	-0.182^{***}	0.742^{***}	0.008	0.340^{***}	0.665^{***}
	(0.044)	(0.206)	(0.066)	(0.069)	(0.081)
$dNTBn$	0.210^{***}	-0.075	-0.209^{**}	0.251^{***}	0.637^{***}
	(0.041)	(0.156)	(0.081)	(0.071)	(0.087)
Exporter×Year FE	✓	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓	✓
Panel A statistics					
Observations	17,465,751	1,649,079	8,444,363	18,613,939	5,035,497
Pseudo-R^2	0.790	0.808	0.736	0.644	0.740
χ^2	40,002	1,955	6,036	20,596	8,914
Log-lik. ($\times 10^9$)	-2.300	-0.279	-0.407	-3.295	-1.008
Panel B statistics					
Observations	6,066,109	441,967	2,490,047	5,405,541	1,534,099
Pseudo-R^2	0.807	0.835	0.773	0.653	0.761
χ^2	11,037	332	3,492	6,600	2,816
Log-lik. ($\times 10^9$)	-1.040	-0.120	-0.131	-1.266	-0.415

Notes: PPML estimation. Sample covers 2001–2022 (eight triennial benchmark years). The baseline specification includes WTO and RTA dummies (not reported for space) and a constant term. Panel A uses the aggregate NTB indicator $dNTB_{ijkt}$ (=1 if any import-side technical or non-technical NTB applies). Panel B disaggregates into $dNTBt_{ijkt}$ (MAST chapters A–C) and $dNTBn_{ijkt}$ (MAST chapters D–O); export-side NTMs (MAST chapter P) are excluded. Panel B has fewer observations because the disaggregated specification is estimated only on the subset of country-product pairs exhibiting bilateral variation in both NTB types. Results are robust to restricting the sample to the period 2001–2016 (available in the online appendix). Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

For HS 70, both are small and insignificant. For HS 72, Panel B yields positive interactions for both components (+0.43 and +0.78), in contrast to the negative aggregate sign in Panel A. This divergence is econometrically expected given the distinct identification conditions of the two panels discussed in Section 4: Panel B isolates the most intensively regulated bilateral corridors, while Panel A captures average effects across the full universe of HS 72 trade relationships.

Table 8: Heterogeneous Effects Specification (Preferred Specification)

	HS 39 Plastics	HS 47 Paper	HS 70 Glass	HS 72 Iron & Steel	HS 76 Aluminum
Panel A — Aggregate NTB specification					
$\ln(Tariff)$	-7.092^{***}	-3.427	0.013	-2.144^{***}	-6.513^{***}
	(0.228)	(2.471)	(0.477)	(0.391)	(0.575)
$\ln(Tariff) \times dWaste$	0.692	15.048^{***}	1.674	1.594	8.863^{***}
	(1.177)	(2.320)	(1.970)	(1.098)	(1.211)
$\ln(Dist)$	-0.976^{***}	-1.058^{***}	-0.953^{***}	-1.090^{***}	-0.943^{***}
	(0.011)	(0.058)	(0.021)	(0.016)	(0.022)
$dNTB$	-0.246^{***}	-0.091	-0.264^{***}	-0.131^{***}	0.252^{***}
	(0.031)	(0.151)	(0.049)	(0.043)	(0.053)
$dNTB \times dWaste$	1.673^{***}	1.530^{***}	-0.316^{**}	-0.288^{***}	0.299^{**}
	(0.096)	(0.134)	(0.142)	(0.095)	(0.122)
Panel B — Disaggregated NTB specification					
$\ln(Tariff)$	-9.500^{***}	1.879	-0.552	-5.863^{***}	-6.748^{***}
	(0.382)	(4.423)	(0.989)	(0.658)	(0.861)
$\ln(Tariff) \times dWaste$	-0.459	3.664	5.434^{**}	8.011^{***}	1.987
	(1.716)	(4.571)	(2.467)	(2.431)	(3.742)
$\ln(Dist)$	-0.876^{***}	-1.268^{***}	-1.014^{***}	-1.098^{***}	-0.971^{***}
	(0.019)	(0.101)	(0.042)	(0.030)	(0.039)
$dNTBt$	-0.283^{***}	0.474^{*}	0.009	0.270^{***}	0.437^{***}
	(0.046)	(0.271)	(0.067)	(0.072)	(0.085)
$dNTBt \times dWaste$	2.539^{***}	0.924^{***}	-0.055	0.431^{***}	1.111^{***}
	(0.134)	(0.261)	(0.360)	(0.144)	(0.207)
$dNTBn$	0.125^{***}	-0.231	-0.214^{***}	0.190^{**}	0.560^{***}
	(0.041)	(0.166)	(0.081)	(0.074)	(0.087)
$dNTBn \times dWaste$	2.692^{***}	1.841^{***}	0.678^{**}	0.783^{***}	0.179
	(0.189)	(0.186)	(0.271)	(0.295)	(0.201)
Exporter×Year FE	✓	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓	✓
Panel A statistics					
Observations	17,465,751	1,649,079	8,444,363	18,613,939	5,035,497
Pseudo-R^2	0.791	0.810	0.736	0.644	0.741
χ^2	40,391	2,134	6,081	21,021	9,053
Log-lik. ($\times 10^9$)	-2.294	-0.276	-0.407	-3.294	-1.006
Panel B statistics					
Observations	6,066,109	441,967	2,490,047	5,405,541	1,534,099
Pseudo-R^2	0.809	0.838	0.773	0.653	0.762
χ^2	11,399	467	3,510	6,666	2,869
Log-lik. ($\times 10^9$)	-1.031	-0.118	-0.131	-1.264	-0.413
Wald test: $dNTBt \times dWaste = dNTBn \times dWaste$					
χ^2	1.146	**9.187**	2.348	0.684	**13.395**

Notes: PPML estimation. Sample, controls, and structure are identical to Table 7. This specification includes waste–tariff and waste–NTB interactions but excludes interactions with distance. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

To assess whether technical and non-technical NTBs have statistically distinguishable effects on waste trade, we test $H_0\colon \beta_{dNTBt \times dWaste_k} = \beta_{dNTBn \times dWaste_k}$ for each chapter. The χ^2

statistics are reported at the bottom of Table 8. H_0 is rejected for HS 47 ($\chi^2 = 9.19$) and HS 76 ($\chi^2 = 13.40$), while it is not rejected for HS 39, HS 70, and HS 72. For HS 39, non-rejection reflects similarity in magnitude between the two components rather than absence of facilitation. For HS 72, it is consistent with the identification structure discussed in Section 4.

The fully extended specification (Table C-6 in Appendix C) confirms that the main results are robust to the inclusion of distance–waste interactions.The distance interaction is negative and significant for HS 47 (-0.59) and HS 70 (-0.15), indicating greater distance sensitivity for waste in these chapters, and positive for HS 72 ($+0.28^{***}$, Panel B) and HS 76 ($+0.49^{***}$, Panel B). Since distance is time-invariant, this variation is identified from cross-sectional differences across country pairs and is therefore interpreted as descriptive rather than causal.

Overall, the results show that waste products do not respond uniformly to trade costs: the direction and magnitude of waste-specific effects vary substantially across chapters, consistent with material-specific mechanisms. Three broad groups emerge from the coefficient patterns: (i) chapters where NTB facilitation dominates (HS 39, HS 76); (ii) chapters where tariff reversal is the defining feature (HS 47); and (iii) chapters where effects are more heterogeneous or confined to regulated sub-corridors (HS 70, HS 72). These patterns provide the empirical basis for the archetype classification developed in Section 6.[13]

5.2 Endogeneity checks

Building on the benchmark estimates, we next address potential endogeneity concerns by examining whether waste-related NTB differentials might themselves be shaped by past or anticipated trade flows. To do so, we estimate dynamic specifications that augment the heterogeneous effects specification in equation (2) with lagged or lead NTB variables. The baseline structure, fixed effects, and sample remain unchanged.

To examine whether past trade flows are associated with subsequent adjustments in regulatory measures, we estimate the following *lag specification*, which adds lagged NTBs and their interactions with $dWaste_k$ to the baseline gravity equation:

$$\begin{aligned} X_{ijkt} = \exp\Bigg[& \theta_{it} + \theta_{jt} + \theta_{kt} + \beta \ln(Tariff_{ijkt}) + \gamma \ln(Dist_{ij}) \\ & + \sum_{\ell=1}^{2} \Big(\lambda_1^{(\ell)}\, dNTB_{ij,k,t-\ell} + \lambda_2^{(\ell)}\, dNTB_{ij,k,t-\ell} \times dWaste_k \Big) \\ & + \mathit{\Gamma}_1 Z_{ij} + \mathit{\Gamma}_2 Z_{ijt} \Bigg] \cdot \varepsilon_{ijkt}. \end{aligned} \tag{3}$$

[13] The results are robust to alternative temporal definitions of NTB variables. In the online appendix we report (i) a restricted sample covering 2001–2016, and (ii) a 3-year moving cumulative specification. In both cases, results remain stable, with stronger effects in the pre-National Sword period.

As in the benchmark analysis, we estimate both an aggregate version using $dNTB$ and a disaggregated version replacing $dNTB$ with its technical and non-technical components ($dNTBt$ and $dNTBn$) and including the corresponding interaction terms.

Table 9: Endogeneity Lag Check

	HS 39 Plastics	HS 47 Paper	HS 70 Glass	HS 72 Iron & Steel	HS 76 Aluminum
Panel A — Aggregate NTB specification					
$dNTB \times dWaste$	-0.558^{***}	-0.238	-0.549	-2.063^{***}	-1.289^{***}
	(0.152)	(0.223)	(0.384)	(0.287)	(0.426)
$dNTB_{L1} \times dWaste$	0.674^{***}	-0.019	-0.262	1.847^{***}	0.528
	(0.191)	(0.262)	(0.735)	(0.371)	(0.527)
$dNTB_{L2} \times dWaste$	1.641^{***}	1.268^{***}	0.550	-0.065	1.202^{***}
	(0.211)	(0.261)	(0.533)	(0.273)	(0.362)
Panel B — Disaggregated NTB specification					
$dNTBt \times dWaste$	1.676^{***}	-0.986^{**}	0.097	0.543^{**}	-0.643^{**}
	(0.544)	(0.458)	(0.452)	(0.270)	(0.320)
$dNTBt_{L1} \times dWaste$	-0.491	0.552	0.424	-4.657^{***}	1.061^{***}
	(0.779)	(0.734)	(0.481)	(0.461)	(0.334)
$dNTBt_{L2} \times dWaste$	1.516^{**}	1.355^{*}	-0.428	4.636^{***}	0.735^{***}
	(0.618)	(0.726)	(0.487)	(0.384)	(0.235)
$dNTBn \times dWaste$	0.559	0.900^{***}	-0.343	1.012	-3.511^{***}
	(0.347)	(0.349)	(0.487)	(0.707)	(0.581)
$dNTBn_{L1} \times dWaste$	-0.345	0.437	0.833^{*}	0.377	2.287^{***}
	(0.791)	(0.329)	(0.495)	(0.841)	(0.646)
$dNTBn_{L2} \times dWaste$	2.595^{***}	0.872^{**}	0.759	-0.601	1.253^{***}
	(0.802)	(0.385)	(0.469)	(0.563)	(0.424)
Exporter×Year FE	✓	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓	✓
Panel A statistics					
Observations	17,465,751	1,649,079	8,444,363	18,613,939	5,035,497
Pseudo-R^2	0.791	0.815	0.736	0.644	0.741
χ^2	40,890	2,276	6,126	21,174	9,161
Panel B statistics					
Observations	5,216,886	373,770	2,106,101	4,546,931	1,294,178
Pseudo-R^2	0.818	0.844	0.785	0.658	0.773
χ^2	10,887	417	3,963	6,205	2,816

Notes: PPML estimation, preferred specification, sample 2001–2022 with eight benchmark years spaced at three-year intervals. Observations for 2001–2004 are excluded because the two-period lag $L2$ is unavailable. Only NTB interaction terms are reported; all level controls $\ln(Tariff)$, $\ln(Dist)$, $dNTB$, $dNTBt$, $dNTBn$, WTO, and RTA are included but omitted for brevity. $L1$ and $L2$ denote one- and two-period lags (three- and six-year intervals given the sampling frequency). Coefficients should be interpreted as semi-elasticities within the PPML exponential framework and are not directly comparable in magnitude across lag horizons. Panel B has fewer observations for the same reason as in Table 8. ${}^{*}p < 0.10$, ${}^{**}p < 0.05$, ${}^{***}p < 0.01$.

Table 10: Endogeneity Lead Check (Falsification)

	HS 39 Plastics	HS 47 Paper	HS 70 Glass	HS 72 Iron & Steel	HS 76 Aluminum
Panel A — Aggregate NTB specification					
$dNTB \times dWaste$	0.371**	0.263	−0.877**	−0.770***	−0.479*
	(0.186)	(0.308)	(0.403)	(0.248)	(0.258)
$dNTB_{F1} \times dWaste$	0.494**	0.594**	1.400*	−0.116	2.546***
	(0.206)	(0.267)	(0.772)	(0.561)	(0.355)
$dNTB_{F2} \times dWaste$	0.824***	−0.004	−0.822	0.604	−1.782***
	(0.213)	(0.307)	(0.930)	(0.535)	(0.318)
Panel B — Disaggregated NTB specification					
$dNTBt \times dWaste$	1.771***	−0.145	0.162	2.270	1.183***
	(0.329)	(0.486)	(0.619)	(.)	(0.249)
$dNTBt_{F1} \times dWaste$	−0.783	0.414	−0.340	1.961	0.493**
	(0.523)	(0.479)	(0.678)	(.)	(0.248)
$dNTBt_{F2} \times dWaste$	1.757***	0.728*	0.539	−3.876	−0.632**
	(0.518)	(0.376)	(0.496)	(.)	(0.247)
$dNTBn \times dWaste$	1.339**	0.772***	0.146	9.297	2.289***
	(0.597)	(0.293)	(0.473)	(.)	(0.771)
$dNTBn_{F1} \times dWaste$	0.808	0.978***	0.631	−9.618	−0.939
	(0.664)	(0.341)	(0.530)	(.)	(0.835)
$dNTBn_{F2} \times dWaste$	0.553**	0.139	0.143	1.421	−1.319***
	(0.246)	(0.278)	(0.360)	(0.393)	
Exporter×Year FE	✓	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓	✓
Panel A statistics					
Observations	17,465,751	1,649,079	8,444,363	18,613,939	5,035,497
Pseudo-R^2	0.791	0.811	0.736	0.644	0.741
χ^2	40,643	2,096	6,194	21,066	9,149
Panel B statistics					
Observations	5,982,501	433,278	2,459,056	5,367,187	1,517,576
Pseudo-R^2	0.811	0.835	0.775	0.653	0.764
χ^2	11,990	495	3,636	6,933	2,986

Notes: PPML estimation, preferred specification, sample 2001–2022. Observations for 2019–2022 are excluded because the two-period lead $F2$ is unavailable. All level controls are included but omitted for brevity. $F1$ and $F2$ denote one- and two-period leads (three and six years respectively). The HS 72 disaggregated lead specification (Panel B, col. 4) fails to produce standard errors. This is a consequence of the stringent bilateral variation requirements of Panel B combined with the additional sample restriction imposed by the two-period lead window, which jointly reduce within-cell variation below the threshold required for PPML identification. Panel A results for HS 72 are unaffected and show no systematic anticipatory pattern. Panel B has fewer observations for the same reason as in Table 8. Standard errors are clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Results are reported in Table 9. Lagged NTB coefficients are generally small or negative across chapters, providing no evidence that past trade flows systematically induce subsequent tightening of regulatory measures. Lagged interaction terms are occasionally significant, but their signs are not stable across horizons, suggesting no robust or systematic dynamic feedback from trade to regulation.

