Quantifying the trade impact of SPS and TBTs with product-level structural gravity

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Abstract

Non-tariff measures (NTMs), especially sanitary and phytosanitary (SPS) measures and technical barriers to trade (TBTs), have become crucial components of climate, industrial, and regulatory policy, impacting the majority of global trade. However, quantifying their effects on trade is challenging because NTMs are usually non-discriminatory and challenging to identify in standard gravity frameworks. Using a multi-stage structural gravity estimation strategy combined with a control-function correction for endogeneity, we estimate the trade elasticities and ad valorem equivalents of NTMs at the HS6 level for over 5,000 products. Our results reveal significant heterogeneity in NTM trade costs, especially in environmentally relevant sectors, such as clean technologies and electric vehicles. These estimates can inform regulatory impact assessments and general-equilibrium analyses of climate-aligned trade policies.

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1 Introduction

Despite the resurgence of tariff protection, non-tariff measures (NTMs), including technical regulations, conformity assessments, and environmental standards, are still essential components of international trade policy. Non-tariff measures are pervasive in global trade and have expanded markedly over time. Trade-weighted coverage ratios reported by UNCTAD (2025) indicate that technical barriers to trade affect almost 70 per cent of world trade, while sanitary and phytosanitary measures cover nearly 20 per cent. This proliferation is particularly pronounced in the context of environmental goods, where governments have adopted a variety of regulatory policies to support climate policies, sustainability goals, and strategic autonomy. The growing number of climate-related regulations, such as carbon content reporting requirements, clean energy performance standards, and restrictions on waste imports, illustrates the increasing intersection of trade and environmental policy. While these measures serve legitimate public policy objectives, they can also restrict market access or create asymmetries among trading partners. This paper quantifies the trade elasticities and ad valorem equivalents (AVEs) of regulatory NTMs – namely, sanitary and phytosanitary (SPS) measures and technical barriers to trade (TBTs) – for more than 5,000 products at the six-digit level of the Harmonized System (HS6) over the 1996-2019 period.

Unlike tariffs, the trade costs associated with NTMs are difficult to measure. NTMs influence trade volumes, production patterns, consumer welfare, and global value chain configurations. They introduce trade frictions, but they may also address informational issues, making the outcome in terms of trade flows uncertain. Careful quantification of the trade response to NTMs is therefore required to assess these complex impacts. Estimating the AVEs of NTMs helps to provide a better understanding of their restrictiveness as well as to assess their efficiency and equity implications.

Such quantification is challenging, first due to the *de jure* non-discriminatory nature of most NTMs and how they are implemented and enforced. Unlike tariffs, which vary for a given importer-product pair depending on the origin of the product, NTMs apply independently of this origin.

Second, the issue of trade elasticity arises. Dhingra et al. (2023) show that reducing NTMs can lead to significant welfare improvements, especially when liberalisation targets regulatory frictions in sectors with high trade elasticity. This highlights the importance of precise elasticity estimates in welfare analysis. Indeed, the elasticity of trade flows to the presence of NTMs will differ from the usual trade elasticities built on price changes. This conceptual difference is important for the quantification of the AVEs of NTMs. The welfare implications of NTMs also manifest through firm-level adjustments. Recent evidence shows that NTMs alter the organisation of production, employment structures, and market participation, especially in sectors exposed to regulatory scrutiny. Recent firm-level evidence has shed new light on how NTMs affect production and organisational outcomes beyond aggregate trade flows. Barba Navaretti et al. (2024) use matched employer-employee data to show that TBTs lead firms to reorganise their labor structure, favouring more stable and skilled employment contracts in sectors more exposed to foreign regulatory requirements. These findings suggest that the fixed costs associated with compliance extend beyond trade frictions, altering firm boundaries and production organisation. Grossman et al. (2021) develop a model in which firms differ in their ability to meet regulatory standards and trade agreements emerge as mechanisms that internalise the heterogeneous preferences of domestic producers. In this framework, regulatory barriers act as sorting devices, filtering which firms engage in trade as well as which exit from or specialise in domestic markets.

Relatedly, Ghodsi (2023) emphasises the measurement challenges inherent in quantifying the trade effects of regulatory NTMs, referring to the 'black box' nature of NTMs. Because regulatory measures often bundle heterogeneous requirements – ranging from legitimate public policy objectives to compliance-intensive technical specifications – observed trade responses reflect a combination of fixed and variable trade costs that are difficult to disentangle. Using product-level data and World Trade Organization (WTO) notifications, their approach highlights both the heterogeneity and opacity of NTM-related trade frictions, underscoring the need for structurally grounded estimation strategies. Our paper builds on this insight by embedding product-level NTMs within a multi-stage structural gravity framework that explicitly accounts for multilateral resistance and endogeneity, thereby opening the NTM 'black box' in a theory-consistent manner.

Early attempts to quantify the trade effects of NTMs relied on frequency indices and coverage ratios, which provided limited insight into their economic significance. A major step forward was made by Kee et al. (2009), who proposed a product-level approach to estimating AVEs of NTMs at the HS 6-digit level. Their methodology is based on a revenue-function framework in which imports enter as intermediate inputs, whereas observed import values are interpreted as quantities by normalising international prices. Under the assumptions of perfect competition and exogenous world prices, this normalisation yields internally consistent, partial-equilibrium measures of trade restrictiveness and allows trade policy effects to be inferred from quantity responses. Within this framework, international price indices are held fixed by construction, and general-equilibrium price adjustments are abstracted from. As a result, the estimated AVEs capture the restrictiveness of NTMs under constant world prices and are naturally interpreted in a partial-equilibrium setting. While well suited for descriptive analysis and partial-equilibrium welfare exercises, this approach does not accommodate environments in which trade costs affect endogenous price indices or where market structure departs from perfect competition. In such settings, AVEs need to be recovered within a framework that explicitly allows for general-equilibrium adjustments, such as structural gravity models.

