Measuring environmental depth in preferential trade agreements across an index for forest-related provisions

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Abstract: We develop an Environmental Depth Index (EDI) that rates the stringency of forest-related provisions in 479 preferential trade agreements concluded by 168 countries between 1945 and 2022. Clauses are sorted into four categories and combined with eleven alternative weighting schemes, from equal weights to exponential progressions, to check measurement stability. Panel estimates with Driscoll–Kraay errors show that a 1% rise in annual tree-cover loss raises the index by 0.19% while a 1% expansion in standing forest stock lowers it by 0.66%, suggesting that governments strengthen treaty language when degradation becomes visible but ease off where forest remains abundant. Outward foreign direct investment is also associated with deeper commitments, and the income terms trace the inverted-U predicted by the environmental Kuznets curve. Rank correlations across weighting schemes exceed 0.80 in every pairwise comparison, confirming robustness. Only 23% of agreements contain explicit forest clauses yet those that do offset the deforestation pressures linked to trade liberalization. When forest-specific clauses receive priority Latin America and the Caribbean post the highest regional scores, surpassing Europe and North America. By moving beyond binary coding, providing transparent weighting options, and aligning with observable drivers of deforestation, the index offers a practical benchmark for negotiators and a versatile tool for empirical research on trade and the environment.
Keywords: Environmental Provisions; Forest Conservation; Environmental Depth Index.
JEL Codes: F13, F15, Q56, Q58.

Medindo a profundidade ambiental em acordos comerciais preferenciais por meio de um índice de cláusulas florestais

Resumo: Desenvolve-se um Índice de Profundidade Ambiental (EDI) que avalia a rigidez das disposições relacionadas a florestas em 479 acordos comerciais preferenciais celebrados por 168 países entre 1945 e 2022. As cláusulas são classificadas em quatro categorias e combinadas em onze esquemas de ponderação, que vão de pesos iguais a progressões exponenciais, para verificar a estabilidade da mensuração. Estimativas em painel com erros de Driscoll-Kraay mostram que um aumento de 1% na perda anual de cobertura arbórea eleva o índice em 0,19%, enquanto um acréscimo de 1% no estoque florestal reduz o índice em 0,66%, sugerindo que os governos endurecem a redação dos acordos quando a degradação se torna visível, mas relaxam-na onde as florestas ainda são abundantes. O investimento estrangeiro de saída está associado a compromissos mais profundos, e a renda segue o formato de U invertido previsto pela curva de Kuznets ambiental. As correlações entre os esquemas de ponderação superam 0,80 em todas as comparações, confirmando robustez. Apenas 23% dos acordos contêm cláusulas explícitas sobre florestas, mas os que o fazem compensam as pressões de desmatamento associadas à liberalização comercial. Quando as cláusulas florestais recebem prioridade, América Latina e Caribe apresentam as maiores pontuações regionais, superando Europa e América do Norte. Ao avançar além da codificação binária, oferecer opções de ponderação transparentes e alinhar-se aos determinantes observáveis do desmatamento, o índice fornece uma referência prática para negociadores e uma ferramenta versátil para pesquisas sobre comércio e meio ambiente.

Palavras-chave: Disposições Ambientais; Conservação Florestal; Índice de Profundidade Ambiental.

1. Introduction

The relationship between international trade and environmental protection has gained prominence in recent decades, prompting negotiators to embed environmental provisions in preferential trade agreements (PTAs). Gauging the ambition and likely effectiveness of these clauses demands a sound composite metric that captures both scope and stringency, especially for forest-related commitments. We therefore propose the Environmental Depth Index (EDI), which classifies provisions into thematically distinct groups and aggregates them with a penalized, nonlinear scheme that highlights the presence (or absence) of targeted forest safeguards.

Composite indicators are necessary to environmental-policy analysis in PTAs, yet their construction is far from mechanical. As Nardo et al. (2005) and Saisana & Tarantola (2011) stress, indicator choice, normalization, aggregation rules and weights all shape interpretation and policy uptake. Morin et al. (2018) supplied an initial taxonomy of environment-related clauses in PTAs, showing that thematic breadth and legal wording vary widely. Building on that groundwork, our EDI applies the penalized power-means method of Mariani et al. (2024). The technique introduces non-linearity to reflect asymmetric importance across categories and imposes an explicit penalty when high-priority provisions are missing, an attractive property for forest governance, where specific commitments are both less common and more consequential.