To assess whether NTBs respond in anticipation of future waste-intensive trade, we estimate the *lead specification*, which introduces forward-looking NTB variables and their interactions with $dWaste_k$ into the baseline model:

$$\begin{aligned} X_{ijkt} = \exp \Bigg[& \theta_{it} + \theta_{jt} + \theta_{kt} + \beta \ln(Tariff_{ijkt}) + \gamma \ln(Dist_{ij}) \\ & + \sum_{\ell=1}^{2} \left(\phi_1^{(\ell)} \, dNTB_{ij,k,t+\ell} + \phi_2^{(\ell)} \, dNTB_{ij,k,t+\ell} \times dWaste_k \right) \\ & + \Gamma_1 Z_{ij} + \Gamma_2 Z_{ijt} \Bigg] \cdot \varepsilon_{ijkt}. \end{aligned} \tag{4}$$

Results are reported in Table 10. Lead coefficients are small, unstable in sign, and rarely statistically significant, providing no systematic evidence of anticipatory NTB adjustments. Where significant, effects are not persistent across horizons, suggesting no stable forward-looking regulatory pattern.

Overall, the dynamic specifications do not provide evidence of systematic reverse causality or anticipatory policy responses. The estimated patterns are more consistent with limited temporal persistence in regulatory measures rather than feedback effects from trade flows. These results support the identifying assumption underlying the contemporaneous specification used in the baseline analysis.

5.3 Robustness checks and extensions

We now extend the analysis along two dimensions that bear on the external validity of the baseline results. We start by examining whether waste-specific NTB differentials vary with the income level of the importing country and with the income direction of bilateral flows. Later, we report a series of additional robustness checks; full results are provided in Appendix D and the online appendix.

Heterogeneity by importer income level. We augment the heterogeneous effects specification with a triple interaction $dNTB \times dWaste_k \times d_{\text{High}}$, where d_{High} equals one for high-income importing countries (World Bank classification, time-varying), and zero otherwise. The coefficient on $dNTB \times dWaste_k$ captures the baseline waste-specific NTB differential for low-income destinations, while the triple interaction measures the differential at high-income destinations. Results are reported in Table 11.

The aggregate triple interaction turns out to be negative and significant for HS 39 (-1.47^{***}), HS 47 (-1.43^{***}), HS 70 (-1.09^{***}), HS 76 (-2.00^{***}), and smaller for HS 72 (-0.51^{***}). This indicates weaker NTB facilitation for waste at high-income destinations essentially across all HS

Table 11: Income heterogeneity in NTB effects on waste trade

	HS 39 Plastics	HS 47 Paper	HS 70 Glass	HS 72 Iron & Steel	HS 76 Aluminum
Panel A — Aggregate NTB specification					
$dNTB$	−0.260***	0.120	−0.430***	−0.010	0.420***
	(0.050)	(0.230)	(0.090)	(0.060)	(0.080)
$dNTB \times dWaste$	2.580***	1.090***	0.420*	−0.090	1.190***
	(0.150)	(0.130)	(0.230)	(0.110)	(0.150)
$dNTB \times HighIncome$	0.020	−0.110	0.250**	−0.190**	−0.300***
	(0.060)	(0.250)	(0.100)	(0.080)	(0.100)
$dNTB \times dWaste \times HighIncome$	−1.470***	−1.430***	−1.090***	−0.510***	−2.000***
	(0.170)	(0.180)	(0.260)	(0.130)	(0.180)
Panel B — Disaggregated NTB specification					
$dNTBt$	−0.350***	0.330	−0.180**	0.210***	0.180*
	(0.060)	(0.350)	(0.090)	(0.080)	(0.100)
$dNTBt \times dWaste$	2.580***	0.110	0.120	0.740***	1.760***
	(0.210)	(0.220)	(0.380)	(0.190)	(0.200)
$dNTBt \times HighIncome$	0.130	−0.290	0.350***	−0.210	0.260
	(0.090)	(0.580)	(0.120)	(0.170)	(0.160)
$dNTBt \times dWaste \times HighIncome$	−0.450**	1.940***	−0.080	−0.660**	−2.810***
	(0.230)	(0.430)	(0.460)	(0.260)	(0.310)
$dNTBn$	0.000	−0.190	−0.520***	0.120	0.410***
	(0.060)	(0.180)	(0.140)	(0.100)	(0.110)
$dNTBn \times dWaste$	3.500***	2.990***	1.220***	0.690**	−0.050
	(0.220)	(0.330)	(0.470)	(0.280)	(0.200)
$dNTBn \times HighIncome$	0.150**	−1.440***	0.610***	0.250*	0.160
	(0.070)	(0.500)	(0.160)	(0.140)	(0.150)
$dNTBn \times dWaste \times HighIncome$	−1.240***	−1.920***	−1.000*	−0.140	−0.190
	(0.170)	(0.420)	(0.540)	(0.210)	(0.240)
Exporter×Year FE	✓	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓	✓
Observations (Panel A)	17,465,751	1,649,079	8,444,363	18,613,939	5,035,497
Pseudo-R^2	0.791	0.813	0.736	0.644	0.744
χ^2	41,040.8	2,343.6	6,177.6	21,117.4	9,234.9
Observations (Panel B)	6,066,109	441,967	2,490,047	5,405,541	1,534,099
Pseudo-R^2	0.810	0.840	0.774	0.654	0.764
χ^2	12,252.6	496.6	3,580.4	6,710.8	3,015.8

Notes: PPML estimation, sample 2001–2022. d_{High} equals one if the importer is classified as high-income by the World Bank (time-varying). The triple interaction captures the differential effect of NTBs on waste trade at high-income destinations, relative to non-high-income destinations and non-waste goods. All specifications include exporter×year, importer×year, and product×year fixed effects. All standard gravity controls (including tariff levels, tariff distance, bilateral distance, and institutional variables) are included in all specifications but omitted from the table for brevity. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

chapters. The effect reflects attenuation rather than reversal, as the baseline interaction $dNTB \times dWaste_k$ remains positive and significant throughout. When splitting NTBs into technical and non-technical measure, we observe more heterogeneity across materials. For HS 39, both technical and non-technical components have a negative coefficient (-0.45^{**} and -1.24^{***}). For HS 76, attenuation is driven by the technical component (-2.81^{***}). For HS 47, the components diverge, with a positive technical effect ($+1.94^{***}$) and a negative non-technical effect (-1.92^{***}), implying partial offsetting channels. For HS 70, the pattern is consistent with stronger baseline effects at lower-income destinations. For HS 72, estimates are small and imprecise across specifications.

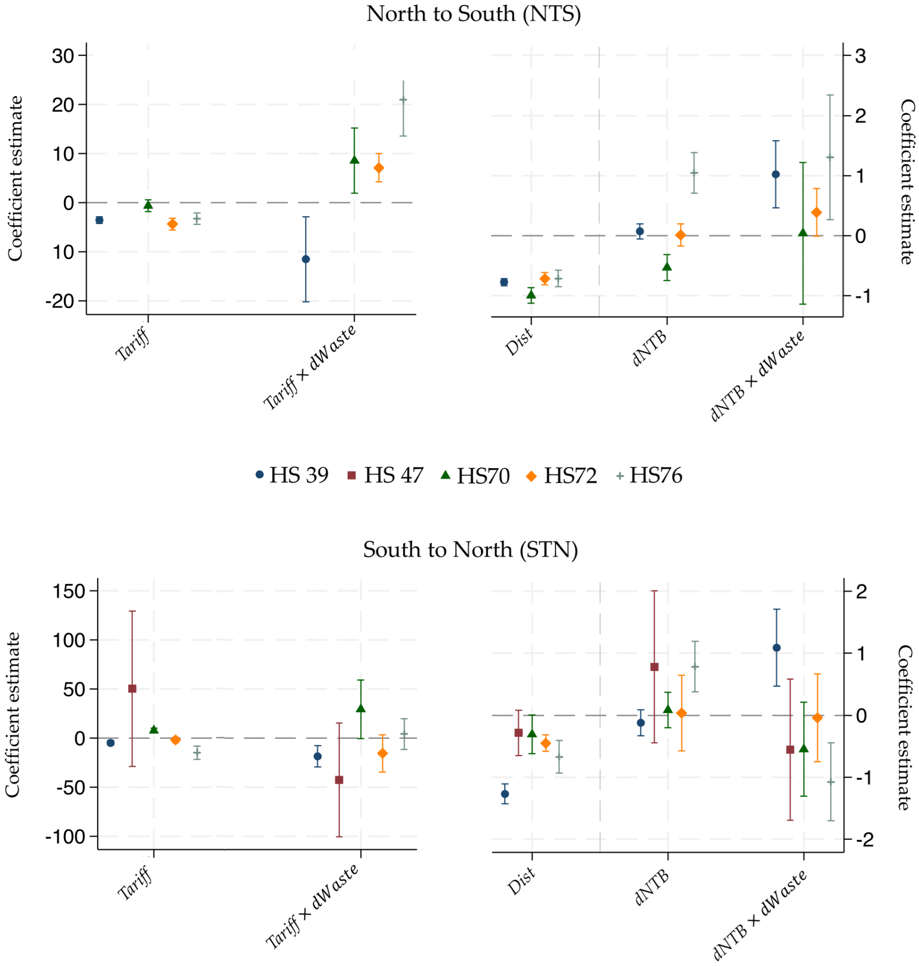
Overall, the results suggest that NTB effects on waste trade are shaped by differences in regulatory stringency and compliance infrastructure across income levels. High-income destinations typically impose more stringent verification and traceability requirements, which raise the fixed costs of compliance and reduce the extent to which NTBs facilitate trade in heterogeneous waste streams. At the same time, in sectors with more structured recycling chains, regulatory stringency may simultaneously restrict entry through tighter screening while enabling transactions by certifying input quality for downstream users, generating offsetting effects across NTB components. These mechanisms imply that the baseline facilitation effect is preserved but varies systematically in intensity across income levels and material types. Section 6 discusses the structural implications.

North-to-South and South-to-North flows. We split the sample by income direction and estimate separate coefficients for North-to-South (NtS: high-income exporter, low- or middle-income importer) and South-to-North (StN: low- or middle-income exporter, high-income importer) pairs. Income classifications again follow World Bank time-varying definitions. Figures 3 and 4 display the key coefficients under aggregate and disaggregated NTB specifications, with full tables reported in Appendix D.1.

Three main results emerge. First, NTB facilitation remains strong in the North-to-South direction for HS 39 and HS 47 ($dNTB \times dWaste_k = +1.74^{***}$ and $+0.60^{***}$), while effects for HS 70 and HS 72 are small or insignificant. This confirms that baseline patterns are not simply an artifact of the income composition of global waste flows. Second, a pronounced tariff asymmetry appears in the South-to-North direction: for HS 39, tariffs are more negative in StN flows (-5.40^{***}) than in NtS flows (-3.61^{***}). For HS 72, the tariff coefficient in the StN direction is small and insignificant (-0.101), contrasting with the significant negative effect in the NtS direction (-5.26^{***}), consistent with trade-remedy actions that disproportionately restrict scrap inflows from developing economies into high-income markets. For HS 47 and HS 76, directional differences in tariff elasticities are more limited. Third, HS 47 exhibits sizeable NTB interactions in the NtS direction for both components ($dNTBt \times dWaste_k = +2.22^{***}$ and $dNTBn \times dWaste_k = +3.26^{***}$), whereas effects in the StN direction are more modest ($dNTBt \times dWaste_k = +1.32^{***}$ and $dNTBn \times dWaste_k = +1.65^{***}$). This indicates a substantial directional asymmetry in regulatory facilitation.

Taken together, these patterns map cleanly into underlying economic mechanisms. NTB facilitation in the North-to-South direction for plastics and pulp of wood/paper reflects the

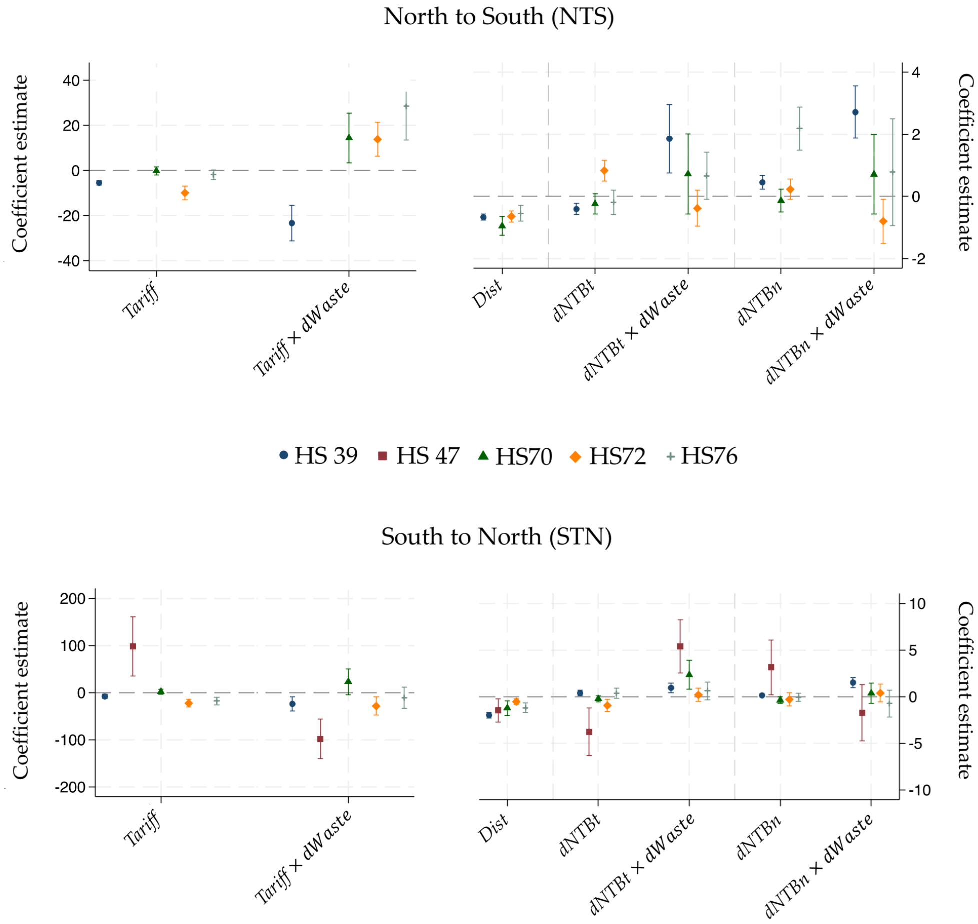
Figure 3: Coefficient estimates under South-to-North and North-to-South trade (Preferred specification, aggregate NTBs)



Notes: Coefficient plots based on the preferred heterogeneous–effects specifications for bilateral flows segmented by income level and direction. Markers display the estimated coefficients and vertical bars their 95% confidence intervals. Each panel uses its own vertical scale to improve readability. Comprehensive coefficient estimates for North–to–South and South–to–North flows appear in Tables D-1 and D-2 in the Appendix.

greater reliance of developing economies on imported secondary inputs, which increases the value of regulatory streamlining on the exporter side. The strong South-to-North tariff asymmetries are consistent with the protection of upstream industries in high-income economies, where tariffs and trade remedies are designed to limit inflows of low-cost secondary materials. Finally, the marked NTB effects observed for HS 47 in the North-to-South direction likely reflect the greater dependence of developing importers on certified recovered paper inputs, which raises the value of

Figure 4: Coefficient estimates under South-to-North and North-to-South trade (Preferred specification, technical vs non-technical NTBs)



Notes: Coefficient plots based on the preferred heterogeneous–effects specifications for bilateral flows segmented by income level and direction. Markers display the estimated coefficients and vertical bars their 95% confidence intervals. Each panel uses its own vertical scale to improve readability. Comprehensive coefficient estimates for North–to–South and South–to–North flows appear in Tables D-1 and D-2 in the Appendix.

NTB-driven quality verification on the exporter side. Overall, the heterogeneity across materials and income directions is economically coherent and mirrors structural differences in input use, quality dispersion, and regulatory objectives across destination markets.

Additional robustness checks. We conduct a set of complementary exercises designed to further assess the stability and economic plausibility of our findings. For brevity, the full set of estimates is provided in Appendix D and in the OSF repository, while we summarize below the main motivations and structure of each check.

Geography of trade. To ensure that results are not driven by dominant hubs in the global waste–materials network, we re-estimate our preferred specification excluding China and the EU-27 as both exporters and importers. Given their central role in global scrap and secondary-material flows, these actors could mechanically influence NTB coefficients. Yet the main interaction patterns for HS 39 and HS 47 remain stable, suggesting that results capture broad structural relationships rather than concentration effects. Figure 5 reports the coefficients on our variables of interest. Full tables available are in Appendix D.2.