More recently, Kee & Nicita (2022) introduced importer-, exporter-, and product-specific AVEs that predict patterns of trade evasion and misinvoicing, offering improved empirical relevance, though still outside a fully structural framework.[1]

Despite these advances, much of the literature still fails to address the fundamental issue raised by Anderson & van Wincoop (2003), namely, the need to account for multilateral resistance terms (MRTs) to derive consistent trade-cost estimates. Omitting MRTs leads to biased and uninterpretable coefficients (Baldwin & Taglioni 2006). This problem is particularly acute in the case of NTMs, which in principle apply uniformly to all trading partners and thus exhibit little bilateral variation. Consequently, previous estimates may conflate the effect of NTMs with unobserved multilateral trends or general-equilibrium forces.

Recently, Freeman et al. (2025) proposed a two-step methodology that allows for consistent estimation of structural gravity models in the presence of non-discriminatory trade barriers. In their framework, MRTs are first recovered using standard gravity estimations with high-dimensional fixed effects and then reintroduced into a second-stage regression focused on the policy variable of interest. This approach preserves theoretical consistency while isolating the trade elasticity of NTMs and other broad regulatory measures. Although Fell & Duver (2024) acknowledge the MRT issue, their methodology falls short of a full structural correction.

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[1]Ghodsi et al. (2017, 2022) estimate importer-specific AVEs using quantity-based gravity regressions combined with WTO notification data. Their approach controls for importer characteristics using country-year covariates (e.g. GDP per capita, population, and regional dummies), which act as proxies for inward multilateral resistance. The two-step structural gravity approach adopted here allows for a more agnostic estimation of country-year effects.

Instead, it relies on partial approximations or simplified fixed-effects structures.

This paper builds on the approach of Freeman et al. (2025) by addressing the MRT problem as well as the endogeneity of NTMs. NTMs are rarely assigned at random; they may respond to domestic lobbying, bilateral trade flows, or unobserved product-level risks. To address this, we adopt the control function methodology developed by Lin & Wooldridge (2019) for nonlinear estimation contexts, such as a Poisson pseudo-maximum-likelihood (PPML) estimator. We construct an instrument based on the interaction between the global prevalence of NTMs at the product level and the regulatory intensity specific to importers. The first-stage prediction yields residuals included in the second-stage regression, which effectively controls for endogenous selection. Combining the structural gravity framework with a nonlinear-control-function strategy provides theory-consistent, policy-relevant estimates of NTM-related trade elasticities across HS6 products, particularly environmentally motivated measures.

The rest of the paper is structured as follows. Section 2 describes the data sources and provides descriptive evidence on the incidence and distribution of NTMs across products and countries. Section 3 presents the empirical framework and outlines the estimation strategy, including the recovery of multilateral resistance terms and the control function approach to correct for endogeneity. Section 4 reports the main results, including baseline estimates and robustness checks. Section 5 discusses policy implications with a focus on environmentally motivated NTMs and their relevance for climate-aligned trade strategies. Section 6 concludes.

2 Empirical Analysis

This section presents the empirical strategy used to quantify the trade restrictiveness of NTMs in a consistent structural gravity framework. We begin by describing the dataset and sources. We then outline the two-step estimation approach used to derive AVEs of NTMs, addressing endogeneity using a control function strategy appropriate for nonlinear estimation.

2.1 Data

The empirical analysis combines product-level bilateral trade data with detailed information on NTMs and standard gravity covariates. Bilateral trade flows at the HS6 level are sourced from the BACI database Gaulier & Zignago (2010), which reconciles mirror trade statistics reported to UN COMTRADE and provides consistent bilateral trade values expressed in current US dollars.

Information on NTMs is obtained from the WTO's Integrated Trade Intelligence Portal (I-TIP), which consolidates notifications and official reports on TBTs and SPS measures.[2] Following Ghodsi et al. (2017), the NTM data are refined to address missing or inconsistently reported HS codes. For each importer-product-year observation, we construct two measures of regulatory exposure: a binary indicator capturing the presence of at least one NTM and a stock count reflecting the cumulative number of measures in force.

We complement trade and NTM data with a comprehensive set of bilateral gravity controls, including distance, contiguity, common language, colonial ties, and shared membership in the European Union (EU) and the WTO, as well as regional trade agreement (RTA) indicators. These variables are drawn from the CEPII Gravity database. Bilaterally applied tariffs are sourced from the World Integrated Trade Solution

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[2] https://i-tip.wto.org

(WITS) database.[3] When multiple tariff rates are reported for a given bilateral tariff line, we construct the effectively applied tariff as the lowest applicable rate between the most-favoured-nation (MFN) and preferential tariffs, using AVEs when tariffs are not ad valorem. Missing years are interpolated when necessary.

The estimation is conducted separately for each HS6 product category in order to preserve maximum granularity and allow for heterogeneity in trade responses across product lines. This product-level approach enables the identification of product-specific trade elasticities and the computation of AVEs of NTMs, avoiding reliance on sector-level or aggregate averages.

To characterise heterogeneity along the value chain, products are classified by production stage using the United Nations' Broad Economic Categories (BEC) classification. The BEC system groups traded goods according to their primary economic use, distinguishing, in particular, between primary goods, intermediate inputs, and final consumption or capital goods. HS6 products are mapped to BEC categories using the official concordance provided by the World Bank through WITS. This classification is used exclusively for aggregation and interpretation; all estimations are performed at the HS6 level.

Special attention is devoted to environmentally relevant products and critical minerals, given their central role in climate, energy-transition, and industrial policy discussions. Environmental goods are identified at the HS6 level using a consolidated list derived from recent trade agreements with an explicit sustainability focus. Specifically, we combine (i) the list of environmental goods contained in Annex B.11 of the Agreement on Climate Change, Trade and Sustainability (ACCTS), which targets products facilitating climate-change mitigation and sustainable development, and (ii) the environmental goods list established under the Singapore-Australia Green Economy Agreement, which covers a broader range of goods promoting sustainable environmental practices and green economic growth. After harmonising product codes and removing duplicates, the combined perimeter comprises 517 HS6 products under the HS 2022 classification.