The EDI groups provisions into four categories: (1) Specific Forest Provisions, such as bans on illegal logging or sustainable-timber trade rules (given the greatest weight); (2) Enforcement and Implementation, covering monitoring, sanctions and institutional capacity; (3) Environmental Principles and Cooperation, spanning due-process clauses, information exchange and technical assistance; and (4) Dispute Resolution, which establish committees, consultations and litigation pathways. Multiple weighting schemes, such as equal, linear, exponential or "forest-priority" (10-2-1-1), test sensitivity to normative assumptions. For each country we calculate the share of adopted clauses in every category, scale them by agreement counts, apply the chosen weights, perform the penalized power transformation (amplifying Category 1), and finally rescale scores to 0–100 against observed maxima. The result is an annual, transparent yet discriminating yard-stick that allows robustness checks and facilitates cross-country comparisons.

Methodological guidance warns that linear averages often blur meaningful contrasts when indicators are highly correlated; non-linearities and penalty terms counteract that compression and reveal substantive gaps (Saltelli et al., 2008). Equally, weighting is "an act of political choice" (ibid.), so transparency is indispensable. Our framework addresses three gaps. First, it moves beyond binary "presence/absence" counts, instead gauging depth, specificity and enforceability. Second, it confronts the weight-assignment problem by offering a menu of plausible schemes and documenting their effect on rankings. Third, an external-consistency panel regression, using Driscoll-Kraay errors to handle cross-sectional dependence, tests whether higher EDI scores align with macro drivers such as FDI inflows or forest-cover change, grounding the index in observable outcomes.

This study explores two core questions: how to systematically measure environmental depth in trade agreements to reflect the breadth? What is the stringency of forest-related commitments, and which economic and environmental factors drive higher environmental depth? This paper aims to develop and validate an EDI for quantifying environmental provisions and to identify key determinants of environmental ambition using econometric analysis.

The rest of the paper proceeds as follows. Section 2 surveys the PTA-environment literature and develops the theoretical basis for measuring depth. Section 3 details data, categorization logic, weighting schemes and the econometric procedures. Section 4 presents descriptive patterns, sensitivity checks and panel results. Section 5 discusses policy implications and future research avenues.

2. Environmental provisions in trade agreements: evolution and theoretical foundations

Over the past three decades environmental language has proliferated in PTAs, yet empirical results on its effectiveness remain mixed, largely because outcomes depend on clause design rather just than presence. Early cross-country evidence associated trade liberalization with environmental degradation unless rigorous domestic governance existed (Copeland & Taylor 2004; Shahbaz et al 2015). Baghdadi et al (2013) compare country pairs with and without environmental clauses and estimate a 5% to 8% drop in CO_2 emissions for the former. Yu et al (2024) find that such clauses raise green total factor energy efficiency by roughly 2% within five years, attributing gains to technology transfer and regulatory learning. Forest outcomes illustrate the importance of thematic focus. Abman et al (2024) report that deforestation remains fully neutralized a decade after PTA entry into force if binding enforcement accompanies those forest provisions. By contrast, Brandi et al (2020) document that PTAs lacking enforcement mechanisms still enlarge the ecological footprint of developing country exports even when they contain sustainable development language, highlighting the gap between shallow and deep commitments.

Design features matter. Bastiaens & Postnikov (2017) focus on North–South agreements and estimate, via difference in differences, a 6% smaller decline in environmental stringency when clauses grant private access to dispute settlement or mandate post ratification monitoring. George & Yamaguchi (2018) confirm that notification and fact finding accelerate compliance, and Lechner & Spilker (2022) observe no measurable emission benefits in South–South PTAs that omit these backstops. Analysing 55 distinct environmental provisions and linking them to three performance measures, these last authors the Environmental Performance Index (EPI), SO_2 emissions per capita and CO_2 emissions per capita, their regressions show that each additional binding commitment on compliance procedures or reporting requirements is associated with a modest but statistically consistent increase in EPI scores and a corresponding reduction in pollutant emissions. By contrast, they find no solid association between treaty provisions and the stringency of nationally determined contributions under the Paris Agreement. These results indicate that, even without formal dispute-settlement mechanisms typical of North-South accords, carefully drafted procedural and monitoring clauses in South-South PTAs can translate into observable environmental improvements.