Proper waste versus secondary raw materials. For HS 47 and HS 72 we separate proper waste from processed secondary materials, as regulatory scrutiny and contamination risks differ meaningfully across these groups. NTB effects diverge across categories, confirming that the $dWaste_k$ indicator masks economically relevant heterogeneity. Given the importance of this distinction, Appendix D.3 provides additional detail.

Net trade exposure. For each 2-digit HS chapter we split the sample by differentiating between pairs in which the importing country is a net importer or a net exporter. The rationale for this exercise is that reliance on foreign secondary inputs could amplify the gains from NTB reductions. Consistently, NTB facilitation is stronger among net importers across chapters, supporting the view that regulatory streamlining is particularly valuable where domestic supply constraints bind. See Appendix D.4 for details and results.

Alternative fixed-effects structures. We probe identification by modifying the fixed-effects structure: (i) adding pair fixed effects θ_{ij}; (ii) replacing product-year with country-product-year fixed effects; and (iii) combining both. Precision naturally declines as bilateral variation is absorbed, but coefficient signs and magnitudes remain qualitatively robust, indicating that results are not driven by unobserved pair heterogeneity or time-varying country shocks. Results are available in Appendix D.5

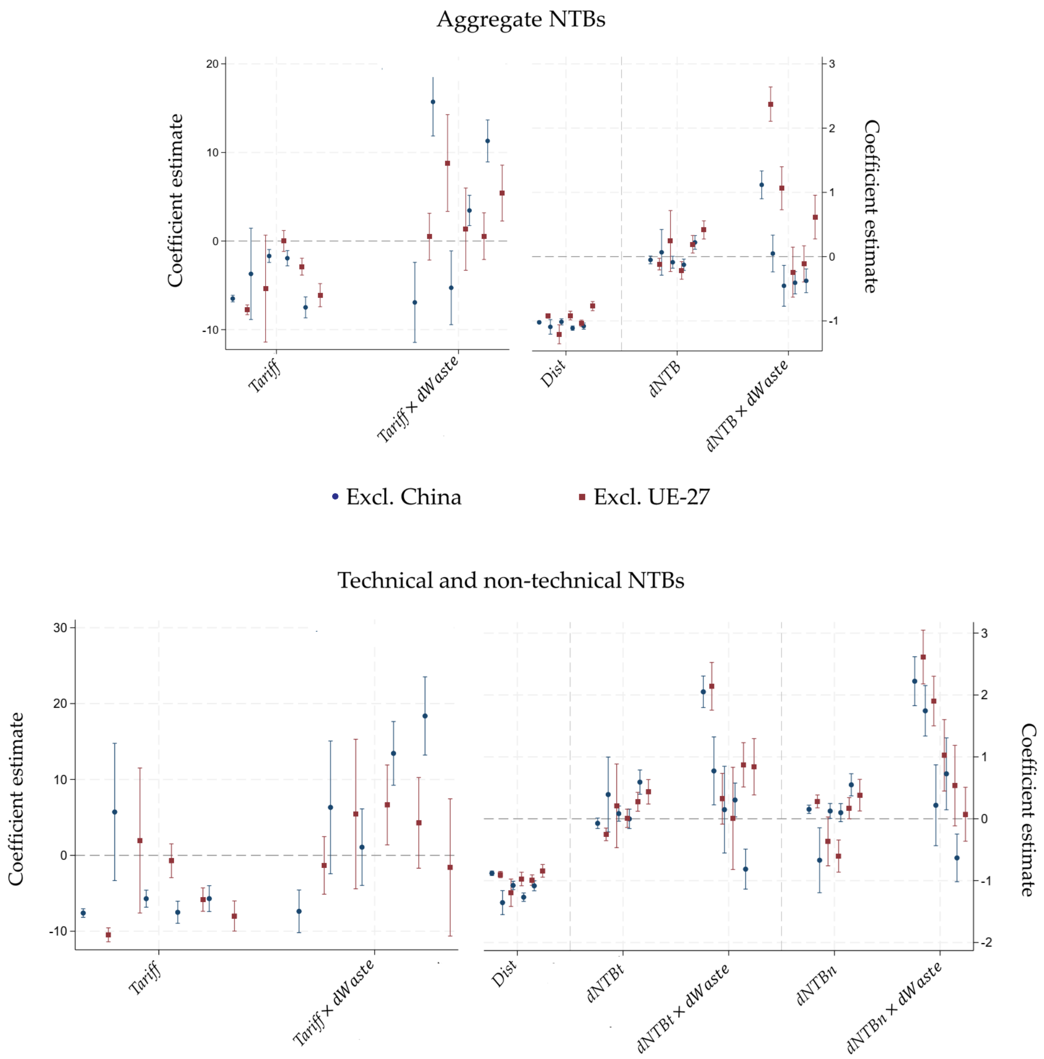
Across all robustness checks, three patterns clearly emerge. First, NTB facilitation is consistently stronger where dependence on imported secondary inputs is higher (net-importing sectors, North-to-South flows, and lower-income exporters). Second, tariff asymmetries in the South-to-North direction align with protection of upstream domestic industries. Third, material-specific differences (proper waste vs. processed materials) reflect underlying variation in regulatory intensity. Taken together, these exercises show that our findings are not driven by specific geographies or modelling choices and rest on coherent, economically interpretable mechanisms.

6 Material Archetypes and Policy Implications

6.1 Archetypes: synthesis and interpretation

The heterogeneous patterns documented in Section 5 show that waste–materials flows respond unevenly to policy and geographic frictions across sectors. While informative, these patterns are

Figure 5: Coefficient stability when excluding China and the EU-27



Notes: Coefficient plots based on the preferred heterogeneous–effects specification after excluding China and the EU-27 as both exporters and importers. Markers display point estimates and vertical bars indicate 95% confidence intervals. Each panel employs its own vertical scale to enhance readability. Complete coefficient tables for this exercise are reported in Appendix D.2.

difficult to interpret without an organizing structure that highlights the dominant mechanisms at play. We therefore move from the reduced-form evidence to a synthesis that groups materials into a small number of recurring empirical configurations.

The material archetypes introduced below (and summarized in Table 12) are descriptive constructs: they summarize systematic co-movements in the interaction coefficients rather than identify deep structural types. They should be interpreted as dominant positions along continuous dimensions of heterogeneity (information frictions, input substitutability, and processing constraints) rather than as mutually exclusive categories.

Three mechanisms consistently emerge from the estimates, giving rise to three broad archetypes.

Information-sensitive materials: pre-transaction quality resolution. For HS 39 (Plastics) and HS 76 (Aluminum), pre-transaction quality heterogeneity is substantial and difficult to verify before purchase. These conditions generate adverse-selection pressures (Akerlof, 1970) that both technical and non-technical NTBs can partly mitigate by standardizing declarations and formalizing compliance. The large positive $dNTBt \times dWaste_k$ interactions in Table 8 ($+2.54^{***}$ for HS 39; $+1.11^{***}$ for HS 76) capture this screening role. Once quality is certified, substitution between waste and virgin inputs is relatively elastic, consistent with the absence of tariff interactions and the pre-/post-certification distinction introduced in Section 2.2. [14] Attenuation at high-income destinations (e.g., -2.00^{***} for HS 39, Table 11) follows naturally: where standards are already stringent, heterogeneous-quality scrap is more likely to be displaced than facilitated.

Complementarity-driven materials: structural derived demand. For HS 47 (Pulp of wood/paper), the dominant mechanism is the strong inverted tariff elasticity: the interaction $\ln(Tariff) \times dWaste_k = 15.05^{***}$ (Table 8, Panel A) is the largest across chapters. Mills equipped for de-inking and fibre management face high switching costs to virgin pulp, generating derived demand for recovered fibre that is inelastic to tariffs on alternatives. Tariffs on virgin pulp therefore *increase* waste-paper imports. The negative distance interaction (-0.59^{***}, Table C-2) reflects the low value-to-weight ratio of recovered fibre, which confines trade to regional supply chains. Divergence between NTB components at high-income destinations (technical $+1.94^{***}$ vs. non-technical -1.92^{***}, Table 11, Panel B) reflects countervailing mechanisms: certification facilitates specialized flows, while non-technical measures restrict them.

Commodity-like materials: market clearing with limited frictions. For HS 70 (Glass) and HS 72 (Iron & steel), quality dispersion is limited and secondary markets are liquid,

[14] For aluminium, recycled metal meets primary-grade specifications once certified (Gaustad et al., 2012); for plastics, recycled resin remains a workable substitute for virgin polymer across a broad range of applications despite residual quality variability (Eriksen et al., 2019).

leading to weaker differential responses to policy instruments. The data show minimal waste-specific effects in Panel A, consistent with markets where prices efficiently aggregate information under low regulatory frictions. Nuance remains within this archetype: HS 72 exhibits localized non-technical NTB facilitation in regulated scrap corridors, while HS 70 shows non-technical NTB patterns concentrated at middle-income destinations. These refinements qualify the archetype without undermining its core logic.

Table 12: Material archetypes: underlying market conditions and characteristic empirical patterns

Archetype	**Underlying market conditions**	**Characteristic empirical patterns**
Information-sensitive (HS 39 Plastics; HS 76 Aluminum)	High pre-transaction heterogeneity (contamination, composition, polymer or alloy grade) difficult to verify before purchase.	Large positive $dNTBt \times dWaste_k$ and $dNTBn \times dWaste_k$ (HS 39: +2.54***, +2.69***; HS 76: +1.11***, n.s.; Table 8, Panel B), consistent with NTBs reducing information frictions. No tariff interaction. NTB facilitation attenuates at high-income destinations (triple interaction: −2.00*** HS 39, −2.81*** HS 76, Table 11).
Complementarity-driven (HS 47 Pulp of wood/paper)	Specialized processing infrastructure creates high switching costs to virgin pulp; mills exhibit structural derived demand for recovered fibre.	Strong inverted tariff elasticity (+15.05***, Table 8, Panel A). Positive NTB facilitation in both components, stronger in the North-to-South direction ($dNTBt \times dWaste_k = +2.22$***, $dNTBn \times dWaste_k = +3.26$***) than in the South-to-North direction (+1.32***, +1.65***). At high-income destinations, technical NTBs facilitate (+1.94***) while non-technical NTBs restrict (−1.92***, Table 11, Panel B). Distance interaction negative (−0.59***, Table C-2).
Commodity-like (HS 70 Glass; HS 72 Iron & steel)	Limited quality dispersion; high substitutability with virgin materials; liquid secondary markets.	Minimal waste-specific responses in Panel A of Table 8. HS 72 shows localized non-technical NTB facilitation; Wald test consistent with no certification channel. HS 70 shows NTB effects concentrated at middle-income destinations.

6.2 Policy implications

The empirical heterogeneity documented in Section 5 and synthesized in Section 6.1 points to a common conclusion: regulatory instruments interact with secondary-material trade through the specific informational, technological, and infrastructural frictions that characterise each material system. Policy design that treats waste categories uniformly is therefore unlikely to achieve circular-economy objectives.

A central implication concerns the role of certification and standards in environments with substantial pre-transaction heterogeneity. For plastics and aluminum, the positive NTB–waste interactions suggest that technical measures operate as information-resolution devices, helping buyers screen heterogeneous-quality scrap. Yet the attenuation at high-income destinations reveals an upper bound: where regulatory and testing infrastructures are already stringent, additional technical measures restrict rather than channel flows. This points to the need for internationally harmonized certification systems that reduce redundant administrative frictions while preserving environmental safeguards. Current initiatives —including the EU's digital product passport and the Basel Convention's prior-informed-consent requirements— move in this direction, though existing non-technical measures still function more as administrative hurdles than as quality screens in high-income destinations.

Relatedly, the interaction of trade policy with technologically grounded complementarities shapes outcomes where processing substitutability is limited. Pulp of wood/paper provides the clearest example: tariffs on virgin pulp increase, rather than reduce, mills' demand for imported recovered fibre, reflecting low short-run substitutability between virgin and recycled inputs. Demand-side instruments (minimum recycled-content mandates, Extended Producer Responsibility schemes, or similar) better align with these technological constraints than tariff-based approaches, which risk deepening import dependence instead of reinforcing domestic circularity.

For materials with inherently low informational or regulatory frictions, such as glass and ferrous scrap, the muted NTB–waste interactions indicate that price signals and established trading practices already convey most relevant quality information. Here, the policy challenge lies primarily in addressing infrastructural bottlenecks (particularly sorting and collection systems) that may be commercially marginal under commodity-like pricing. Targeted investment support or improvements to scrap classification standards can alleviate these constraints without distorting otherwise efficient markets.

The income-direction results add a distributional dimension. NTB facilitation is stronger in North-to-South flows for plastics and paper, with NtS coefficients exceeding StN counterparts for HS 47, indicating that regulatory capacity in low-income importing countries is often insufficient to impose binding restrictions on heterogeneous-quality waste. At the same time, high-income tariffs disproportionately constrain North-to-South scrap flows for HS 72, where the tariff coefficient is large and significant in the NtS direction (-5.26^{***}) but small and insignificant in the StN direction (-0.101), consistent with trade remedies that incidentally restrict secondary-material movements. Strengthening prior-consent mechanisms and building regulatory capacity in importing countries may therefore be more effective for environmental-justice objectives than further tariff escalation.

Finally, the temporal scope of the estimates warrants caution in extrapolating magnitudes. Post-2018 disruptions—most pronounced for plastics—reflect abrupt regulatory shifts rather than the structural parameters captured in our regressions. Nonetheless, the directional implications remain robust: materials reliant on information-resolving regulatory mechanisms or on technologically grounded complementarities proved most exposed to regulatory discontinuity. This reinforces the broader policy message that circular-economy governance must be material-specific, aligning instruments with the friction profile governing each secondary-material flow.

7 Conclusion

This paper provides the first systematic within-sector comparison of trade elasticities for waste and non-waste products across five major material categories. By embedding waste–non-waste interactions in a gravity framework with comprehensive fixed effects, we identify a set of regularities that organize otherwise heterogeneous material behaviors. These regularities align with three broad archetypes: *information-sensitive materials* (Plastics, Aluminum), where the positive association between NTBs and waste trade is consistent with certification mechanisms that help resolve pre-transaction quality uncertainty; *complementarity-driven materials* (Pulp of wood/paper), where an inverted tariff elasticity reflects mills' short-run technological dependence on imported recovered fibre; and *commodity-like materials* (Glass, Iron & steel), whose responses to policy and geographic frictions follow conventional patterns. The income-direction analysis adds a distributional dimension, showing that NTB facilitation operates in both directions but is stronger in the North-to-South direction for HS 47 (Pulp of wood/paper), while tariffs disproportionately affect North-to-South scrap flows for HS 72 (Iron & steel), with a large significant effect in the NtS direction and a negligible one in the StN direction.

Three limitations qualify these results. First, the estimates capture conditional correlations within a high-dimensional fixed-effects structure rather than causal effects; lag and lead checks help rule out simple reverse causality, but structural identification remains beyond reach with the present data. Second, the HS classification partially conflates waste with secondary raw materials, a boundary that our robustness exercises for HS 47 and HS 72 show to be economically meaningful. Third, the archetype interpretation rests on chapter-level averages that inevitably smooth over substantial within-sector heterogeneity.

These limitations point to two direct avenues for further research. The first concerns causal identification: recent policy discontinuities —most notably the 2019 Basel Convention amendment on plastic waste— offer quasi-experimental variation well suited to event-study designs. The second concerns within-archetype heterogeneity: extending the waste–secondary distinction to polymer-level variation within HS 39 or alloy-grade variation within HS 76 would allow a finer mapping between material characteristics and the regulatory mechanisms governing trade, with direct implications for the design of emerging digital product passport frameworks.

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Appendix

Part I

Content

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A Data and Variable Construction

This appendix provides technical details on data construction, complementing the discussion in Sections 3 and 2.2. We retain only the five HS 2-digit chapters discussed in the main text and, within them, the 413 HS6 products associated with those chapters, of which 23 are classified as waste, scrap, or secondary material.