Critical minerals are identified using the product list compiled by the WTO and made available through its Critical Minerals Dataset.[4] The dataset provides an HS-based classification of minerals that are widely recognised as economically important and subject to elevated supply risks, reflecting their strategic relevance for cleanenergy technologies, electrification, and advanced manufacturing. The classification is applied at the HS6 level and harmonised with the product nomenclature used in the trade and NTM data. As with environmental goods, critical minerals are analysed within the same product-level estimation framework, allowing for direct comparison with both green goods and the broader universe of traded products.

2.2 Stylised facts: the expansion of SPS and TBT measures

Figure 1 documents the rapid expansion of SPS and TBT measures worldwide between 1996 and 2019, distinguishing between environmentally relevant products and the rest of the HS 6-digit products. Two patterns stand out. First, both the stock of measures in force and the annual flow of new regulations increase sharply over time, highlighting the growing importance of regulatory instruments in trade policy. Second, the expansion is particularly pronounced for environmental goods and critical minerals, whose regulatory intensity accelerates markedly after the mid-2000s and continues to rise through the late 2010s. While the timing coincides with major international climate initiatives – notably, the Paris Agreement of

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[3]https://wits.worldbank.org
[4]https://data.wto.org/dataset/critmin

2015 – the figure is purely descriptive and does not attribute causality to specific policy events. Instead, it illustrates the background against which the identification challenge addressed in this paper arises: NTMs have become pervasive, largely non-discriminatory, and increasingly product-specific. Descriptive evidence shows that SPS and TBT interventions have expanded rapidly over time, especially for environmentally relevant products and critical minerals. This proliferation highlights the importance of quantifying the impact of regulatory measures on bilateral trade flows in partial equilibrium while providing meaningful product-level parameters that can be embedded in general-equilibrium trade simulations. Our estimation strategy, which adopts a structural gravity framework, preserves multilateral resistance and delivers trade elasticities that are fully consistent with modern non-quantitative trade models (NQTMs). This allows regulatory trade costs to be coherently interpreted across both partial and general-equilibrium analyses.

Figure 1: Evolution of SPS and TBT measures by product group (1996 = 1)
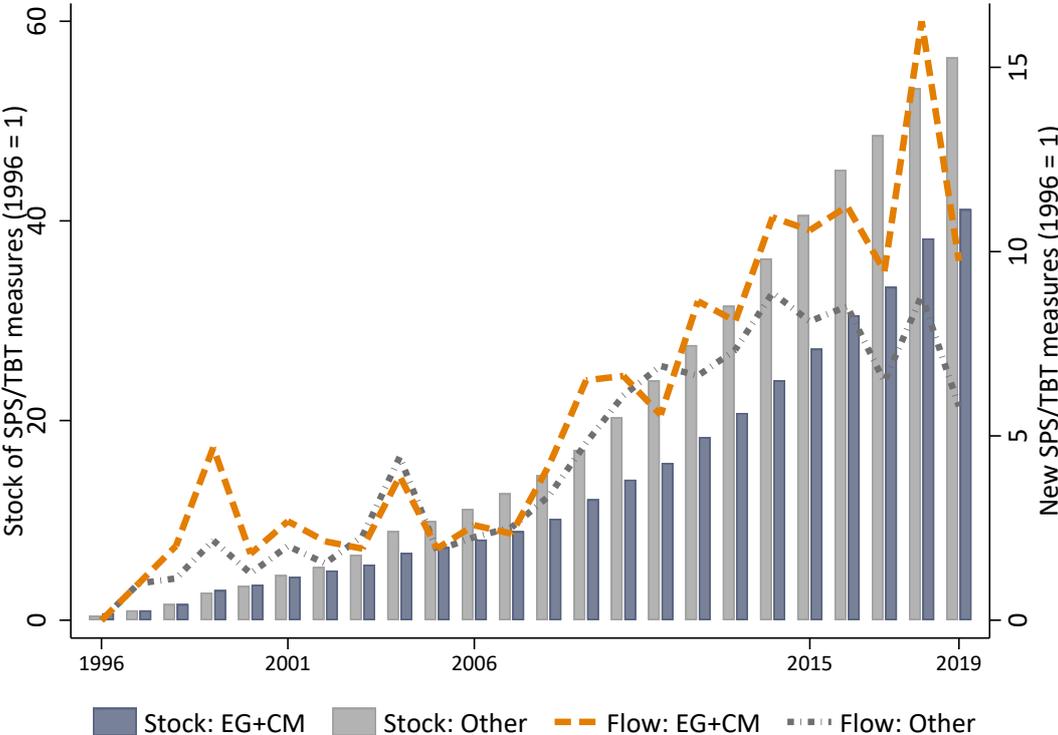
Notes: The figure reports the cumulative stock (bars) and annual flow (lines) of SPS and TBT measures affecting environmental goods and critical minerals (EG+CM) versus all other products. Series are normalised to their 1996 value. Data are aggregated across importers and HS6 products using WTO notifications mapped to HS classifications.

3   Estimation

Following the methodology developed by Freeman et al. (2025), our estimation proceeds in two steps. First, we estimate a structural gravity model for each HS 6-digit product using Poisson pseudo-maximum-likelihood (PPML) estimation. Second, we estimate the effect of NTMs on bilateral trade values while reintroducing the MRTs recovered in the first step. Following the approach of Kee et al. (2009), we correct trade flows for the effects of tariffs by constructing an offset that captures tariff impacts in the second-stage estimation. This two-step strategy ensures consistency with structural gravity theory and enables us to identify the trade-restrictive effects of NTMs when trade flows are zero or heteroskedasticity is present.

The first-stage regression is run on the bilateral trade value of each product between exporter i and importer j at time t. It is estimated separately for each product category k and includes standard bilateral gravity controls Z_{ij} (distance, contiguity, common language, colonial history), as well as exporter-year γ_{it}^k and importer-year δ_{jt}^k fixed effects to control for multilateral resistance terms. The first-stage estimating equation for each product is:

$$X_{ijt}^k = \exp\left(\beta_1 Z_{ij} + \gamma_{it}^k + \delta_{jt}^k\right) + \varepsilon_{ijt}^k, \tag{1}$$

where Z_{ij} is the vector of bilateral gravity controls, and γ_{it}^k and δ_{jt}^k denote exporter-year and importer-year fixed effects, respectively. Following Freeman et al. (2025), we retrieve the fixed-effects estimates $\hat{\gamma}_{it}^k$ and $\hat{\delta}_{jt}^k$ from the first-stage equation to be included in the second stage.