Forest specific work reinforces this conclusion. Using a satellite-based panel, Grigoras (2024) distinguishes clauses that merely restate pre-existing multilateral forest obligations from genuinely new, binding commitments within PTAs and finds that only the latter are linked to statistically significant reductions in tropical deforestation. Also analyzing a satellite-based panel, Abman and Lundberg (2020) finding RTAs without forest or biodiversity clauses are followed by a 23% surge in annual forest loss, whereas agreements that include such clauses erase the effect entirely. Andersen (2012) and Abdulaï & Ramcke (2009) link trade induced price shocks rather than domestic demand to forest conversion, implying that PTAs must counterbalance those incentives with concrete safeguards.

Although these studies analyze PTAs, forests, or both, none of them builds a composite indicator. Instead, weighting schemes and penalty functions should influence to high-impact provisions and discount simple clause counts. Drawing on one of the first systematic taxonomies of PTA environmental clauses, Morin et al. (2018) show that variation in both thematic scope and binding language maps onto measurable differences in state behavior, underscoring the need for indicators that capture qualitative depth rather than mere frequency. Building on that taxonomy, the EDI groups provisions into four themes: specific forest commitments, enforcement and implementation measures, general principles and cooperation, and governance with dispute resolution. The index follows the penalized power means method proposed by Mariani et al (2024) which extend the standard power-means framework by inserting two distortions that make composite scores exquisitely sensitive to the presence (or absence) of top-priority components. First, a non-linear exponent ($x > 1$) is applied to the weighted share of those components, stretching the distance between countries that fully embed them and countries that only partly do so. Second, a proportional penalty (P) is imposed whenever the high-priority share falls to zero, pulling the entire index toward the lower bound and preventing mediocre scores from being masked by strong performance in less-critical categories. In practice, this means that even small differences in the adoption of forest-specific clauses can generate large swings in the EDI.

The penalized power-means approach adopted in EDI is designed to capture precisely that discontinuity. It multiplies the share of Category 1 provisions by a non-linear exponent and applies a proportional penalty when that share is zero, so a single, binding forest commitment can catapult a country's score, while its absence drags the score sharply downward. The resulting index thus mirrors the empirically observed leverage of forest-specific clauses rather than merely counting provisions.

3. Methodology

This section has four parts: 3.1 defines the clause categories, 3.2 presents the weighting schemes, 3.4 details the index algorithm, and 3.5 outlines the panel estimation strategy.

3.1 Categorization framework and provision selection

This study uses the Design of Trade Agreements (DESTA) database, which records trade agreements signed from 1945 to 2022 and codes provisions in each agreement (Dür et al., 2014). The analysis focuses on provisions on forest conservation, sustainable forest management and environmental governance. The dataset covers 479 agreements and 168 countries for the full period, allowing examination of changes in environmental provisions over seven decades.

DESTA uses a binary coding system: each provision is marked 1 if present and 0 if absent. This facilitates comparison and quantitative analysis but does not capture wording, implementation or enforcement details. Data preparation standardized country names, resolved coding inconsistencies, expanded each plurilateral agreement into separate records for its member countries and assigned development classifications via country code.

The construction of the EDI begins with the selection and categorization of forest-related provisions from the DESTA database. Following methods in the literature, we build a framework for identifying and classifying provisions by their institutional requirements, enforcement mechanisms and impact on governance (Lechner & Spilker, 2022; Bastiaens & Postnikov, 2017).

The selection process applies criteria that ensure relevance and reproducibility. The first step was to select provisions that mention forests, timber, logging, or related resources or that apply directly to deforestation issues (Grigoras, 2024; Abman et al., 2024). After, provisions that establish commitments, institutional mechanisms or procedural requirements (Lechner & Spilker, 2022), provisions that include elements for monitoring, implementation or sanction of environmental commitments (Bastiaens & Postnikov, 2017) and dispute resolution. Category 1 comprises provisions with a direct link to deforestation, whereas subsequent categories may affect deforestation more indirectly as their connection to forest issues becomes more remote.

Category 1, Specific Forest Commitments (3 provisions), includes PTAs that establish explicit obligations related to forest conservation and sustainable forest management. These provisions reflect the highest level of environmental ambition in addressing deforestation, often requiring institutional capacity and dedicated resources for effective implementation.