HS harmonization. All product codes are converted to the HS2012 revision using concordance tables from the World Customs Organization. This vintage was selected for consistency with the NTM data: while TRAINS does not explicitly declare a single HS reference revision, Kravchenko et al. (2019) note that most six-digit code lists in TRAINS are based on the 2007, 2012, and 2017 versions of the HS, and the HS2012 classification minimizes the number of codes requiring concordance in our sample. To harmonize trade and tariff data across vintages, we follow the established practice in the product-level trade elasticity literature (Fontagné et al., 2022). Where multiple HS2012 codes map to a single earlier code, trade values are split proportionally using average trade shares computed over the full sample period; where a single HS2012 code maps to multiple earlier codes, values are aggregated. Waste status is defined after harmonization to ensure classification stability across years. Harmonization affected trade data for 2001, 2004, 2007, and 2010, and tariff data for 2001, 2004, 2007, 2010, 2019, and 2022.

NTB processing. TRAINS reports individual policy measures, each characterized by issuing country, affected partners, product coverage, duration, enforcement year, and MAST type (chapters A–O for import-related measures; chapter P for export measures, excluded from the analysis). Raw data are unstructured and required several cleaning steps. First, enforcement dates are standardized to calendar years, with measures active for any fraction of a year coded as active for the full year t. Second, each observation is duplicated across all declared target countries; for non-discriminatory (*erga omnes*) measures, duplication covers all countries in our sample. Third, a time-varying component is added by duplicating observations across the declared enforcement period and assigning value one throughout. The type of each measure is codified following the MAST taxonomy (UNCTAD, 2019); since a single measure may belong to multiple MAST categories, we create one binary variable per category. Individual measures are then aggregated to the *importer* × *exporter* × *product* × *year* level. The baseline indicator $dNTB_{ijkt}$ equals one when at least one measure is active for a given cell. Disaggregated indicators $dNTBt_{ijkt}$ and $dNTBn_{ijkt}$ are constructed analogously, restricting to MAST chapters A–C and D–O respectively.

Sample and additional cleaning. The final dataset merges BACI trade flows, MAcMap-HS6 tariffs, processed TRAINS NTBs, and CEPII gravity variables at the exporter–importer–HS6–year level. Observations are retained only when both trade and tariff data are available for a given $pair \times product \times year$ cell. Observations with implausible unit values (e.g. negative trade values) are dropped, as are $pair \times product$ cells exhibiting persistent zero variation. The eight benchmark years retained are 2001, 2004, 2007, 2010, 2013, 2016, 2019, and 2022, corresponding to the triennial release cycle of MAcMap-HS6. The final dataset covers 96,585,846 observations across the five HS chapters; summary statistics are reported in Table B-4.

B Additional Descriptive Figures and Tables

This appendix provides supplementary descriptive material complementing Section 3. Tables B-1 and B-2 report the top-5 exporters and importers by trade value for the aggregate waste sample and for plastics (HS 39) separately, at three benchmark years. Figure B-1 extends the Sankey diagrams of Section 3 to the plastics chapter. Table B-3 reports pairwise correlations among NTM subtypes supporting the multicollinearity discussion in Section 4. Table B-4 provides full summary statistics for all regression variables, by HS chapter.

Table B-1: Top-5 exporters and importers in waste-related products (Aggregate)

	Exporters			**Importers**	
	Country	Value		Country	Value
year 2001					
1.	USA	44,161	1.	USA	43,027
2.	DEU	43,195	2.	DEU	31,673
3.	JPN	24,457	3.	CHN	23,967
4.	CAN	20,621	4.	ITA	19,741
5.	FRA	20,082	5.	FRA	19,055
year 2016					
1.	CHN	146,928	1.	USA	99,350
2.	DEU	95,843	2.	CHN	92,949
3.	USA	94,920	3.	DEU	73,813
4.	JPN	55,570	4.	ITA	38,128
5.	KOR	52,972	5.	MEX	37,735
year 2022					
1.	CHN	253,235	1.	USA	178,408
2.	DEU	134,257	2.	CHN	137,795
3.	USA	130,432	3.	DEU	111,661
4.	KOR	78,562	4.	ITA	71,354
5.	JPN	69,835	5.	MEX	57,205

Notes: Top 5 importers and exporters across all five waste material categories (see Table 3). Values in thousands USD.

Table B-2: Top-5 exporters and importers in waste-related products — HS 39 (Plastics)

	Exporters			**Importers**	
	Country	Value		Country	Value
		year 2001			
1.	USA	24,875	1.	USA	16,998
2.	DEU	22,543	2.	DEU	11,626
3.	CHN	9,331	3.	CHN	10,220
4.	JPN	9,115	4.	FRA	8,789
5.	NLD	8,264	5.	MEX	7,910
		year 2016			
1.	CHN	65,265	1.	CHN	49,377
2.	USA	57,080	2.	USA	48,205
3.	DEU	55,341	3.	DEU	31,840
4.	KOR	28,828	4.	MEX	21,356
5.	JPN	23,808	5.	FRA	18,613
		year 2022			
1.	CHN	129,455	1.	USA	84,903
2.	USA	79,550	2.	CHN	61,874
3.	DEU	73,713	3.	DEU	46,761
4.	KOR	43,001	4.	MEX	30,227
5.	JPN	27,615	5.	ITA	26,221

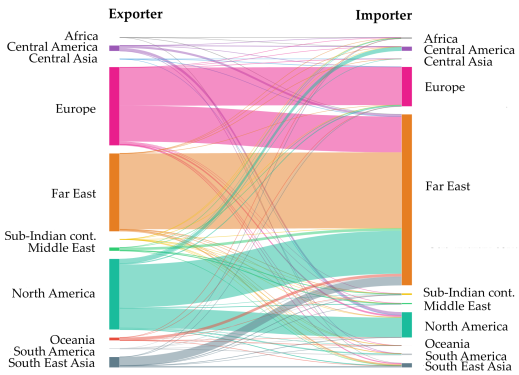
Notes: Top 5 importers and exporters of HS 39 (Plastics) waste-related products. Values in thousand USD.

Figure B-1 shows the disaggregated counterpart of Figure 2, restricted to the plastics chapter (HS 39). The 2001 panel reflects the early geography of global plastic scrap trade, dominated by intra-OECD flows and a nascent but already significant export stream toward China, which was rapidly expanding its recycling processing capacity at the time. By 2016, China had become the dominant destination for plastic waste worldwide, absorbing flows originating primarily from Europe, North America, and Japan, and accounting for the bulk of inter-regional trade in this category.

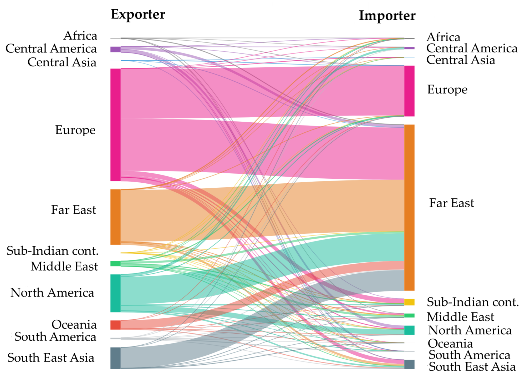
The 2022 panel documents the structural break induced by China's National Sword policy, implemented in January 2018, which imposed strict contamination thresholds effectively banning most categories of mixed and low-grade plastic scrap. The reallocation of flows away from China is sharp and visible: export streams that previously converged on the Far East cluster are redirected toward Southeast Asia (Malaysia, Vietnam, Indonesia), the Indian subcontinent, and the Middle East, none of which had comparable processing capacity or regulatory infrastructure. This redirection was largely absorptive rather than substitutive, generating well-documented concerns about environmental standards and enforcement at destination.

The plastics case is disproportionately responsible for the post-2016 contraction visible in the aggregate Sankey diagram of Figure 2 in the main text. Among the five material categories, plastic scrap is the one most directly affected by China's import ban, both in terms of trade value lost and in terms of geographic disruption. The rebound of aggregate waste trade after 2019, also visible in Figure 1, reflects partial rerouting rather than recovery of pre-ban volumes, and masks persistent fragmentation in the global plastic scrap market that the other material categories —particularly HS 72 (Iron & steel) and HS 76 (Aluminum), whose flows toward China remained largely unaffected— do not display.

Figure B-1: Gross trade flow values in waste-related HS6 products (HS 39. Plastics)



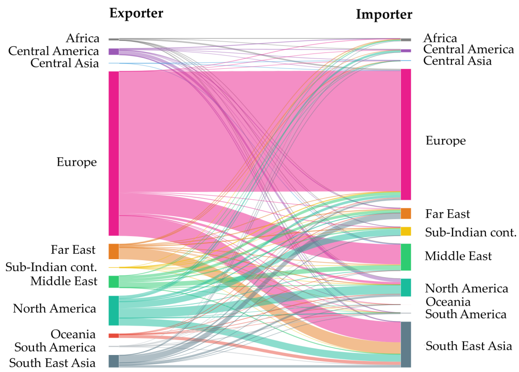
(a) 2001



(b) 2016

Note: The figures report aggregated for HS 39 (Plastics) at three benchmark years. Flows are expressed in USD millions. The structure highlights both intra-regional clustering and inter-regional asymmetries in global waste trade. China is included in the regional cluster labelled "Far East". The sharp contraction of flows toward Far East between 2016 and 2022 reflects the impact of China's National Sword policy. Higher-resolution diagrams are available in the OSF repository. Higher-resolution diagrams for the remaining sectors are available in the dedicated OSF repository.

Source: Authors' elaboration on CEPII data.



(c) 2022

Regarding pairwise correlations among NTM subtypes, Table B-3 shows that only few chapter-level pairs exceed $|r| = 0.25$. The patterns are economically interpretable: licenses and price controls tend to substitute for one another in HS 47, while investment and intellectual property measures co-occur in HS 72, reflecting the more complex regulatory environment of organised scrap markets. Crucially, no correlation approaches the threshold conventionally associated with severe multicollinearity (i.e., $|r| = 0.70$), supporting the reliability of the disaggregated NTB indicators used in the preferred specification.

Table B-3: Notable pairwise correlations among NTM subtypes

Chapter	Pair	r	Interpretation
HS 47	E & F	−0.41	Licenses and price controls are substitutes: countries use one or the other
	A & N	+0.39	SPS and IP measures co-occur (both regulatory/technical)
	G & H	+0.35	Finance and anti-competitive measures tend to come together
	A & E	−0.26	SPS-intensive exporters face fewer quantity restrictions
HS 72	I & N	+0.637	Trade-related investment and IP measures co-occur strongly; highest correlation across all chapters
HS 39, HS 70, HS 76	—	—	No pair with $\|r\| \geq 0.25$

Notes: Threshold for severe pairwise collinearity: $|r| = 0.70$. Not exceeded in any chapter or product group. HS 72 I & N ($r = 0.637$) is closest to threshold; both variables collapse into a single dummy in the aggregate specification. For HS 39, HS 70, and HS 76, no pair exceeds $|r| = 0.25$.

Table B-4: Summary statistics

Variable	N	Mean	SD	Min	Max	$N{\neq}0$
Panel A: HS 39 (Plastics)						
Trade value ($'000 USD)	28,957,824	116.791	4630.800	0.000	5.211e+06	2,264,272
Waste/scrap dummy	29,592,870	0.032	0.175	0.000	1.000	936,117
Tariff (ad valorem, %)	29,004,962	0.074	0.094	0.000	2.667	18,951,475
Distance (pop.-weighted, km)	23,476,628	7932.651	4523.003	5.000	19706.000	23,476,628
NTM (any)	29,592,870	0.367	0.482	0.000	1.000	10,857,631
Technical NTM	11,365,220	0.745	0.436	0.000	1.000	8,463,820
Non-technical NTM	11,365,220	0.599	0.490	0.000	1.000	6,804,183
Colony	23,476,628	0.008	0.087	0.000	1.000	179,051
Contiguous	23,476,628	0.016	0.126	0.000	1.000	376,318
Common language	23,476,628	0.156	0.363	0.000	1.000	3,670,129
Both WTO members	29,592,870	0.528	0.499	0.000	1.000	15,616,203
RTA	23,476,628	0.126	0.332	0.000	1.000	2,951,312

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Variable	N	Mean	SD	Min	Max	N≠0
Panel B: HS 47 (Waste paper)						
Trade value ($'000 USD)	4,673,088	72.707	5314.773	0.000	3.236e+06	75,624
Waste/scrap dummy	4,784,851	0.477	0.499	0.000	1.000	2,280,991
Tariff (ad valorem, %)	4,744,693	0.035	0.060	0.000	0.800	2,299,813
Distance (pop.-weighted, km)	3,788,703	7843.491	4493.941	5.000	19706.000	3,788,703
NTM (any)	4,784,851	0.308	0.461	0.000	1.000	1,471,405
Technical NTM	1,547,145	0.617	0.486	0.000	1.000	953,937
Non-technical NTM	1,547,145	0.762	0.426	0.000	1.000	1,179,353
Colony	3,788,703	0.008	0.087	0.000	1.000	28,775
Contiguous	3,788,703	0.016	0.127	0.000	1.000	62,089
Common language	3,788,703	0.153	0.360	0.000	1.000	578,479
Both WTO members	4,784,851	0.536	0.499	0.000	1.000	2,563,465
RTA	3,788,703	0.128	0.334	0.000	1.000	484,405
Panel C: HS 70 (Glass)						
Trade value ($'000 USD)	14,708,736	29.401	1378.692	0.000	1.373e+06	908,581
Waste/scrap dummy	14,912,871	0.016	0.125	0.000	1.000	236,607
Tariff (ad valorem, %)	14,651,346	0.094	0.108	0.000	1.000	10,021,512
Distance (pop.-weighted, km)	11,833,592	7934.712	4525.907	5.000	19706.000	11,833,592
NTM (any)	14,912,871	0.307	0.461	0.000	1.000	4,578,033
Technical NTM	4,970,860	0.707	0.455	0.000	1.000	3,513,540
Non-technical NTM	4,970,860	0.540	0.498	0.000	1.000	2,685,464
Colony	11,833,592	0.008	0.087	0.000	1.000	89,555
Contiguous	11,833,592	0.016	0.126	0.000	1.000	189,964
Common language	11,833,592	0.157	0.363	0.000	1.000	1,852,866
Both WTO members	14,912,871	0.527	0.499	0.000	1.000	7,861,622
RTA	11,833,592	0.125	0.331	0.000	1.000	1,480,844
Panel D: HS 72 (Iron & Steel)						
Trade value ($'000 USD)	38,380,608	65.082	3716.112	0.000	1.285e+07	1,194,129
Waste/scrap dummy	39,019,970	0.042	0.200	0.000	1.000	1,635,501
Tariff (ad valorem, %)	38,599,332	0.052	0.074	0.000	1.660	22,336,007
Distance (pop.-weighted, km)	30,957,189	7933.551	4525.192	5.000	19706.000	30,957,189
NTM (any)	39,019,970	0.307	0.461	0.000	1.000	11,992,278
Technical NTM	13,109,256	0.663	0.473	0.000	1.000	8,696,840
Non-technical NTM	13,109,256	0.514	0.500	0.000	1.000	6,739,682
Colony	30,957,189	0.008	0.087	0.000	1.000	233,415

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Variable	N	Mean	SD	Min	Max	$N \neq 0$
Contiguous	30,957,189	0.016	0.126	0.000	1.000	498,693
Common language	30,957,189	0.156	0.363	0.000	1.000	4,828,264
Both WTO members	39,019,970	0.527	0.499	0.000	1.000	20,569,821
RTA	30,957,189	0.125	0.330	0.000	1.000	3,861,300
Panel E: HS 76 (Aluminum)						
Trade value ($'000 USD)	8,043,840	141.643	6260.586	0.000	4.880e+06	556,838
Waste/scrap dummy	8,275,284	0.028	0.166	0.000	1.000	233,277
Tariff (ad valorem, %)	8,085,197	0.076	0.087	0.000	0.900	5,480,682
Distance (pop.-weighted, km)	6,560,723	7941.949	4530.185	5.000	19706.000	6,560,723
NTM (any)	8,275,284	0.320	0.467	0.000	1.000	2,651,049
Technical NTM	2,953,582	0.674	0.469	0.000	1.000	1,990,929
Non-technical NTM	2,953,582	0.518	0.500	0.000	1.000	1,529,629
Colony	6,560,723	0.008	0.087	0.000	1.000	49,483
Contiguous	6,560,723	0.016	0.126	0.000	1.000	105,329
Common language	6,560,723	0.157	0.364	0.000	1.000	1,030,565
Both WTO members	8,275,284	0.527	0.499	0.000	1.000	4,364,084
RTA	6,560,723	0.125	0.331	0.000	1.000	819,300

Finally, with respect to the summary statistics for all regression variables, Table B-4 shows their distribution disaggregated by HS chapter. Two patterns stand out. First, the waste/scrap dummy is sparse in most chapters —particularly HS 39 (3.2%) and HS 76 (2.8%)— reflecting the limited number of waste-designated HS6 codes within each chapter. Second, the prevalence of NTMs varies markedly across chapters, with HS 39 exhibiting the highest incidence (36.7%) and HS 47 the lowest (30.8%), consistent with the regulatory heterogeneity documented in Section 3.2.