In the second step, we estimate a product-specific regression that focuses on the effect of NTMs on trade value while controlling for the MRTs ($\hat{\gamma}_{it}^k$ and $\hat{\delta}_{jt}^k$) retrieved from the first-stage regression, bilateral gravity controls Z_{ij}, and dummies for bilateral EU membership, WTO membership, and regional trade agreements (RTAs). In the offset specification of this second-stage PPML, applied ad valorem tariffs are incorporated using the trade elasticity for product category k, sourced from Fontagné et al. (2022), as $(1 + \tau_{ijt})^{\sigma_k}$. This transformation removes the portion of trade variation that is mechanically explained by tariffs, allowing for a more precise identification of the effects attributable to NTMs. Offsetting tariffs in the estimation is equivalent to defining the tariff-adjusted export variable $\tilde{X}_{ijt}^k$ as:

$$\tilde{X}_{ijt}^k = \frac{X_{ijt}^k}{(1 + \tau_{ijt}^k)^{\sigma_k}}$$

Thus, the second-stage estimation is as follows:

$$\tilde{X}_{ijt}^k = \exp\left(\beta_{ntm}\text{NTM}_{jt}^k + \beta_1 \text{EU}_{ijt} + \beta_2 \text{WTO}_{ijt} + \beta_3 \text{RTA}_{ijt} + \beta_4 Z_{ij} + \hat{\gamma}_{it}^k + \hat{\delta}_{jt}^k\right) + \nu_{ijt}^{k0} \tag{2}$$

This procedure yields consistent estimates of the trade effects of NTMs within a theoretically grounded gravity model. We use two measures of NTM_{jt}^k: (i) NTM_{jt}^{kd}, a dummy for the stock of NTMs imposed up to year t in the estimation, indicating the presence of either a TBT or an SPS measure; and (ii) NTM_{jt}^{kc}, the stock count of NTMs. Since NTMs are unilateral and, owing to the harmonisation of standards and mutual recognition in the EU single market, intra-EU NTMs are set to zero. The use of PPML estimation ensures robustness to zero trade flows and heteroskedasticity. Standard errors are clustered by importer-year, and we implement a non-parametric bootstrap with 200 replications to assess the stability of the estimates.

3.1 Control Function Correction

A key empirical challenge in estimating the effect of NTMs on trade is endogeneity. NTMs may be adopted in response to past trade patterns, lobbying pressures, or regulatory risks associated with specific products or trading partners. As a result, treating NTMs as exogenous may lead to biased estimates of their trade effects. To address this concern, we adopt the control function approach developed by Lin & Wooldridge (2019), which applies to a broad class of nonlinear models with exponential conditional means, including Poisson regressions estimated via PPML. Specifically, we estimate a reduced-form model for the potentially endogenous NTM variable, recover the residuals, and include them as a control function in the second-stage structural gravity equation.

We construct two exogenous instruments for NTMs: (i) the global average of NTM_{jt}^k imposed on product k across all importers, excluding the importer j under estimation IV_{1jt}^k, and (ii) the average NTM_{jt}^k across all products imported by country j, excluding product k under estimation IV_{2jt}^k. We then estimate the probability of NTM adoption using a probit model for NTM_{jt}^{kd} that includes the same covariates and fixed effects as our structural gravity equation 2:

$$\mathbb{P}(\text{NTM}_{jt}^{kd} = 1 \mid \text{IV}_{1jt}^{kd}, \text{IV}_{2jt}^{kd}, \tilde{X}_{ijt}^k) = \Phi\Big(\alpha_1 \text{IV}_{1jt}^{kd} + \alpha_2 \text{IV}_{2jt}^{kd} + \alpha_3 \text{EU}_{ijt} \\ + \alpha_4 \text{WTO}_{ijt} + \alpha_5 \text{RTA}_{ijt} + \alpha_6 Z_{ij} + \hat{\gamma}_{it}^k + \hat{\delta}_{jt}^k \Big) + \nu_{ijt}^{k1}. \tag{3}$$

We also estimate the pseudo-likelihood of the number of NTMs in force using PPML regressions for NTM_{jt}^{kc}, which include the same covariates and fixed effects as our structural gravity equation:

$$\text{NTM}_{jt}^{kc} = \exp\Big(\alpha_1 \text{IV}_{1jt}^{kc} + \alpha_2 \text{IV}_{2jt}^{kc} + \alpha_3 \text{EU}_{ijt} + \alpha_4 \text{WTO}_{ijt} + \alpha_5 \text{RTA}_{ijt} + \alpha_6 Z_{ij} + +\hat{\gamma}_{it}^k + \hat{\delta}_{jt}^k \Big) + \nu_{ijt}^{k2} \tag{4}$$

In the final step, we include the control function $\hat{\nu}_{ijt}^{k1}$ (or $\hat{\nu}_{ijt}^{k2}$) – that is, the residuals from equation 3 (or equation 4) – in the product-specific PPML gravity equation as follows:

$$\tilde{X}_{ijt}^k = \exp\Big(\theta\, \text{NTM}_{jt}^{kd} + \rho \hat{\nu}_{ijt}^{k1} + \beta_1 \text{EU}_{ijt} + \beta_2 \text{WTO}_{ijt} + \beta_3 \text{RTA}_{ij} + \beta_4 Z_{ij} + +\hat{\gamma}_{it}^k + \hat{\delta}_{jt}^k \Big) + \nu_{ijt} \tag{5}$$

The inclusion of $\hat{\nu}_{ijt}^{k1}$ (or $\hat{\nu}_{ijt}^{k2}$) accounts for unobserved determinants of NTM adoption that may be correlated with the structural error term in equation 5. By augmenting the gravity specification with this correction term, the estimation remains consistent even when NTMs are endogenously determined. The significance of the coefficient ρ provides a formal test of endogeneity: if $\rho \neq 0$, treating NTM_{jt}^k as exogenous would yield biased results. Standard errors are clustered by importer-year to account for potential correlation across the importer's partners in each year. As a robustness check, we implement a non-parametric bootstrap on a subset of 200 randomly selected products to validate the reliability of the two-way cluster inference.