- Forest conservation (DESTA 10.05.01): requiring parties to protect and sustainably manage their forest resources, including commitments to maintain forest cover and prevent deforestation.
- Sustainable trade in forestry products (DESTA 10.05.02): promoting sustainable practices in the production and trade of forest products, including requirements for sustainable forest management certification.
- Combat illegal exploitation of forests (DESTA 10.05.03): requiring parties to prevent and combat illegal logging and associated trade, including measures to ensure the legality of timber imports and exports.

Category 2, Enforcement and Implementation (39 provisions), gathers clauses that establish institutional mechanisms for environmental governance, enforcement, and implementation. Although not forest-specific, these provisions create arrangements that can be applied to deforestation-related issues and signal a broader institutional commitment to environmental compliance.

Key provisions include binding obligations (DESTA 5.01.01); specific governmental action for enforcement (5.02); private access to remedies, procedural guarantees, and appropriate sanctions (5.03); commitment to consider alleged violations brought by citizens of any Party (5.04.01) and by foreigners (5.04.02); cooperation on enforcement (5.05); factual report on enforcement (5.06); education and public awareness (6.01); promotion of voluntary measures (6.02.01; 6.02.02); economic and market instruments (6.03.01; 6.03.02); conservation of natural resources (8.01.02); technical assistance, training, and capacity building (9.01.01); funding mechanisms for capacity building, cooperation activities, and implementation (9.03.01; 9.03.02; 9.03.03; 9.03.04); capacity building and assistance to third countries (9.05); protected areas, parks, and natural reserves (10.13); soil erosion prevention (10.19); references to multilateral environmental agreements including CITES (14.01.14; 14.02.14.01; 14.02.14.02; 14.03.01; 14.04.01), CBD (14.01.12; 14.02.12.01; 14.02.12.02; 14.03.12; 14.04.12), Nagoya Protocol (14.04.14), and REDD+ (14.04.24); institutional mechanisms including intergovernmental committees (12.01), international secretariats (12.02.01, 13.01.01; 13.02.01), and stakeholder committees (12.03).

Category 3, Environmental Principles and Cooperation (26 provisions), brings together general principles and cooperation commitments that frame environmental action. These clauses represent an intermediate level of ambition and usually demand limited institutional capacity. They encompass the prevention principle (1.03); the precautionary principle (1.04); the polluter-pays principle (1.05); sovereignty over natural resources in general and specific resources (1.07.01; 1.07.02; 1.07.03; 1.07.04); commitments to avoid encouraging trade or investment by relaxing environmental measures and to maintain existing levels of environmental protection (2.01.01; 2.01.02; 2.01.03); pursuit of high levels of environmental protection and commitment to enhance environmental protection (2.02.01; 2.02.02); interaction between rural development and the environment (4.08); interaction between land use planning and the environment (4.10); interaction between agriculture and the environment (4.12); joint environmental assessment, study, and monitoring (7.02.04); provision of information when taking environmental measures (7.03.04); harmonization of environmental measures and related provisions (7.04.01; 7.04.02; 7.04.03; 7.04.04; 7.04.05; 7.04.06; 7.04.07); and environmental impact assessment of the agreement (11.04).

Category 4, Dispute Resolution (4 provisions), covers transparency, communication, and procedural instruments that facilitate monitoring, accountability, and coordination in environmental governance. This group stands at the lowest level of normative ambition and generally requires only minimal institutional effort. Relevant provisions concern the establishment of specialized organizations on specific environmental issues (12.02.02); non-jurisdictional mechanisms for failure to enforce (13.03.01); and general dispute settlement procedures, including suspension of benefits (13.04.02.01; 13.04.02.02).

3.2 Weighting systems and theoretical justification

The EDI uses eleven (table 1) weighting systems that operationalize theoretical assumptions about the importance of environmental provision categories. All schemes keep the highest numerical weight on Category 1 because this category groups provisions with a direct link to deforestation. Variation across schemes changes how rapidly weight declines across the remaining categories, which permits comparison of index behavior under alternative weighting gradients and supports robustness checks.

Table 1. Overview of composite indicator weighting schemes with rationale.