C Compendium to Benchmark Estimates: Full Regression Tables by 2-digit Chapter

This appendix reports the complete coefficient estimates underlying the results discussed in Section 5.1, complementing the cross-sectoral summaries in Tables 7 and 8. For each of the five HS2 chapters, we report the preferred heterogeneous-effects specification and the fully extended specification (which additionally includes the $\ln(d) \times dWaste_k$ interaction) under both the aggregate (Panel A) and disaggregated (Panel B) NTB specifications. All estimates exclude export-side NTBs (MAST chapter P), and cover the full 2001–2022 sample.

Table C-1: Baseline Estimates — HS 39 (Plastics)

	Aggregate NTB (Panel A)		Disaggregated NTB (Panel B)	
	Preferred	Extended	Preferred	Extended
$\ln(Tariff)$	-7.092^{***}	-7.122^{***}	-9.500^{***}	-9.457^{***}
	(0.228)	(0.229)	(0.382)	(0.383)
$\ln(Tariff) \times dWaste_k$	0.692	0.076	-0.459	-0.943
	(1.177)	(1.188)	(1.716)	(1.710)
$\ln(Dist)$	-0.976^{***}	-0.974^{***}	-0.876^{***}	-0.879^{***}
	(0.011)	(0.011)	(0.019)	(0.020)
$\ln(Dist) \times dWaste_k$		-0.171^{**}		0.128
		(0.072)		(0.096)
$dNTB$	-0.246^{***}	-0.248^{***}		
	(0.031)	(0.031)		
$dNTB \times dWaste_k$	1.673^{***}	1.799^{***}		
	(0.096)	(0.121)		
$dNTBt$			-0.283^{***}	-0.282^{***}
			(0.046)	(0.046)
$dNTBt \times dWaste_k$			2.539^{***}	2.577^{***}
			(0.134)	(0.130)
$dNTBn$			0.125^{***}	0.129^{***}
			(0.041)	(0.041)
$dNTBn \times dWaste_k$			2.692^{***}	2.781^{***}
			(0.189)	(0.193)
Colony	0.572^{***}	0.573^{***}	0.665^{***}	0.663^{***}
	(0.056)	(0.056)	(0.068)	(0.068)
Contiguity	0.562^{***}	0.562^{***}	0.651^{***}	0.652^{***}
	(0.020)	(0.020)	(0.041)	(0.041)
Common language	0.178^{***}	0.178^{***}	0.087^{*}	0.089^{**}
	(0.025)	(0.025)	(0.045)	(0.045)
WTO	0.991^{***}	0.992^{***}	1.016^{***}	1.016^{***}
	(0.093)	(0.093)	(0.192)	(0.192)
RTA	0.231^{***}	0.230^{***}	0.143^{***}	0.144^{***}
	(0.023)	(0.023)	(0.037)	(0.037)
Exporter×Year FE	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓
Observations	17,465,751	17,465,751	6,066,109	6,066,109
Pseudo-R^2	0.791	0.791	0.809	0.809
Wald χ^2	40,391	40,833	11,399	11,768
Log-lik. ($\times 10^9$)	-2.294	-2.294	-1.031	-1.031

Notes: PPML estimation, sample 2001–2022, export-side NTBs (MAST chapter P) excluded. The preferred specification corresponds to the heterogeneous-effects specification of Table 8; the extended specification additionally includes $\ln(d) \times dWaste_k$ as in Table C-6. Panel B is estimated on the subset of country–product pairs exhibiting bilateral variation in both $dNTBt$ and $dNTBn$. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table C-2: Baseline Estimates — HS 47 (Pulp of wood/paper)

	Aggregate NTB (Panel A)		Disaggregated NTB (Panel B)	
	Preferred	Extended	Preferred	Extended
$\ln(Tariff)$	-3.427	-4.416^{*}	1.879	1.058
	(2.471)	(2.595)	(4.423)	(4.416)
$\ln(Tariff) \times dWaste_k$	15.048^{***}	11.217^{***}	3.664	5.688
	(2.320)	(2.090)	(4.571)	(4.711)
$\ln(Dist)$	-1.058^{***}	-0.930^{***}	-1.268^{***}	-0.938^{***}
	(0.058)	(0.059)	(0.101)	(0.111)
$\ln(Dist) \times dWaste_k$		-0.585^{***}		-0.896^{***}
		(0.050)		(0.090)
$dNTB$	-0.091	-0.203		
	(0.151)	(0.150)		
$dNTB \times dWaste_k$	1.530^{***}	1.530^{***}		
	(0.134)	(0.134)		
$dNTBt$			0.474^{*}	0.512^{*}
			(0.271)	(0.276)
$dNTBt \times dWaste_k$			0.924^{***}	0.997^{***}
			(0.261)	(0.268)
$dNTBn$			-0.231	-0.208
			(0.166)	(0.160)
$dNTBn \times dWaste_k$			1.841^{***}	2.049^{***}
			(0.186)	(0.193)
Colony	0.294	0.407^{**}	1.109^{***}	0.983^{**}
	(0.219)	(0.193)	(0.299)	(0.301)
Contiguity	0.792^{***}	0.789^{***}	0.778^{***}	0.868^{***}
	(0.110)	(0.109)	(0.216)	(0.206)
Common language	-0.032	-0.038	-0.053	-0.032
	(0.097)	(0.096)	(0.182)	(0.178)
WTO	1.402^{***}	1.387^{***}	1.155^{**}	1.282^{**}
	(0.205)	(0.206)	(0.518)	(0.525)
RTA	0.120	0.165^{*}	-0.163	-0.122
	(0.091)	(0.089)	(0.151)	(0.147)
Exporter×Year FE	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓
Observations	1,649,079	1,649,079	441,967	441,967
Pseudo-R^2	0.810	0.813	0.838	0.844
Wald χ^2	2,134	2,524	467	690
Log-lik. ($\times 10^9$)	-0.279	-0.271	-0.118	-0.114

Notes: See Table C-1.

Table C-3: Baseline Estimates — HS 70 (Glass)

	Aggregate NTB (Panel A)		Disaggregated NTB (Panel B)	
	Preferred	Extended	Preferred	Extended
$\ln(Tariff)$	0.013	-0.001	-0.552	-0.554
	(0.477)	(0.479)	(0.989)	(0.992)
$\ln(Tariff) \times dWaste_k$	1.674	0.991	5.434^{**}	5.530^{**}
	(1.970)	(1.929)	(2.467)	(2.532)
$\ln(Dist)$	-0.953^{***}	-0.952^{***}	-1.014^{***}	-1.014^{***}
	(0.021)	(0.021)	(0.042)	(0.042)
$\ln(Dist) \times dWaste_k$		-0.151^{**}		-0.054
		(0.064)		(0.122)
$dNTB$	-0.264^{***}	-0.265^{***}		
	(0.049)	(0.049)		
$dNTB \times dWaste_k$	-0.316^{**}	-0.252^{*}		
	(0.142)	(0.150)		
$dNTBt$			0.009	0.009
			(0.067)	(0.067)
$dNTBt \times dWaste_k$			-0.055	-0.057
			(0.360)	(0.359)
$dNTBn$			-0.214^{***}	-0.214^{***}
			(0.081)	(0.081)
$dNTBn \times dWaste_k$			0.678^{**}	0.649^{**}
			(0.271)	(0.271)
Colony	0.990^{***}	0.989^{***}	0.956^{***}	0.956^{***}
	(0.124)	(0.124)	(0.108)	(0.108)
Contiguity	0.636^{***}	0.636^{***}	0.780^{***}	0.780^{***}
	(0.037)	(0.037)	(0.068)	(0.068)
Common language	0.116^{**}	0.116^{**}	0.123^{**}	0.123^{**}
	(0.048)	(0.048)	(0.057)	(0.057)
WTO	1.754^{***}	1.754^{***}	0.327^{*}	2.327^{***}
	(0.109)	(0.109)	(0.189)	(0.189)
RTA	0.269^{***}	0.268^{***}	0.342^{***}	0.342^{***}
	(0.053)	(0.053)	(0.080)	(0.080)
Exporter×Year FE	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓
Observations	8,444,363	8,444,363	2,490,047	2,490,047
Pseudo-R^2	0.736	0.736	0.773	0.773
Wald χ^2	6,081	6,170	3,510	3,551
Log-lik. ($\times 10^9$)	-0.407	-0.407	-0.131	-0.131

Notes: See Table C-1.

Table C-4: Baseline Estimates — HS 72 (Iron & Steel)

	Aggregate NTB (Panel A)		Disaggregated NTB (Panel B)	
	Preferred	Extended	Preferred	Extended
$\ln(Tariff)$	-2.144^{***}	-2.163^{***}	-5.863^{***}	-5.651^{***}
	(0.391)	(0.386)	(0.658)	(0.654)
$\ln(Tariff) \times dWaste_k$	1.594	1.474	8.011^{***}	5.776^{**}
	(1.098)	(1.031)	(2.431)	(2.472)
$\ln(Dist)$	-1.090^{***}	-1.088^{***}	-1.098^{***}	-1.128^{***}
	(0.016)	(0.016)	(0.030)	(0.031)
$\ln(Dist) \times dWaste_k$		-0.019		0.282^{***}
		(0.046)		(0.082)
$dNTB$	-0.131^{***}	-0.134^{***}		
	(0.043)	(0.043)		
$dNTB \times dWaste_k$	-0.288^{***}	-0.279^{***}		
	(0.095)	(0.105)		
$dNTBt$			0.270^{***}	0.278^{***}
			(0.072)	(0.072)
$dNTBt \times dWaste_k$			0.431^{***}	0.507^{***}
			(0.144)	(0.143)
$dNTBn$			0.190^{**}	0.183^{**}
			(0.074)	(0.075)
$dNTBn \times dWaste_k$			0.783^{***}	0.783^{***}
			(0.295)	(0.295)
Colony	0.154^{**}	0.154^{**}	0.476^{***}	0.478^{***}
	(0.056)	(0.056)	(0.088)	(0.090)
Contiguity	0.651^{***}	0.651^{***}	0.527^{***}	0.524^{***}
	(0.026)	(0.026)	(0.053)	(0.053)
Common language	0.348^{***}	0.348^{***}	0.451^{***}	0.450^{***}
	(0.032)	(0.032)	(0.053)	(0.053)
WTO	0.848^{***}	0.848^{***}	0.603^{**}	0.609^{**}
	(0.110)	(0.110)	(0.189)	(0.190)
RTA	0.445^{***}	0.445^{***}	0.389^{***}	0.387^{***}
	(0.031)	(0.031)	(0.045)	(0.045)
Exporter×Year FE	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓
Observations	18,613,939	18,613,939	5,405,541	5,405,541
Pseudo-R^2	0.644	0.644	0.653	0.654
Wald χ^2	21,021	24,075	6,666	7,178
Log-lik. ($\times 10^9$)	-3.294	-3.294	-1.264	-1.263

Notes: See Table C-1. The positive disaggregated NTB interactions in Panel B coexist with a negative aggregate interaction in Panel A due to sample selection: the preferred Panel B specification retains only country–product pairs with bilateral variation in both $dNTBt$ and $dNTBn$ simultaneously, capturing the most intensively regulated scrap corridors. See Section 5.1 for discussion.

Table C-5: Baseline Estimates — HS 76 (Aluminum)

	Aggregate NTB (Panel A)		Disaggregated NTB (Panel B)	
	Preferred	Extended	Preferred	Extended
$\ln(Tariff)$	-6.513^{***}	-6.413^{***}	-6.748^{***}	-6.141^{***}
	(0.575)	(0.544)	(0.861)	(0.814)
$\ln(Tariff) \times dWaste_k$	8.863^{***}	9.214^{***}	1.987	−1.163
	(1.211)	(1.152)	(3.742)	(3.842)
$\ln(Dist)$	-0.943^{***}	-0.947^{***}	-0.971^{***}	-1.022^{***}
	(0.022)	(0.023)	(0.039)	(0.041)
$\ln(Dist) \times dWaste_k$		0.065		0.491^{***}
		(0.068)		(0.136)
$dNTB$	0.252^{***}	0.254^{***}		
	(0.053)	(0.053)		
$dNTB \times dWaste_k$	0.299^{**}	0.272^{**}		
	(0.122)	(0.115)		
$dNTBt$			0.437^{***}	0.429^{***}
			(0.085)	(0.085)
$dNTBt \times dWaste_k$			1.111^{***}	1.181^{***}
			(0.207)	(0.215)
$dNTBn$			0.560^{***}	0.558^{***}
			(0.087)	(0.086)
$dNTBn \times dWaste_k$			0.179	0.122
			(0.201)	(0.191)
Colony	-0.195^{**}	-0.196^{**}	0.348^{**}	0.339^{**}
	(0.095)	(0.095)	(0.124)	(0.123)
Contiguity	0.678^{***}	0.678^{***}	0.463^{***}	0.461^{***}
	(0.046)	(0.046)	(0.092)	(0.090)
Common language	0.169^{***}	0.169^{***}	0.039	0.029
	(0.051)	(0.051)	(0.078)	(0.077)
WTO	−0.103	−0.103	0.487^{*}	0.501^{**}
	(0.161)	(0.162)	(0.252)	(0.250)
RTA	0.398^{***}	0.402^{***}	0.427^{***}	0.437^{***}
	(0.046)	(0.046)	(0.068)	(0.068)
Exporter×Year FE	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓
Observations	5,035,497	5,035,497	1,534,099	1,534,099
Pseudo-R^2	0.741	0.741	0.762	0.763
Wald χ^2	9,053	9,186	2,869	2,878
Log-lik. ($\times 10^9$)	−1.006	−1.006	−0.413	−0.412

Notes: See Table C-1. The large tariff interaction ($\ln(Tariff) \times dWaste_k$) in Panel A is stable across preferred and extended specifications ($+8.86^{***}$ and $+9.21^{***}$); its instability in Panel B reflects collinearity between the tariff and distance interactions in the extended specification, making the Panel A preferred estimate ($+8.86^{***}$) the more reliable reference.