4 Results

The results highlight substantial heterogeneity in the trade effects of NTMs across products, sectors, and policy-relevant groups. This heterogeneity is a central contribution of the paper and motivates the product-level estimation strategy adopted throughout.

We summarise the product-level estimates in two steps. First, Table 1 provides a diagnostic overview of (i) where the estimation delivers statistically informative variation and (ii) the predominant sign of the estimated effects across broad HS chapter groups. For each group, the table reports the total number of HS6 tariff lines, the number of products for which the estimated NTM coefficient is statistically significant at the 10% level, and the subset of significant estimates that are negative, indicating trade-restrictive effects.

Two patterns emerge. First, for the majority of products, the estimated NTM coefficient is statistically significant, confirming that NTMs are associated with economically meaningful trade responses at the product level. Second, among statistically significant estimates, the dominant sign is negative in almost all chapters. In several manufacturing-intensive sectors (e.g. machinery and equipment, chemicals and pharmaceuticals, and vehicles) over 90% of the significant coefficients are trade-restrictive. By contrast, minerals and fuels stand out as an exception: this group displays both a lower incidence of statistically significant estimates and a comparatively larger share of positive coefficients, suggesting greater heterogeneity in how regulatory measures interact with trade in upstream and resource-based sectors.

Table 2 focuses on environmentally relevant products and critical minerals, which are central to climate, energy-transition, and industrial policy discussions. Panel A reports results for environmental goods disaggregated by category. Across most categories, a large fraction of HS6 product categories exhibit statistically significant NTM effects, and the overwhelming majority of these effects are trade-restrictive. This pattern is particularly pronounced for renewable-energy production and storage, clean transportation, and waste-management technologies, for which more than 90% of significant estimates carry a negative sign. At the same time, the incidence of significance and the relative prevalence of negative coefficients vary across categories, underscoring that even within the set of environmental goods, NTMs do not operate uniformly.

Panel B of Table 2 reports the corresponding counts for critical minerals. While the majority of critical-mineral products display statistically significant NTM effects, this group exhibits slightly more dispersion in estimated signs compared to environmental goods. This finding is consistent with the dual role of regulatory measures in critical mineral markets, which may simultaneously reflect compliance costs, strategic trade considerations, and resource-specific governance objectives.

Table 3 translates coefficient estimates into AVEs to characterise the magnitude of NTM-related trade costs. AVEs are reported by production stage and for selected product groups using two complementary aggregation strategies. The 'significant-only' columns summarise AVEs across tariff lines for which the NTM coefficient is statistically significant, while the 'conservative' columns set non-significant coefficients to zero prior to aggregation, providing a lower-bound measure of average trade costs.

Across all products, implied AVEs are largest for primary products and decline for intermediate and final goods when product-specific trade elasticities are used. This pattern is consistent with regulatory frictions playing a relatively stronger role in upstream stages of production. For environmental goods, average AVEs are lower and more compressed across production stages under product-specific elasticities, suggesting more homogeneous regulatory impacts within this group. Under a uniform elasticity benchmark ($\sigma = -5$), implied

AVEs are mechanically larger, particularly for upstream products, highlighting the sensitivity of magnitude comparisons to elasticity assumptions.

Critical minerals display intermediate AVE levels when using product-specific elasticities but substantially higher AVEs under the uniform elasticity benchmark. This contrast reflects both the heterogeneity of estimated NTM coefficients across mineral products and the importance of elasticity variation in translating regulatory effects into tariff-equivalent trade costs.

While Table 3 summarises average trade costs by broad product group and production stage, Figure 2 complements this analysis by illustrating the full distribution of AVEs across HS6 products. The distribution is highly right-skewed, with a large mass of products exhibiting relatively modest AVEs and a long upper tail of products facing very high implied trade costs. Environmental goods display a more concentrated distribution, with fewer extreme values, whereas critical minerals exhibit greater dispersion and a heavier right tail. In contrast, the distribution for other products is characterised by pronounced right-skewness, reflecting substantial variation in regulatory trade costs even within narrowly defined sectors.

Taken together, the results underscore that NTMs cannot be meaningfully summarised by a single average effect. Product-level heterogeneity is substantial, policy-relevant, and particularly pronounced in environmentally sensitive sectors and critical mineral markets. This heterogeneity is precisely what enables the estimates to inform targeted regulatory impact assessments and general-equilibrium simulations of climate-aligned trade policies.

Table 1: Counts of significant and negative NTM estimates by broad HS chapter group (all products)

HS chapter group	HS6 #	Significant $p \leq 0.10$	Significant & negative
Agriculture and Livestock	743	647	506
Base Metals	570	470	406
Chemicals and Pharma	923	844	809
Electronics	296	224	210
Food and Beverages	220	186	175
Footwear and Accessories	47	41	36
Leather and Footwear	69	62	57
Machinery and Equipment	538	470	463
Minerals and Fuels	147	94	63
Other Manufactures	591	490	452
Other Transport	74	57	47
Plastics and Rubber	211	178	170
Textiles and Apparel	797	529	388
Vehicles	98	89	87
Wood and Paper	286	207	188

Notes: The table reports the number of HS6 tariff lines (N) within each broad HS chapter group. 'Significant' counts the number of product-level NTM coefficients that are statistically significant at the 10% level. 'Significant & negative' counts the subset of significant estimates with $\hat{\beta}_{NTM} < 0$ (trade-restrictive sign). Positive significant estimates are the difference between the two columns.