Scheme	Weights	Category shares (1-4)	Justification
Hierarchical Moderate	(8, 4, 2, 1)	53 %, 27 %, 13 %, 7 %	Uses powers of two to ensure each category differs by a factor of two; offers moderate separation without overemphasizing any single category.
Exponential	($e^3 \approx 20.09$, $e^2 \approx 7.39$, $e^1 \approx 2.72$, 1)	64 %, 24 %, 9 %, 3 %	Applies natural exponential declines to accentuate the highest category while maintaining a consistent multiplicative drop between successive levels.
Equal Weights	(1, 1, 1, 1)	25 %, 25 %, 25 %, 25 %	Assigns uniform importance to each category to assess how ranking outcomes respond when no category is prioritized over others.
Evidence Based	(6, 3, 2, 1)	50 %, 25 %, 17 %, 8 %	Reflects empirically observed ratios (6 :3 :2 :1) to mirror patterns in real data; allows moderate emphasis on primary provisions with graduated emphasis on secondary ones.
Implementation Focus	(5, 5, 2, 1)	38 %, 38 %, 15 %, 8 %	Equates direct forest and enforcement provisions to examine their joint influence; then reduces weight for broader cooperation and transparency measures.
Forest Priority	(10, 2, 1, 1)	71 %, 14 %, 7 %, 7 %	Concentrates most weight on explicit forest commitments to highlight their comparative scarcity and importance relative to other categories.
Balanced Approach	(4, 4, 3, 2)	31 %, 31 %, 23 %, 15 %	Maintains a mild decline and ties the top categories to provide a balanced perspective on direct provisions and enforcement without extreme differentiation.
Linear Decline	(4, 3, 2, 1)	40 %, 30 %, 20 %, 10 %	Implements a uniform decrement between categories to produce a smooth gradient in weight distribution.
Quadratic Weights	(16, 4, 2, 1)	70 %, 17 %, 9 %, 4 %	Uses squared magnitudes to impose a steeper drop after the first category and intensify its dominance in the composite measure.
Conservative	(3, 2, 2, 1)	38 %, 25 %, 25 %, 13 %	Limits differentiation by tying the middle categories; ensures the top category leads while retaining relative parity between mid-level provisions.
Progressive	(12, 6, 3, 1)	55 %, 27 %, 14 %, 5 %	Halves the weight at each step following the first category to create a consistent geometric decline with moderate emphasis on the highest level.

Author's elaboration.

These different weighting schemes are compared with EDI calculation to gauge ranking stability under alternative assumptions. Pearson correlation coefficients between each pair of schemes quantify convergence in country rankings, with values near one indicating stability and lower values revealing sensitivity to weight choice. Spearman rank correlations confirm whether relative orderings persist across schemes. Score distributions are examined to identify skewness or uniformity in differentiation. Finally, outliers and extreme values are reviewed to ensure they reflect genuine provision coverage rather than coding errors or data anomalies.

3.4 Mathematical formulation and EDI construction

The EDI calculation proceeds in three stages: first, Category 1 provisions undergo a nonlinear amplification; second, scores are weighted across the four thematic categories; third, a penalty is imposed whenever no Category 1 provisions appear. Each operation is applied separately under each weighting scheme. For every country, data are sorted by year, and each provision dummy is transformed into a cumulative count that captures the total number of in-force agreements containing the provision of the year, including the provisions of the previous years. Employing cumulative annual data reflects the fact that, once concluded, trade agreements remain operative in subsequent years and continue to shape a country's stock of commitments at the end of each period.

For country i in year t, let $A_{i,t}$ be the set of PTAs that are in force. Let $P_{k,i,a,t}$ denote the number of provisions in category k that are coded as present for country i in agreement $a \in A_{i,t}$. With P_k equal to the total possible items in category $k(|P_1| = 3,\ |P_2| = 39,\ |P_3| = 26,\ |P_4| = 4)$, the cumulative share of covered provisions is

$$C_{k,i,t} = \frac{\sum_{a \in A_{i,t}} |P_{k,i,a,t}|}{|A_{i,t}| \times |P_k|} \quad (1)$$

Because the counts are cumulative and vary over time for each country, $C_{k,i,t}$ may rise or fall over time for a country as new agreements are added.