Table C-6: Heterogeneous Effects Specification — Fully Extended Specification (cross-sectoral summary)

	HS 39 Plastics	HS 47 Paper	HS 70 Glass	HS 72 Iron & Steel	HS 76 Aluminum
Panel A — Aggregate NTB specification					
$\ln(Tariff)$	−7.122***	−4.416*	−0.001	−2.163***	−6.413***
	(0.229)	(2.595)	(0.479)	(0.386)	(0.544)
$\ln(Tariff) \times dWaste$	0.076	11.217***	0.991	1.474	9.214***
	(1.188)	(2.090)	(1.929)	(1.031)	(1.152)
$\ln(Dist)$	−0.974***	−0.930***	−0.952***	−1.088***	−0.947***
	(0.011)	(0.059)	(0.021)	(0.016)	(0.023)
$\ln(Dist) \times dWaste$	−0.171**	−0.585***	−0.151**	−0.019	0.065
	(0.072)	(0.050)	(0.064)	(0.046)	(0.068)
$dNTB$	−0.248***	−0.203	−0.265***	−0.134***	0.254***
	(0.031)	(0.150)	(0.049)	(0.043)	(0.053)
$dNTB \times dWaste$	1.799***	1.530***	−0.252*	−0.279***	0.272**
	(0.121)	(0.134)	(0.150)	(0.105)	(0.115)
Panel B — Disaggregated NTB specification					
$\ln(Tariff)$	−9.457***	1.058	−0.554	−5.651***	−6.141***
	(0.383)	(4.416)	(0.992)	(0.654)	(0.814)
$\ln(Tariff) \times dWaste$	−0.943	5.688	5.530**	5.776**	−1.163
	(1.710)	(4.711)	(2.532)	(2.472)	(3.842)
$\ln(Dist)$	−0.879***	−0.938***	−1.014***	−1.128***	−1.022***
	(0.020)	(0.111)	(0.042)	(0.031)	(0.041)
$\ln(Dist) \times dWaste$	0.128	−0.896***	−0.054	0.282***	0.491***
	(0.096)	(0.090)	(0.122)	(0.082)	(0.136)
$dNTBt$	−0.282***	0.512*	0.009	0.278***	0.429***
	(0.046)	(0.276)	(0.067)	(0.072)	(0.085)
$dNTBt \times dWaste$	2.577***	0.997***	−0.057	0.507***	1.181***
	(0.130)	(0.268)	(0.359)	(0.143)	(0.215)
$dNTBn$	0.129***	−0.208	−0.214***	0.183**	0.558***
	(0.041)	(0.160)	(0.081)	(0.075)	(0.086)
$dNTBn \times dWaste$	2.781***	2.049***	0.649**	0.783***	0.122
	(0.193)	(0.193)	(0.271)	(0.295)	(0.191)
Exporter×Year FE	✓	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓	✓
Panel A statistics					
Observations	17,465,751	1,649,079	8,444,363	18,613,939	5,035,497
Pseudo-R^2	0.791	0.813	0.736	0.644	0.741
χ^2	40,833	2,524	6,170	24,075	9,186
Log-lik. ($\times 10^9$)	−2.294	−0.271	−0.407	−3.294	−1.006
Panel B statistics					
Observations	6,066,109	441,967	2,490,047	5,405,541	1,534,099
Pseudo-R^2	0.809	0.844	0.773	0.654	0.763
χ^2	11,768	690	3,551	7,178	2,878
Log-lik. ($\times 10^9$)	−1.031	−0.114	−0.131	−1.263	−0.412
Wald test: $dNTBt \times dWaste = dNTBn \times dWaste$					
χ^2	0.687	8.506	2.539	1.143	13.004

Notes: PPML estimation. Sample, controls, and fixed-effects structure are identical to Table 8. This table reports the fully extended specification, which augments the preferred heterogeneous-effects specification with the distance–waste interaction $\ln(d) \times dWaste_k$. Chapter-specific tables are reported in Tables C-1–C-5. Panel B has fewer observations for the same reason as in Table 8. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Looking at Tables C-1–C-5, standard gravity controls behave as expected throughout and are stable across preferred and extended specifications. Distance is uniformly negative and precisely estimated across all chapters, with elasticities ranging from approximately −0.93 (HS 47, extended) to −1.27 (HS 47, Panel B preferred), consistent with the broader gravity literature. Colonial ties and contiguity are positive in most chapters, with contiguity particularly large for HS 47 ($+0.79^{***}$) and HS 72 ($+0.65^{***}$), reflecting the importance of regional recycling networks for paper and ferrous scrap. Common language is positive but smaller and less precisely estimated, turning insignificant in HS 47 and HS 76 Panel B, where the disaggregated sample is more restricted. Joint WTO membership and RTA participation are consistently positive across chapters, with WTO effects largest in HS 70 ($+1.75^{***}$), possibly reflecting the role of multilateral commitments in opening glass cullet markets.

Table C-6 collects the extended specification estimates in a single cross-sectoral display, facilitating direct comparison across chapters and with the preferred specification in Table 8. We note that the distance–waste interaction is negative and significant for HS 47 (-0.59^{***}) and HS 70 (-0.15^{**}), indicating greater distance sensitivity for waste in these chapters, consistent with the low value-to-weight ratio of recovered fibre and cullet. For HS 72 and HS 76, the interaction is positive in Panel B ($+0.28^{***}$ and $+0.49^{***}$), reflecting the global rather than regional nature of organized scrap markets for ferrous metals and aluminum. Since distance is time-invariant, these patterns are identified from cross-sectional variation across country pairs and are interpreted as descriptive; they do not alter the archetype classification developed in Section 6.

D Compendium to Robustness Tests and Extensions

This appendix reports the full coefficient tables underlying the robustness checks and heterogeneity analyses discussed in Section 5.3. All specifications use the preferred heterogeneous-effects model and are estimated on the same 2001–2022 sample. Five sets of exercises are presented, each addressing a specific concern about the baseline results. On balance, they confirm that the archetype classification developed in Section 6 is robust to alternative samples, trade directions, income groupings, waste definitions, and identification strategies. Where differences emerge across exercises, they are economically interpretable and consistent with the mechanisms described in the main text.

D.1 Heterogeneity by income direction.

Tables D-1 and D-2 split the sample into North-to-South (NtS: high-income exporter, low- or middle-income importer) and South-to-North (StN: low- or middle-income exporter, high-income importer) flows, and report the full coefficient estimates underlying Figures 3 and 4 of Section 5.3. The observed stability of the key interactions across both directions and both NTB specifications rules out the concern that baseline NTB facilitation patterns simply mirror the income composition of global waste flows rather than structural mechanisms.

Table D-1: Preferred Specification Estimates — North-to-South trade flows

	HS 39 Plastics	HS 47 Paper	HS 70 Glass	HS 72 Iron & Steel	HS 76 Aluminum
Panel A — Aggregate NTB specification					
$\ln(Tariff)$	−3.608	4.733(!)	−0.487	−5.262***	−3.646***
	(0.346)	(0.000)	(0.729)	(0.647)	(0.688)
$\ln(Tariff) \times dWaste$	−9.679**	−0.874(!)	9.892***	11.712***	23.379 * **
	(3.871)	(0.000)	(3.081)	(1.519)	(2.042)
$\ln(Dist)$	−1.012***	−1.745(!)	−1.377***	−1.227***	−1.213***
	(0.031)	(0.000)	(0.071)	(0.055)	(0.068)
$dNTB$	−0.024	0.873(!)	−0.802***	0.057	1.238***
	(0.068)	(0.000)	(0.114)	(0.097)	(0.159)
$dNTB \times dWaste$	1.740***	0.595(!)	0.843	0.762***	1.822***
	(0.287)	(0.000)	(0.628)	(0.214)	(0.239)
Panel B — Disaggregated NTB specification					
$\ln(Tariff)$	−5.537***	−15.897(!)	−0.195	−11.249***	−1.678
	(0.521)	(0.000)	(0.933)	(1.564)	(1.087)
$\ln(Tariff) \times dWaste$	−21.210***	23.587(!)	12.854***	16.684***	22.937***
	(4.349)	(0.000)	(3.997)	(3.287)	(4.075)
$\ln(Dist)$	−0.888***	−1.125(!)	−1.185***	−1.122***	−0.916***
	(0.051)	(0.000)	(0.156)	(0.091)	(0.124)
$dNTBt$	−0.435***	0.646(!)	−0.207	0.806***	−0.113
	(0.096)	(0.000)	(0.181)	(0.170)	(0.197)
$dNTBt \times dWaste$	2.224***	0.563(!)	1.514***	−0.334	0.073
	(0.611)	(0.000)	(0.498)	(0.302)	(0.387)
$dNTBn$	0.431***	0.168(!)	−0.232	0.298*	3.039***
	(0.117)	(0.000)	(0.198)	(0.172)	(0.372)
$dNTBn \times dWaste$	3.256***	2.924(!)	1.203**	−0.513	1.100*
	(0.387)	(0.000)	(0.535)	(0.391)	(0.635)
Exporter×Year FE	✓	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓	✓
Panel A statistics					
Observations	2,488,663	273,947	1,197,745	2,891,985	675,970
Pseudo-R^2	0.7919	0.8546	0.7308	0.7480	0.7450
χ^2	3,755.7425	347.3252	1,242.6861	1,782.3052	985.0386
Log-lik. ($\times 10^9$)	−0.1911	−0.0205	−0.0181	−0.1974	−0.0499
Panel B statistics					
Observations	704,675	66,911	267,584	698,009	155,743
Pseudo-R^2	0.8123	0.8934	0.7992	0.7809	0.8131
χ^2	1,689.7185	187.2203	524.9222	796.7120	415.7579
Log-lik. ($\times 10^9$)	−0.0645	−0.0101	−0.0063	−0.0961	−0.0191

Notes: PPML estimation, preferred heterogeneous-effects specification, sample 2001–2022. North-to-South flows restrict the sample to country pairs where the exporter is classified as high-income and the importer as low- or middle-income (World Bank classification, time-varying). All gravity controls included but omitted for brevity. These estimates underlie Figure 3 (aggregate NTB) and Figure 4 (disaggregated NTB) in Section 5.3. Panel B has fewer observations for the same reason as in Table 8. The HS 47 specification fails to produce standard errors, a consequence of the stringent bilateral variation requirements of the North-to-South sub-sample combined with the small number of HS 47 country–product pairs satisfying the income-direction restriction, which jointly reduce within-cell variation below the threshold required for PPML identification; Panel A results for HS 47 are unaffected. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table D-2: Preferred Specification Estimates — South-to-North trade flows

	HS 39 Plastics	HS 47 Paper	HS 70 Glass	HS 72 Iron & Steel	HS 76 Aluminum
Panel A — Aggregate NTB specification					
$\ln(Tariff)$	-5.403^{***}	-46.241	7.245^{***}	-0.101	-23.221^{***}
	(1.277)	(35.850)	(1.140)	(1.599)	(3.116)
$\ln(Tariff) \times dWaste$	-22.320^{***}	9.951	17.687^{***}	-27.414^{***}	10.250^{**}
	(5.318)	(33.680)	(5.565)	(10.106)	(4.920)
$\ln(Dist)$	-1.537^{***}	-0.979^{***}	-0.610^{***}	-0.946^{***}	-1.039^{***}
	(0.079)	(0.176)	(0.154)	(0.072)	(0.151)
$dNTB$	-0.182^{*}	-1.458^{*}	0.020	-0.076	0.828^{***}
	(0.107)	(0.861)	(0.141)	(0.334)	(0.238)
$dNTB \times dWaste$	1.272^{***}	0.777^{*}	-0.449	-0.147	-1.942^{***}
	(0.306)	(0.445)	(0.364)	(0.343)	(0.356)
Panel B — Disaggregated NTB specification					
$\ln(Tariff)$	-8.690^{***}	-108.876^{**}	1.098	-20.954^{***}	-28.211^{***}
	(2.049)	(51.965)	(2.361)	(4.810)	(5.104)
$\ln(Tariff) \times dWaste$	-26.669^{***}	57.110	24.321^{*}	-42.065^{***}	-2.046
	(7.725)	(46.944)	(13.177)	(8.613)	(14.571)
$\ln(Dist)$	-2.227^{***}	-2.759^{***}	-1.622^{***}	-1.259^{***}	-1.691^{***}
	(0.134)	(0.570)	(0.340)	(0.179)	(0.297)
$dNTBt$	0.414^{***}	-4.390^{***}	-0.449^{**}	-0.776^{**}	0.251
	(0.139)	(0.998)	(0.197)	(0.369)	(0.316)
$dNTBt \times dWaste$	1.316^{***}	5.541^{***}	3.000^{***}	-0.570	0.494
	(0.243)	(1.305)	(0.839)	(0.369)	(0.564)
$dNTBn$	0.117	0.168	-0.359^{*}	-0.430	0.646^{***}
	(0.083)	(2.219)	(0.191)	(0.465)	(0.242)
$dNTBn \times dWaste$	1.652^{***}	-1.782	0.233	-1.136^{***}	-1.761^{**}
	(0.279)	(2.128)	(0.581)	(0.437)	(0.719)
Exporter×Year FE	✓	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓	✓
Panel A statistics					
Observations	2,156,098	79,511	975,782	1,934,388	610,433
Pseudo-R^2	0.869	0.841	0.821	0.726	0.789
χ^2	772.008	81.728	120.257	467.687	307.413
Log-lik. ($\times 10^9$)	-0.068	-0.003	-0.018	-0.192	-0.063
Panel B statistics					
Observations	1,083,025	25,109	417,672	834,173	270,808
Pseudo-R^2	0.889	0.853	0.816	0.740	0.825
χ^2	753.000	110.602	271.538	245.227	196.347
Log-lik. ($\times 10^9$)	-0.034	0.000	-0.005	-0.063	-0.020

Notes: PPML estimation, preferred heterogeneous-effects specification, sample 2001–2022. South-to-North flows restrict the sample to country pairs where the exporter is classified as low- or middle-income and the importer as high-income (World Bank classification, time-varying). All gravity controls included but omitted for brevity. These estimates underlie Figure 3 (aggregate NTB) and Figure 4 (disaggregated NTB) in Section 5.3. Panel B has fewer observations for the same reason as in Table 8. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table D-3: Preferred Specification Estimates — Excluding China and EU-28 (Aggregate NTB)

	HS 39		HS 47		HS 70		HS 72		HS 76	
	Excl. China	Excl. EU-28	Excl. China	Excl. EU-28	Excl. China	Excl. EU-28	Excl. China	Excl. EU-28	Excl. China	Excl. EU-28
$\ln(Tariff)$	-6.496^{***}	-7.759^{***}	-3.704	-5.367^{*}	-1.686^{***}	0.005	-1.935^{***}	-2.888^{***}	-7.486^{***}	-6.107^{***}
	(0.188)	(0.281)	(2.628)	(3.077)	(0.372)	(0.602)	(0.439)	(0.484)	(0.603)	(0.665)
$\ln(Tariff) \times dWaste$	-6.925^{***}	0.494	15.713^{***}	8.808^{***}	-5.274^{**}	1.341	3.451^{***}	0.554	11.302^{***}	5.416^{***}
	(2.305)	(1.346)	(1.964)	(2.787)	(2.125)	(2.368)	(0.872)	(1.344)	(1.210)	(1.609)
$\ln(Dist)$	-1.022^{***}	-0.924^{***}	-1.093^{***}	-1.208^{***}	-1.015^{***}	-0.916^{***}	-1.112^{***}	-1.037^{***}	-1.081^{***}	-0.770^{***}
	(0.010)	(0.017)	(0.058)	(0.075)	(0.024)	(0.035)	(0.017)	(0.025)	(0.025)	(0.036)
$dNTB$	-0.051^{*}	-0.116^{**}	0.067	0.243	-0.087^{*}	-0.214^{***}	-0.126^{***}	0.193^{***}	0.221^{***}	0.416^{***}
	(0.031)	(0.046)	(0.181)	(0.242)	(0.047)	(0.070)	(0.045)	(0.070)	(0.055)	(0.072)
$dNTB \times dWaste$	1.118^{***}	2.374^{***}	0.049	1.064^{***}	-0.454^{***}	-0.241	-0.406^{***}	-0.112	-0.376^{***}	0.616^{***}
	(0.110)	(0.136)	(0.146)	(0.171)	(0.162)	(0.198)	(0.088)	(0.143)	(0.094)	(0.173)
Observations	17,212,383	12,098,631	1,608,138	932,462	8,322,038	5,760,858	18,317,873	12,231,028	4,965,527	3,485,819
Pseudo-R^2	0.790	0.816	0.792	0.855	0.717	0.781	0.636	0.690	0.751	0.784
Log-lik. ($\times 10^9$)	-1.634	-1.446	-0.197	-0.139	-0.305	-0.219	-2.767	-1.896	-0.819	-0.563

Notes: PPML estimation, preferred heterogeneous-effects specification, sample 2001–2022. Columns labeled Excl. China (Excl. EU-28) exclude China (the EU-28) as both exporters and importers. All gravity controls included but omitted for brevity. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table D-4: Preferred Specification Estimates — Excluding China and EU-28 (Disaggregated NTB)