Table 2: Counts of significant and trade-restrictive NTM estimates for green goods and critical minerals

| HS chapter group	HS6 #	Significant $p \leq 0.10$	Significant & negative
Environmental goods (by category):			
Air, Water, Soil Pollution Prevention and Control	25	16	15
Clean Transportation	84	68	64
Energy-efficient Technologies and Products	52	34	30
Environmental Monitoring, Analysis, and Assessment	52	44	44
Environmentally Preferable Materials and Products	95	55	47
Natural-resource and Environment Conservation	14	6	5
Recycled, Recovered, or Remanufactured Goods	38	30	30
Renewable-energy Production and Storage	123	106	102
Solid and Hazardous Waste Management	17	14	14
Water and Waste-water Treatment	17	14	14
Critical Minerals	252	217	210

Notes: The table reports counts of HS6 tariff lines. 'Significant' denotes the number of products for which the estimated NTM coefficient is statistically significant at the 10% level. 'Significant & negative' denotes the subset of significant estimates with $\hat{\beta}_{NTM} < 0$ (trade-restrictive sign). Positive significant estimates can be inferred as the difference between the two columns. Environmental goods and critical minerals are defined using the project product lists.

Table 3: Ad valorem equivalents of NTMs by production stage and selected product groups

Group / production stage	HS6 #	Significant-only AVE (%) σ_k	$\sigma = -5$	Conservative AVE (%) σ_k	$\sigma = -5$
All products:					
Primary	654	13.8	27.5	10.2	20.9
Intermediate	3412	7.1	19.7	5.7	15.8
Final	1544	7.4	13.9	5.7	10.7
Environmental goods:					
Primary	42	4.7	21.5	3.5	14.9
Intermediate	280	4.6	18.0	3.3	12.9
Final	195	5.4	13.8	4.2	10.7
Critical minerals:					
All critical minerals	252	6.2	27.3	5.2	22.7

Notes: The table reports average ad valorem equivalents (AVEs) of NTMs across HS6 products, aggregated by production stage and selected product groups. AVEs are computed as $AVE_k = \left[\exp\left(\hat{\beta}_{NTM,k} / \hat{\sigma}_k \right) - 1 \right] \times 100$, where $\hat{\beta}_{NTM,k}$ is the estimated NTM coefficient for product k and $\hat{\sigma}_k$ is the corresponding product-specific trade elasticity. Columns labeled $\sigma = -5$ use a uniform elasticity benchmark. In the 'significant-only' columns, $\hat{\beta}_{NTM,k}$ is set to missing when the estimate is not significant at the 10% level; in the 'conservative' columns, non-significant estimates are set to zero prior to aggregation. Production stages are defined using the United Nations' Broad Economic Categories (BEC) classification, mapped to HS6 products via the WITS concordance. Environmental goods and critical minerals are defined as described in Section 2.1.

Figure 2: Distribution of ad valorem equivalents of NTMs across product groups

Ad valorem equivalent of NTMs (%)

— Environmental goods   - - Critical minerals   -·-·- Other products
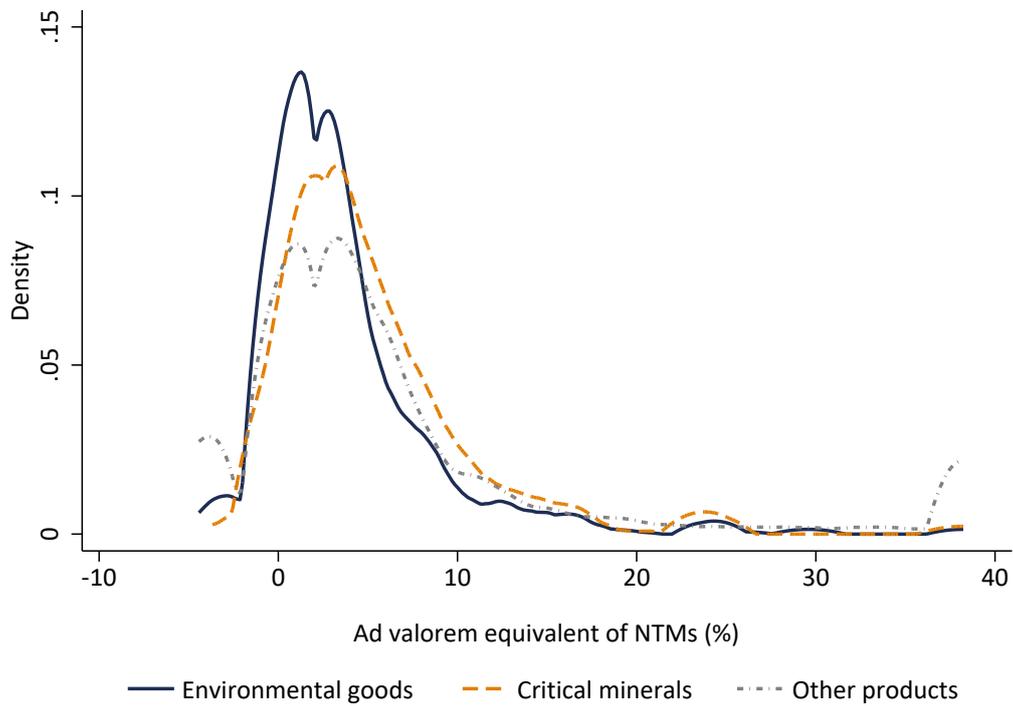
Notes: The figure reports kernel density estimates of AVEs of non-tariff measures (NTMs) at the HS6 level, computed using product-specific trade elasticities. The distribution is shown separately for environmental goods, critical minerals, and all other products. AVEs are constructed using the conservative definition, which assigns zero trade costs to products for which the estimated NTM effect is not statistically significant. $\text{AVE} = \left[\exp\left(\hat{\beta}_{\text{NTM,k}}/\hat{\sigma}_k \right) - 1 \right] \times 100$.

5   Conclusion

Regulatory NTMs, particularly SPS and TBT measures, have become central instruments of trade, industrial, and environmental policy. Yet their trade effects remain difficult to quantify in a theoretically consistent manner, especially given their predominantly non-discriminatory nature and the need to account for multilateral resistance terms in gravity models. This paper addresses this challenge by developing a multi-stage structural gravity framework that restores the identification of NTM trade effects while remaining fully consistent with modern trade theory.

Using product-level data at the HS6 level, we estimate the elasticity of trade in relation to the occurrence of NTMs and corresponding AVEs for more than 5,000 product categories. The results reveal substantial heterogeneity in both the incidence and magnitude of NTM-related trade costs across products. While the majority of statistically significant NTM effects are trade-restrictive, their economic magnitude varies widely even within narrowly defined sectors. This heterogeneity is obscured by aggregate or sector-level approaches and represents a central empirical finding of the paper.

The analysis highlights particularly salient patterns for environmentally relevant products and critical minerals. Environmental goods tend to exhibit lower and more homogeneous AVEs across production stages when product-specific elasticities are used, suggesting that regulatory frictions in these sectors are more uniform and, on average, less trade-restrictive. Critical minerals, by contrast, display greater dispersion in implied trade costs, reflecting the coexistence of moderate regulatory frictions for many products and very high trade costs for a smaller subset. These differences underscore the importance of product-level analysis in sectors that are central to climate policy, energy transitions, and strategic industrial planning.

Beyond documenting heterogeneity, the paper's main contribution lies in providing estimates that are directly usable for policy analysis. The product-level AVEs derived here can be integrated into regulatory impact assessments, ex ante policy design, and general-equilibrium trade models. By translating regulatory measures into tariff-equivalent trade costs that are consistent with structural gravity, the estimates allow policymakers and researchers to assess how changes in NTMs affect trade patterns, sectoral reallocation, and welfare under alternative policy scenarios.

Several caveats are worth noting. First, the analysis focuses on trade effects and does not evaluate the welfare effects associated with NTMs, such as improved health, safety, or environmental outcomes. Second, while the control-function approach addresses key endogeneity concerns, the estimates should be interpreted as capturing average trade responses conditional on the observed regulatory environment. Future research could extend the framework to distinguish between different types of regulatory instruments or to jointly model trade and non-trade policy objectives.

Overall, the results suggest that NTMs cannot be meaningfully summarised by a single average effect. Product-level heterogeneity is substantial, policy-relevant, and especially pronounced in environmentally sensitive sectors and critical mineral markets. By providing theory-consistent, granular estimates of NTM trade costs, this paper offers a foundation for more targeted, transparent, and climate-aligned trade policy analysis.

Bibliography

Anderson, J. E. & van Wincoop, E. (2003), 'Gravity with gravitas: A solution to the border puzzle', *American Economic Review* **93**(1), 170–192.

Baldwin, R. & Taglioni, D. (2006), Gravity for Dummies and Dummies for Gravity Equations, NBER Working Papers 12516, National Bureau of Economic Research, Inc.
URL: *https://ideas.repec.org/p/nbr/nberwo/12516.html*

Barba Navaretti, G., Fontagné, L., Orefice, G., Pica, G. & Rosso, A. C. (2024), 'Tbts, firm organization and labor structure', *Review of International Economics* **32**(3), 958–992.
URL: *https://onlinelibrary.wiley.com/doi/abs/10.1111/roie.12714*

Conte, M., Cotterlaz, P. & Mayer, T. (2022), The cepii gravity database, CEPII Working Paper 2022-05, CEPII.
URL: *http://www.cepii.fr/CEPII/en/publications/wp/abstract.asp?NoDoc=13213*

Dhingra, S., Freeman, R. & Huang, H. (2023), 'The impact of non-tariff barriers on trade and welfare', *Economica* **90**(357), 140–177.
URL: *https://onlinelibrary.wiley.com/doi/abs/10.1111/ecca.12450*

Fell, J. & Duver, A. (2024), 'Non-tariff measures: a methodology for the quantification of bilateral trade effects of policy measures at a product level', *Applied Economics* **56**(36), 4374–4388.

Fontagné, L., Guimbard, H. & Orefice, G. (2022), 'Tariff-based product-level trade elasticities', *Journal of International Economics* **137(C)**, 103593.

Freeman, R., Larch, M., Theodorakopoulos, A. & Yotov, Y. V. (2025), 'Unlocking new methods to estimate country-specific effects and trade elasticities with the structural gravity model', *Journal of Applied Econometrics* **n/a**(n/a).
URL: *https://onlinelibrary.wiley.com/doi/abs/10.1002/jae.3133*

Gaulier, G. & Zignago, S. (2010), Baci: International trade database at the product-level. the 1994–2007 version, CEPII Working Paper 2010-23, CEPII.
URL: *http://www.cepii.fr/CEPII/en/publications/wp/abstract.asp?NoDoc=2726*

Ghodsi, M. (2023), 'Exploring the 'non-tariff measures black box': Whose regulatory ntms on which products improve the imported quality?', *International Economics* **173**, 45–67.
URL: *https://doi.org/10.1016/j.inteco.2022.11.007*

Ghodsi, M., Grübler, J., Reiter, O. & Stehrer, R. (2017), The evolution of non-tariff measures and their diverse effects on trade, wiiw Research Report 419, The Vienna Institute for International Economic Studies (wiiw).
URL: *https://wiiw.ac.at/the-evolution-of-non-tariff-measures-and-their-diverse-effects-on-trade-dlp-4213.pdf*

Ghodsi, M. & Stehrer, R. (2022), 'Trade policy and global value chains: tariffs versus non-tariff measures', *Review of World Economics* **158**(3), 887–916.

Grossman, G. M., McCalman, P. & Staiger, R. W. (2021), 'The "new" economics of trade agreements: From trade liberalization to regulatory convergence?', *Econometrica* **89**(1), 215–249.
URL: *https://onlinelibrary.wiley.com/doi/abs/10.3982/ECTA17536*

Gurevich, T., Herman, P., Toubal, F. & Yotov, Y. V. (2024), The domestic and international common language database, Working Paper 2024-2, LeBow College of Business, Drexel University.

Kee, H. L. & Nicita, A. (2022), 'Non-tariff measures and trade discrepancies', *Journal of International Economics* **136**, 103586.