	HS 39		HS 47		HS 70		HS 72		HS 76	
	Excl. China	Excl. EU-28	Excl. China	Excl. EU-28	Excl. China	Excl. EU-28	Excl. China	Excl. EU-28	Excl. China	Excl. EU-28
$\ln(Tariff)$	-6.087^{***}	-7.343^{***}	-4.011	-6.206^{**}	-1.644^{***}	-0.027	-1.823^{***}	-2.799^{***}	-7.513^{***}	-6.255^{***}
	(0.199)	(0.289)	(2.670)	(3.130)	(0.380)	(0.607)	(0.445)	(0.487)	(0.608)	(0.669)
$\ln(Tariff) \times dWaste$	-8.087^{***}	-1.017	15.923^{***}	8.661^{***}	-5.503^{**}	1.304	3.521^{***}	0.567	11.252^{***}	5.293^{***}
	(2.305)	(1.359)	(1.983)	(2.803)	(2.130)	(2.373)	(0.871)	(0.365)	(1.205)	(1.604)
$\ln(Dist)$	-1.019^{***}	-0.921^{***}	-1.091^{***}	-1.202^{***}	-1.009^{***}	-0.911^{***}	-1.108^{***}	-1.031^{***}	-1.079^{***}	-0.767^{***}
	(0.010)	(0.017)	(0.058)	(0.075)	(0.024)	(0.035)	(0.017)	(0.025)	(0.025)	(0.036)
$dNTBt$	-0.089^{***}	-0.167^{***}	0.102	0.289	-0.128^{***}	-0.282^{***}	-0.181^{***}	0.129^{*}	0.196^{***}	0.383^{***}
	(0.023)	(0.035)	(0.162)	(0.222)	(0.041)	(0.062)	(0.041)	(0.068)	(0.049)	(0.066)
$dNTBt \times dWaste$	1.318^{***}	2.481^{***}	-0.174	0.841^{***}	-0.634^{***}	-0.441^{**}	-0.565^{***}	-0.050	-0.404^{***}	0.655^{***}
	(0.118)	(0.155)	(0.176)	(0.199)	(0.172)	(0.207)	(0.094)	(0.130)	(0.100)	(0.181)
$dNTBn$	-0.067	-0.068	-0.370	-0.182	-0.010	-0.009	0.042	-0.041	0.252^{***}	0.134
	(0.044)	(0.063)	(0.402)	(0.533)	(0.078)	(0.119)	(0.071)	(0.108)	(0.084)	(0.108)
$dNTBn \times dWaste$	-0.364	0.598^{***}	1.389^{**}	1.636^{***}	0.188	0.149	0.381^{***}	0.419^{***}	-0.143	0.436^{***}
	(0.247)	(0.205)	(0.544)	(0.543)	(0.232)	(0.316)	(0.145)	(0.155)	(0.162)	(0.166)
Observations	17,212,383	12,098,631	1,608,138	932,462	8,322,038	5,760,858	18,317,873	12,231,028	4,965,527	3,485,819
Pseudo-R^2	0.790	0.816	0.792	0.855	0.717	0.781	0.636	0.690	0.751	0.784
Log-lik. ($\times 10^9$)	-1.634	-1.446	-0.197	-0.139	-0.305	-0.219	-2.767	-1.896	-0.819	-0.563

Notes: PPML estimation, preferred heterogeneous-effects specification, sample 2001–2022. Columns labeled Excl. China (Excl. EU-28) exclude China (the EU-28) as both exporters and importers. $dNTBt$ denotes technical NTBs (MAST chapters A–C); $dNTBn$ denotes non-technical NTBs (MAST chapters D–O). All gravity controls included but omitted for brevity. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

D.2 Robustness to dominant trading blocs.

Tables D-3 and D-4 report the full coefficient estimates underlying Figure 5 in Section 5.3, obtained excluding China and the EU-28 from the sample as both importers and exporters. The archetype classification developed in Section 6 proves broadly robust to both exclusions. The NTB facilitation effects for HS 39 remain positive and significant across both sub-samples (+1.12*** and +2.37***), as does the tariff reversal for HS 47 (+15.71*** and +8.81***). The commodity-like pattern for HS 70 and HS 72 is also confirmed. Only results for HS 76 show some sensitivity to the exclusion of China, consistent with aluminum scrap facilitation being more concentrated in high-volume China-related corridors.

Table D-5: Waste vs. Secondary Raw Materials — Aggregate NTB specification

	Pooled		Secondary		Waste	
	HS 47 Paper	HS 72 Iron & Steel	HS 47 Paper	HS 72 Iron & Steel	HS 47 Paper	HS 72 Iron & Steel
$\ln(Tariff)$	−3.221	−2.144***	−3.417	−1.493***	−2.858	−2.347***
	(2.469)	(0.391)	(2.644)	(0.373)	(2.538)	(0.394)
$\ln(Tariff)_{secondary}$	12.391***	4.171**				
	(2.155)	(1.798)				
$\ln(Tariff)_{waste}$	10.956***	0.495				
	(2.160)	(1.226)				
$\ln(Tariff)_{*}$			11.186***	3.917**	10.758***	0.489
			(1.964)	(1.875)	(2.195)	(1.234)
$\ln(Dist)$	−1.059***	−1.090***	−1.057***	−1.108***	−1.087***	−1.101***
	(0.058)	(0.016)	(0.061)	(0.016)	(0.060)	(0.016)
$dNTB$	−0.086	−0.131***	0.030	−0.259***	−0.082	−0.148***
	(0.150)	(0.043)	(0.176)	(0.044)	(0.153)	(0.044)
$dNTB_{secondary}$	0.174	−0.160				
	(0.162)	(0.155)				
$dNTB_{waste}$	0.884***	−0.317***				
	(0.137)	(0.110)				
$dNTB_{type}$			0.131	−0.093	0.885***	−0.309***
			(0.168)	(0.157)	(0.137)	(0.110)
Exporter×Year FE	✓	✓	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓	✓	✓
Statistics						
Observations	1,649,079	18,613,939	968,308	17,681,436	1,207,805	18,323,172
Pseudo-R^2	0.810	0.644	0.834	0.644	0.811	0.646
χ^2	2,141.933	21,021.970	1,548.129	23,180.090	2,038.299	20,426.410
Log-lik. ($\times 10^9$)	−0.276	−3.294	−0.190	−3.003	−0.260	−3.206

Notes: PPML estimation, preferred heterogeneous-effects specification, sample 2001–2022. The pooled columns replicate the baseline specification with separate interactions for secondary ($dNTB_{sec}$, $\ln(Tariff)_{secondary}$) and proper waste ($dNTB_{waste}$, $\ln(Tariff)_{waste}$) codes. The secondary and waste columns restrict the sample to the respective sub-category, with $\ln(Tariff)_{*}$ and $dNTB_{type}$ denoting the relevant interaction. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

D.3 Waste versus secondary raw materials.

The baseline $dWaste_k$ indicator aggregates proper waste codes (post-consumption or post-production materials not yet processed) and secondary raw material codes (partially processed materials competing more directly with primary inputs), as discussed in Section 2.2.

Table D-6: Waste vs. Secondary Raw Materials — Disaggregated NTB specification

	Pooled		Secondary		Waste	
	HS 47 Paper	HS 72 Iron & Steel	HS 47 Paper	HS 72 Iron & Steel	HS 47 Paper	HS 72 Iron & Steel
$\ln(Tariff)$	2.668	-5.863^{***}	4.174	-5.110^{***}	4.092	-5.812^{***}
	(4.611)	(0.657)	(6.159)	(0.672)	(4.600)	(0.667)
$\ln(Tariff)_{sec}$	26.534^{***}	19.418^{***}				
	(4.720)	(2.818)				
$\ln(Tariff)_{waste}$	1.911	4.774				
	(5.072)	(3.007)				
$\ln(Tariff)_{type}$			23.397^{***}	19.371^{***}	1.050	4.891
			(4.718)	(2.765)	(5.067)	(2.991)
$\ln(Dist)$	-1.275^{***}	-1.098^{***}	-0.941^{***}	-1.122^{***}	-1.382^{***}	-1.101^{***}
	(0.101)	(0.030)	(0.121)	(0.032)	(0.103)	(0.031)
$dNTBt$	0.478^{*}	0.271^{***}	0.269	0.164^{**}	0.482^{*}	0.275^{***}
	(0.276)	(0.072)	(0.370)	(0.082)	(0.282)	(0.073)
$dNTBt_{secondary}$	-0.221	0.318				
	(0.349)	(0.199)				
$dNTBt_{waste}$	1.041^{***}	0.466^{***}				
	(0.280)	(0.164)				
$dNTBt_{*}$			-0.164	0.509^{**}	1.029^{***}	0.418^{***}
			(0.346)	(0.201)	(0.284)	(0.162)
$dNTBn$	-0.234	0.191^{***}	-0.446^{***}	0.116	-0.226	0.112
	(0.167)	(0.074)	(0.151)	(0.082)	(0.168)	(0.078)
$dNTBn_{secondary}$	1.194^{***}	3.445^{***}				
	(0.243)	(0.258)				
$dNTBn_{waste}$	2.561^{***}	0.502^{*}				
	(0.245)	(0.298)				
$dNTBn_{*}$			1.357^{***}	3.591^{***}	2.528^{***}	0.558^{*}
			(0.243)	(0.253)	(0.249)	(0.297)
Exporter×Year FE	✓	✓	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓	✓	✓
Statistics						
Observations	441,967	5,405,541	191,862	4,990,009	342,962	5,287,403
Pseudo-R^2	0.839	0.654	0.856	0.655	0.842	0.655
χ^2	530.356	6,914.328	316.103	7,333.780	441.280	6,470.516
Log-lik. ($\times 10^9$)	-0.117	-1.264	-0.072	-1.158	-0.110	-1.237
Wald test: $dNTBt_* = dNTBn_*$						
χ^2	16.373	0.011	15.264	115.740	15.204	0.168

Notes: Same as Table D-5. The pooled columns replicate our preferred specification with separate interactions for secondary ($dNTBt_{secondary}$, $dNTBn_{secondary}$, $\ln(Tariff)_{sec}$) and proper waste ($dNTBt_{waste}$, $dNTBn_{waste}$, $\ln(Tariff)_{waste}$) codes, while the secondary and waste columns restrict the sample to the corresponding sub-category. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

For HS 47 and HS 72, the HS6 classification allows a cleaner separation: proper waste codes (HS 4707xx for recovered paper; HS 72041x–72044x for ferrous scrap) can be distinguished from secondary raw material codes (HS 4706xx for recovered fibres; HS 720450 for semi-finished secondary steel). The distinction blurs for the remaining three chapters, where the boundary between secondary and primary raw material is impossible to derive from the 6-digit classification.

Tables D-5 and D-6 show that the NTB interaction terms diverge substantially across sub-categories: aggregate NTB effects are negative for secondary raw materials and positive for proper waste, with the difference statistically significant in both chapters. This confirms that the facilitation channel operates specifically through proper waste subject to certification and prior-notification requirements, consistent with Basel Convention procedures, while secondary raw materials (which compete more directly with virgin input) face a more restrictive regulatory environment. The overall archetype structure is unchanged, but the disaggregation reveals that the $dWaste_k$ indicator masks economically meaningful heterogeneity that is increasingly relevant for policy, given ongoing regulatory reforms (such as the EU's Circular Economy Act, due for adoption in 2026) that explicitly distinguish between waste and secondary raw materials.

D.4 Net trade exposure.

Tables D-7 and D-8 split the sample by net trade position of the importing country within each chapter, comparing pairs where the importer is a net importer versus a net exporter of secondary materials. The rationale is that structural dependence on foreign secondary inputs amplifies the value of regulatory streamlining: a country that relies on imported scrap to feed its recycling industry has stronger incentives to maintain permissive NTB regimes, generating more pronounced facilitation effects where domestic supply constraints bind.

Among net importers (Table D-7), NTB facilitation is consistently positive and significant across the information-sensitive and complementarity-driven chapters. The aggregate $dNTB \times dWaste$ interaction is particularly large for HS 39 ($+2.12^{***}$) and positive for HS 47 ($+0.60^{***}$), while it turns negative for the commodity-like chapters HS 70 (-0.55^{***}) and HS 72 (-0.49^{***}), consistent with the archetype structure. The tariff reversal for HS 47 survives this sub-sample restriction ($+13.37^{***}$), confirming its robustness to the exclusion of net-exporting importers. In the disaggregated specification, both technical and non-technical NTB interactions are positive and significant for HS 39 and HS 47, reinforcing the certification interpretation.

Among net exporters (Table D-8), the picture is more mixed, as expected. Facilitation remains positive and significant for HS 47 ($+1.27^{***}$) and HS 76 ($+0.59^{***}$), consistent with net exporters also having incentives to source cheaper secondary inputs for their domestic recycling industries. For HS 39, the aggregate interaction is positive ($+0.93^{***}$) but smaller than in the net-importer sub-sample, reflecting the attenuation expected when supply constraints are less binding. For the commodity-like chapters, interactions remain small or insignificant. Taken together, the comparison confirms that NTB facilitation is strongest where import dependence is highest, without disappearing entirely among net exporters: This pattern appears consistent with the dual role of NTBs as both quality screens and market-access mechanisms across all trading partners.

Table D-7: Preferred Specification Estimates — Net importer sub-sample

	HS 39 Plastics	HS 47 Paper	HS 70 Glass	HS 72 Iron & Steel	HS 76 Aluminum
Panel A — Aggregate NTB specification					
$\ln(Tariff)$	-5.633^{***}	-6.481^{**}	-0.614	-3.180^{***}	-6.029^{***}
	(0.203)	(2.748)	(0.435)	(0.458)	(0.600)
$\ln(Tariff) \times dWaste$	-7.143^{***}	13.365^{***}	-5.643^{**}	0.342	8.458^{***}
	(1.988)	(2.382)	(2.336)	(1.403)	(1.322)
$\ln(Dist)$	-1.196^{***}	-1.056^{***}	-0.983^{***}	-1.222^{***}	-0.931^{***}
	(0.012)	(0.061)	(0.030)	(0.024)	(0.026)
$dNTB$	-0.104^{***}	-0.094	-0.152^{***}	-0.089^{*}	0.125^{**}
	(0.032)	(0.165)	(0.052)	(0.050)	(0.060)
$dNTB \times dWaste$	2.116^{***}	0.598^{***}	-0.554^{***}	-0.486^{***}	-0.491^{***}
	(0.134)	(0.136)	(0.203)	(0.099)	(0.125)
Panel B — Disaggregated NTB specification					
$\ln(Tariff)$	-12.632^{***}	6.731	1.796	2.208^{**}	-7.406^{***}
	(0.866)	(4.623)	(1.192)	(1.084)	(1.085)
$\ln(Tariff) \times dWaste$	5.032^{*}	1.754	5.007^{*}	-0.685	-0.416
	(2.893)	(3.143)	(2.700)	(7.838)	(6.398)
$\ln(Dist)$	-0.720^{***}	-1.216^{***}	-0.785^{***}	-1.020^{***}	-1.304^{***}
	(0.031)	(0.131)	(0.066)	(0.038)	(0.058)
$dNTBt$	-0.288^{***}	-0.336	0.048	0.348^{***}	0.390^{***}
	(0.078)	(0.293)	(0.110)	(0.111)	(0.103)
$dNTBt \times dWaste$	1.894^{***}	1.720^{***}	0.033	0.341	1.307^{***}
	(0.199)	(0.306)	(0.438)	(0.225)	(0.218)
$dNTBn$	0.271^{***}	-2.176^{***}	-0.330^{***}	0.374^{*}	0.949^{***}
	(0.062)	(0.469)	(0.107)	(0.222)	(0.107)
$dNTBn \times dWaste$	1.906^{***}	1.915^{***}	0.333	0.775^{*}	0.476^{*}
	(0.296)	(0.344)	(0.435)	(0.402)	(0.252)
Exporter×Year FE	✓	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓	✓
Panel A statistics					
Observations	15,114,518	989,356	7,317,078	14,454,393	4,008,173
Pseudo-R^2	0.794	0.802	0.745	0.657	0.759
χ^2	32,674.420	1,498.078	3,758.721	11,628.530	6,538.563
Log-lik. ($\times 10^9$)	-1.267	-0.219	-0.285	-2.295	-0.747
Panel B statistics					
Observations	1,241,163	157,231	403,366	1,281,638	430,023
Pseudo-R^2	0.811	0.874	0.772	0.702	0.763
χ^2	4,154.593	463.770	632.135	1,416.801	1,737.937
Log-lik. ($\times 10^9$)	-0.528	-0.014	-0.033	-0.316	-0.120

Notes: PPML estimation, preferred heterogeneous-effects specification, sample 2001–2022. Sample restricted to country pairs where the importing country is a net importer of secondary materials in the relevant HS chapter. All gravity controls included but omitted for brevity. Panel B has fewer observations for the same reason as in Table 8. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table D-8: Preferred Specification Estimates — Net exporter sub-sample

	HS 39 Plastics	HS 47 Paper	HS 70 Glass	HS 72 Iron & Steel	HS 76 Aluminum
Panel A — Aggregate NTB specification					
$\ln(Tariff)$	−10.313***	2.692	1.841*	0.118	−8.583***
	(0.613)	(3.332)	(1.005)	(0.808)	(1.209)
$\ln(Tariff) \times dWaste$	5.781***	−0.873	1.176	4.537***	9.635***
	(1.492)	(2.227)	(2.411)	(0.975)	(2.157)
$\ln(Dist)$	−0.748***	−1.078***	−0.896***	−0.944***	−1.286***
	(0.020)	(0.115)	(0.033)	(0.022)	(0.039)
$dNTB$	−0.396***	−0.226	−0.537***	−0.370***	0.576***
	(0.056)	(0.289)	(0.103)	(0.095)	(0.097)
$dNTB \times dWaste$	0.933***	1.268***	0.084	0.376*	0.590***
	(0.144)	(0.216)	(0.205)	(0.201)	(0.155)
Panel B — Disaggregated NTB specification					
$\ln(Tariff)$	−12.632***	6.731	1.796	2.208**	−7.406***
	(0.866)	(4.623)	(1.192)	(1.084)	(1.085)
$\ln(Tariff) \times dWaste$	5.032*	1.754	5.007*	−5.370	−2.662
	(2.893)	(3.143)	(2.700)	(7.838)	(6.398)
$\ln(Dist)$	−0.720***	−1.216***	−0.785***	−1.020***	−1.304***
	(0.031)	(0.131)	(0.066)	(0.038)	(0.058)
$dNTBt$	−0.288***	−0.336	0.048	0.348***	0.390***
	(0.078)	(0.293)	(0.110)	(0.111)	(0.103)
$dNTBt \times dWaste$	1.894***	1.720***	0.033	0.341	1.307***
	(0.199)	(0.306)	(0.438)	(0.225)	(0.218)
$dNTBn$	0.271***	−2.176***	−0.330***	0.374*	0.949***
	(0.062)	(0.469)	(0.107)	(0.222)	(0.107)
$dNTBn \times dWaste$	1.906***	1.915***	0.333	0.775*	0.476*
	(0.296)	(0.344)	(0.435)	(0.402)	(0.252)
Exporter×Year FE	✓	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓	✓
Panel A statistics					
Observations	2,303,218	553,715	1,016,020	3,981,272	935,828
Pseudo-R^2	0.786	0.851	0.722	0.649	0.719
χ^2	13,998.560	1,309.193	3,509.617	9,852.066	3,254.387
Log-lik. ($\times 10^9$)	−0.916	−0.047	−0.109	−0.882	−0.215
Panel B statistics					
Observations	1,241,163	157,231	403,366	1,281,638	430,023
Pseudo-R^2	0.811	0.874	0.772	0.702	0.763
χ^2	4,154.593	463.770	632.135	1,416.801	1,737.937
Log-lik. ($\times 10^9$)	−0.528	−0.014	−0.033	−0.316	−0.120

Notes: PPML estimation, preferred heterogeneous-effects specification, sample 2001–2022. Sample restricted to country pairs where the exporting country is a net exporter of secondary materials in the relevant HS chapter. All gravity controls included but omitted for brevity. Panel B has fewer observations for the same reason as in Table 8. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

D.5 Alternative fixed-effects structures.

Tables D-9–D-11 probe identification by progressively enriching the fixed-effects structure beyond the baseline specification (*exporter*×*year*, *importer*×*year*, and *product*×*year*) used in Table 8. Each structure addresses a distinct identification concern and imposes increasingly demanding requirements on the data. The three exercises are designed to be read jointly: robustness across all three provides strong evidence that the archetype classification rests on genuine policy variation rather than on artefacts of the identification strategy.

Table D-9 adds pair fixed effects θ_{ij}, absorbing all time-invariant bilateral heterogeneity: unobserved bilateral trade costs, historical trade relationships, and persistent regulatory asymmetries between specific country pairs. This is arguably the most informative robustness check, as it restricts identification to within-pair variation in NTBs and tariffs over time, ruling out the possibility that facilitation patterns simply reflect the composition of trade corridors. The *information-sensitive* archetype survives this test: NTB facilitation for HS 39 ($+1.68^{***}$) and HS 47 ($+0.83^{***}$) remains significant and of comparable magnitude to the preferred specification, as does the tariff reversal for HS 47 ($+10.37^{***}$). In Panel B, the disaggregated NTB interactions for HS 39 are also stable ($dNTBt \times dWaste = +2.57^{***}$; $dNTBn \times dWaste = +2.68^{***}$), confirming that both technical and non-technical channels survive the inclusion of pair fixed effects. The *commodity-like* pattern for HS 70 and HS 72 is also confirmed, with aggregate NTB interactions negative and significant.

The next step requires replacing *product*×*year* fixed effects with *exporter*×*year*×*product* and *importer*×*year*×*product* fixed effects, controlling for country-specific product-level demand and supply shocks. This structure absorbs substantially more variation than the baseline and eliminates any concern about time-varying country-product-level confounders. Results are shown in Table D-10. Under this demanding specification, NTB interactions in Panel A are attenuated relative to the preferred specification, as one would expect given the extensive absorption of regulatory variation by the three-way FEs. However, the tariff reversal for HS 47 remains visible in Panel B and the commodity-like null for HS 70 and HS 72 is preserved. Notably, the Pseudo-R^2 values rise substantially across all chapters, reflecting the explanatory power of the more saturated structure rather than any change in the underlying mechanisms.

Table D-11 combines both extensions simultaneously. The empirical model therefore includes *exporter*×*year*×*product*, *importer*×*year*×*product*, and pair fixed effects, representing the most saturated identification structure considered in this paper. The sharp decline in observations and the instability of some coefficients (notably the sign changes for HS 47 in Panel A and the inability to estimate some interactions for HS 72 and HS 76) reflect extreme absorption of bilateral variation when pair and three-way FEs are included jointly. Under these conditions, identification relies on a very small fraction of the original variation, and coefficient estimates should be interpreted with considerable caution. This outcome is expected and does not undermine the baseline interpretation: the preferred specification in Table 8 provides the appropriate balance between identification strength and sufficient variation for reliable inference.

To sum up, the three exercises confirm that the archetype classification is not driven by unobserved pair heterogeneity, time-varying country-level shocks, or country-specific product-level demand conditions, and that the key interactions survive all but the most extreme identification demands.

Table D-9: Alternative fixed-effects structure — Adding pair fixed effects

	HS 39 Plastics	HS 47 Paper	HS 70 Glass	HS 72 Iron & Steel	HS 76 Aluminum
Panel A — Aggregate NTB specification					
$\ln(Tariff)$	−5.688***	−0.560	1.664***	−1.857***	−4.203***
	(0.241)	(2.872)	(0.452)	(0.428)	(0.559)
$\ln(Tariff) \times dWaste$	−0.502	10.373***	1.557	2.219**	8.362***
	(1.221)	(2.073)	(1.711)	(0.951)	(1.122)
$dNTB$	−0.151***	−0.118	−0.202***	0.071	0.358***
	(0.033)	(0.152)	(0.051)	(0.051)	(0.053)
$dNTB \times dWaste$	1.679***	0.831***	−0.373***	−0.324***	0.322***
	(0.098)	(0.127)	(0.143)	(0.091)	(0.113)
Panel B — Disaggregated NTB specification					
$\ln(Tariff)$	−8.061***	3.319	1.093	−5.023***	−3.810***
	(0.408)	(4.285)	(0.978)	(0.714)	(0.765)
$\ln(Tariff) \times dWaste$	−0.517	6.607	5.710***	8.652***	−2.405
	(1.643)	(4.531)	(2.217)	(2.286)	(3.231)
$dNTBt$	−0.305***	0.405	0.017	0.291***	0.470***
	(0.043)	(0.268)	(0.065)	(0.071)	(0.080)
$dNTBt \times dWaste$	2.567***	0.996***	−0.087	0.392***	1.151***
	(0.130)	(0.256)	(0.356)	(0.145)	(0.178)
$dNTBn$	0.121***	−0.276	−0.201***	0.217***	0.534***
	(0.037)	(0.173)	(0.077)	(0.071)	(0.082)
$dNTBn \times dWaste$	2.684***	1.896***	0.722***	0.773***	0.135
	(0.183)	(0.189)	(0.278)	(0.297)	(0.200)
Exporter×Year FE	✓	✓	✓	✓	✓
Importer×Year FE	✓	✓	✓	✓	✓
Product×Year FE	✓	✓	✓	✓	✓
Pair FE	✓	✓	✓	✓	✓
Panel A statistics					
Observations	12,347,961	550,639	4,899,807	10,026,682	2,590,048
Pseudo-R^2	0.814	0.818	0.756	0.654	0.775
Log-lik. ($\times 10^9$)	−1.914	−0.220	−0.340	−2.866	−0.776
χ^2	976.9	125.29	49.77	39.93	157.39
Panel B statistics					
Observations	4,282,062	148,944	1,394,972	2,939,482	777,207
Pseudo-R^2	0.831	0.839	0.788	0.665	0.798
Log-lik. ($\times 10^9$)	−0.856	−0.098	−0.110	−1.096	−0.310
χ^2	1,008.65	167.22	27.96	89.74	193.13

Notes: PPML estimation, preferred heterogeneous-effects specification, sample 2001–2022. This specification augments the baseline fixed-effects structure with pair fixed effects θ_{ij}, absorbing all time-invariant bilateral heterogeneity. Observations decline relative to Table 8 due to the absorption of pairs with near-zero within-cell variation. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table D-10: Alternative fixed-effects structure — Country×product×year fixed effects

	HS 39 Plastics	HS 47 Paper	HS 70 Glass	HS 72 Iron & Steel	HS 76 Aluminum
Panel A — Aggregate NTB specification					
$\ln(Tariff)$	−8.739***	−3.715	−3.170***	−6.786***	−10.864***
	(0.213)	(2.337)	(0.357)	(0.376)	(0.586)
$\ln(Tariff) \times dWaste$	−7.865***	−8.884***	−6.449***	4.531	13.556***
	(1.916)	(3.202)	(2.368)	(4.070)	(3.128)
$dNTB$	−0.214***	−0.172*	−0.270***	−0.484***	−0.026
	(0.031)	(0.099)	(0.036)	(0.046)	(0.048)
$dNTB \times dWaste$	−0.190*	−0.310**	−0.724***	−0.021	−0.497***
	(0.112)	(0.136)	(0.198)	(0.134)	(0.151)
Panel B — Disaggregated NTB specification					
$\ln(Tariff)$	−8.565***	10.763**	−5.616***	−13.583***	−10.198***
	(0.352)	(5.428)	(0.499)	(0.708)	(0.890)
$\ln(Tariff) \times dWaste$	−10.569***	−21.374***	1.920	20.773***	14.348***
	(2.517)	(5.873)	(3.268)	(4.975)	(3.463)
$dNTBt$	−0.193*	0.417	−0.241	−0.567***	−0.245
	(0.101)	(0.312)	(0.204)	(0.207)	(0.166)
$dNTBt \times dWaste$	0.334	−2.382***	−0.285	3.292**	−1.230**
	(0.208)	(0.862)	(0.818)	(1.413)	(0.524)
$dNTBn$	−1.122***	0.007	−0.620***	−0.645***	0.206
	(0.130)	(0.122)	(0.233)	(0.194)	(0.181)
$dNTBn \times dWaste$	0.893***	0.582	0.936*	0.000	0.000
	(0.289)	(0.474)	(0.540)		
Exporter×Year×Product FE	✓	✓	✓	✓	✓
Importer×Year×Product FE	✓	✓	✓	✓	✓
Pair FE	×	×	×	×	×
Panel A statistics					
Observations	10,968,292	641,547	5,090,773	9,220,700	3,191,871
Pseudo-R^2	0.917	0.932	0.892	0.874	0.892
Log-lik. ($\times 10^9$)	−0.831	−0.085	−0.151	−1.031	−0.387
χ^2	128,306.12	4,998.25	30,679.95	64,377.26	20,883.85
Panel B statistics					
Observations	3,217,880	156,521	1,222,011	2,073,768	818,122
Pseudo-R^2	0.937	0.964	0.917	0.896	0.915
Log-lik. ($\times 10^9$)	−0.299	−0.022	−0.042	−0.317	−0.132
χ^2	28,428.92	796.97	13,242.70	19,925.94	5,966.90

Notes: PPML estimation, preferred heterogeneous-effects specification, sample 2001–2022. This specification replaces the baseline *product×year* fixed effects with *exporter×year×product* and *importer×year×product* fixed effects, allowing for country-specific product-level shocks. Pair fixed effects are not included. Observations decline relative to Table 8 due to near-zero within-cell variation. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table D-11: Alternative fixed-effects structure — Country×product×year and pair fixed effects

	HS 39 Plastics	HS 47 Paper	HS 70 Glass	HS 72 Iron & Steel	HS 76 Aluminum
Panel A — Aggregate NTB specification					
$\ln(Tariff)$	−5.669***	0.311	0.562**	−5.814***	−5.177***
	(0.187)	(2.064)	(0.276)	(0.373)	(0.499)
$\ln(Tariff) \times dWaste$	−8.497***	−6.840**	−3.973*	15.251***	15.724***
	(1.931)	(2.762)	(2.403)	(3.541)	(4.000)
$dNTB$	0.049**	−0.126*	−0.122***	−0.088*	−0.003
	(0.022)	(0.064)	(0.047)	(0.049)	(0.054)
$dNTB \times dWaste$	−0.218	−0.817***	−0.522**	0.152	−0.408***
	(0.136)	(0.139)	(0.215)	(0.113)	(0.142)
Panel B — Disaggregated NTB specification					
$\ln(Tariff)$	−4.721***	12.573***	−2.138***	−11.817***	−3.931***
	(0.310)	(3.583)	(0.382)	(0.753)	(0.770)
$\ln(Tariff) \times dWaste$	−9.477***	−12.302**	0.952	27.818***	12.042***
	(2.596)	(5.177)	(2.915)	(3.886)	(4.156)
$dNTBt$	−0.041	−0.361	−0.174	−0.120	0.031
	(0.060)	(0.239)	(0.162)	(0.115)	(0.119)
$dNTBt \times dWaste$	0.229	0.022	−0.184	6.002***	−2.077***
	(0.161)	(0.659)	(0.763)	(1.412)	(0.635)
$dNTBn$	−0.260***	−0.179**	−0.291*	−0.288*	−0.067
	(0.091)	(0.077)	(0.168)	(0.152)	(0.159)
$dNTBn \times dWaste$	0.036	1.515***	0.295	0.000	0.000
	(0.281)	(0.459)	(0.710)		
Exporter×Year×Product FE	✓	✓	✓	✓	✓
Importer×Year×Product FE	✓	✓	✓	✓	✓
Pair FE	✓	✓	✓	✓	✓
Panel A statistics					
Observations	8,844,533	306,656	3,620,210	6,469,462	2,029,634
Pseudo-R^2	0.941	0.960	0.920	0.904	0.928
Log-lik. ($\times 10^9$)	−0.563	−0.043	−0.105	−0.735	−0.236
χ^2	1,024.34	92.90	23.00	270.77	132.94
Panel B statistics					
Observations	2,613,972	70,858	878,690	1,516,727	531,623
Pseudo-R^2	0.958	0.982	0.942	0.925	0.950
Log-lik. ($\times 10^9$)	−0.191	−0.009	−0.027	−0.215	−0.072
χ^2	308.96	34.06	36.68	315.85	53.52

Notes: PPML estimation, preferred heterogeneous-effects specification, sample 2001–2022. This specification combines *exporter×year×product* and *importer×year×product* fixed effects with pair fixed effects, representing the most saturated identification structure considered. The sharp decline in observations and the instability of some interactions (notably the sign reversal for HS 47) reflect extreme absorption of bilateral variation and should be interpreted with caution. Standard errors clustered at the country-pair level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

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