Kee, H. L., Nicita, A. & Olarreaga, M. (2009), 'Estimating trade restrictiveness indices', *The Economic Journal* **119**(534), 172–199.

Lin, W. & Wooldridge, J. M. (2019), Chapter 2 - testing and correcting for endogeneity in nonlinear unobserved effects models, *in* M. Tsionas, ed., 'Panel Data Econometrics', Academic Press, pp. 21–43. **URL:** *https://www.sciencedirect.com/science/article/pii/B9780128143674000022*

UNCTAD (2025), Key statistics and trends in trade policy 2024, Technical Report UNCTAD/DITC/TAB/2025/1, United Nations Conference on Trade and Development, Geneva.

A Data Sources and Variable Descriptions

This appendix describes the main variables used in the empirical analysis, together with their respective data sources and references.

Trade Data Bilateral trade flows at the HS6 product level are sourced from the BACI database developed by CEPII. BACI harmonises and reconciles bilateral trade data reported to the UN COMTRADE database using mirror statistics. The trade variable X_{ijkt} denotes exports from country i to j of product k in year t, measured in current US dollars. *Source:* Gaulier & Zignago (2010).

Tariffs Applied bilateral tariffs are taken from the World Integrated Trade Solution (WITS) database, maintained by the World Bank and the World Trade Organization (WTO). These tariffs are reported at the HS6 level. When available, most-favoured-nation (MFN) applied rates are used; otherwise, preferential rates are considered. The variable Tariff$_{ijkt}$ measures the ad valorem tariff rate imposed by country j on imports from country i for product k in year t.

Non-Tariff Measures (NTMs) Information on NTMs is drawn from the WTO's Integrated Trade Intelligence Portal (I-TIP), which compiles official notifications on sanitary and phytosanitary (SPS) measures and technical barriers to trade (TBTs). Following Ghodsi et al. (2017), we harmonise HS codes and correct for missing or inconsistently reported classifications. For each importer-product-year, we define two indicators of regulatory exposure: a dummy for the presence of at least one NTM and a cumulative count of measures in force.

Gravity Variables The set of standard gravity covariates includes bilateral distance, measured as the great-circle distance between the economic centres of countries i and j, and a contiguity dummy equal to one if the two countries share a land border. Colonial ties are captured through an indicator variable equal to one when the trading partners shared a common coloniser after 1945. We also include a common spoken language variable, set to one when a language is spoken by a significant share of the population in both countries, based on linguistic proximity. Institutional proximity is accounted for through two additional dummies: one for European Union (EU) membership and one for WTO membership, each equal to one when both countries are members in a given year. Data for distance, contiguity, colonial ties, and EU/WTO membership come from the CEPII Gravity database (Conte et al. 2022),

Common Spoken Language The indicator for shared language is taken from the Domestic and International Common Language Database (Gurevich et al. 2024). The variable Comlang$_{ij}$ equals one if a common spoken language is present between countries i and j, based on linguistic proximity and co-spoken usage across borders.

B   Additional Tables & Graphs

This appendix provides additional graphical evidence to complement the main results. In particular, Figure B1 reports the distribution of ad valorem equivalents based on statistically significant NTM estimates only. While this definition conditions on statistical significance and therefore alters the support of the distribution, the qualitative differences across environmental goods, critical minerals, and other products remain consistent with the patterns observed in the main text.

Figure B1: Distribution of ad valorem equivalents using significant-only estimates
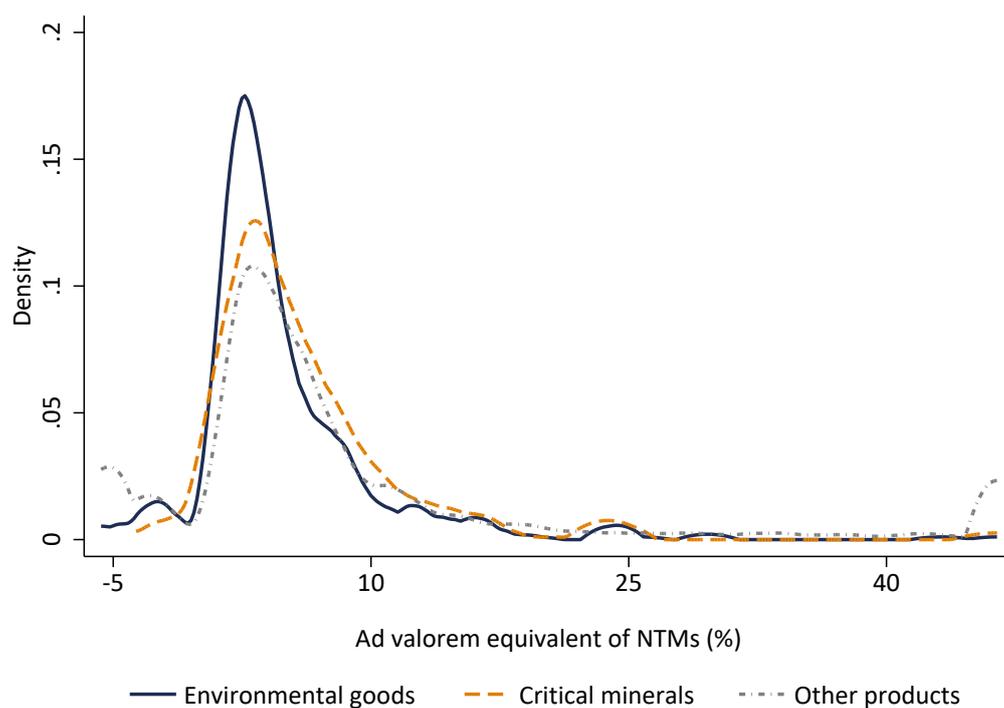
Notes: The figure reports kernel density estimates of ad valorem equivalents (AVEs) of non-tariff measures (NTMs) at the HS6 level, computed using product-specific trade elasticities. AVEs are constructed using the significant-only definition, retaining only products for which the estimated NTM effect is statistically significant at the 10% level. The figure mirrors Figure 2 in the main text but focuses on the subset of statistically informative estimates. The x-axis is truncated for readability.

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