Category 1 receives a nonlinear amplification to increase score dispersion where coverage is higher. A weighted raw value is calculated as

$$S_{1,raw,t} = w_1 \times C_{1,i,t} \quad (2)$$

and is then transformed by a power function

$$S_{1,amp,t} = (S_{1,raw,t})^x \quad (3)$$

with $x = 2$ in the baseline specification, for three pragmatic reasons that follow common guidance on composite-indicator design (Nardo, 2008; Saltelli et al., 2019): i) delivers a moderate convexity that amplifies consistently high values while preserving the relative ordering among lower-coverage cases (exponents below two yield only mild differentiation, and higher exponents produce overly steep gradients that compress the distribution's middle); ii) the square function is straightforward to interpret: doubling proportional coverage more than doubles the amplified score; and iii) sensitivity tests at 1.5 and 3 yielded Spearman correlations above 0.95 with the baseline, demonstrating robustness. Its use also follows precedents in composite metrics (for example, the Atkinson inequality index and the Human Development Index), providing a mathematically tractable means of modelling increasing returns to coverage.

The amplified Category 1 term is combined with the weighted proportions from the remaining categories to form an unpenalized linear composite:

$$L_{lin,i,t} = S_{1,amp,i,t} + (w_2 \times C_{2,i,t}) + (w_3 \times C_{3,i,t}) + (w_4 \times C_{4,i,t}) \quad (4)$$

A penalty is applied when a country has no Category 1 coverage. Let $P = 0.1$. If $C_{1,i,t} = 0$, the composite is multiplied by P; otherwise, it is left unchanged:

$$L_{pen,t} = \begin{cases} L_{lin,i,t} \times P, C_{1,i,t} = 0 \\ L_{lin,i,t}, \quad\quad C_{1,i,t} > 0 \end{cases} \quad (5)$$

Multiplying by a constant less than 1 compresses the scores of all countries with zero forest-specific provisions while preserving their ordering relative to one another and creates a break between countries with and without any such provisions. Sensitivity analysis can vary P; values nearer zero strengthen the penalty and values nearer one weaken it (setting $P = 1$ removes the penalty).

Finally, penalized values are normalized to a common range to aid comparison across weighting systems:

$$EDI_{i,t} = \frac{L_{pen,t} - L_{min,t}}{L_{max,t} - L_{min,t}} \times 100 \quad (6)$$

Where $L_{max,t}$ and $L_{min,t}$ are the minimum and maximum $L_{pen,t}$ values observed across all countries in t, under the given weighting scheme.

This formulation increases the influence of forest-related provisions when present, applies a penalty to countries with zero Category 1 coverage so they cannot rank highly based solely on other provisions, and rescales all penalized values to a 0-100 range, producing a standardized index that is comparable across weighting schemes while preserving each scheme's internal ranking; by combining non-linear amplification of Category 1, a multiplicative penalty for its absence, and a normalization step, the method ensures that strong forest commitments receive disproportionately higher scores, that countries lacking any such commitments are appropriately down-weighted, and that results remain comparable under alternative weight specifications.

3.5 Empirical strategy: panel specification and estimation

This econometric strategy is limited to the period 2001–2021, as that is when consistent data for all explanatory variables are available. To assess the relationship between macro-structural variables and environmental ambition in PTAs' design, we estimate pooled ordinary least squares regressions corrected for serial correlation and cross-sectional dependence using Driscoll-Kraay (DK) standard errors. This approach is appropriate for EDI, which exhibits limited within-country variation over time but considerable cross-sectional heterogeneity. Although the dataset spans twenty years, descriptive tests show that the index changes very little within countries from one year to the next, while variation across countries is large. A panel with fixed-effects estimator, which relies only on the within-country dimension, discards most of the relevant effects and leaves coefficients imprecise. At the same time, standard pooled ordinary least squares ignore two common features of trade-and-environment panels: serial correlation in each country's trajectory and contemporaneous correlation across countries facing the same global shocks. When those patterns are present, conventional standard errors tend to be understated. Brandi et al. (2020), the choice of the estimated DK due to the need to correct the serial demonstration and the dependence between sections (countries) in their panel data

To retain the informative cross-sectional variation and, at the same time, obtain reliable inference, the analysis employs pooled ordinary least squares with Driscoll-Kraay standard errors. This covariance estimator remains consistent in the presence of arbitrary heteroskedasticity, autocorrelation of unknown order, and cross-sectional dependence that decays slowly with distance or is common to all units (Abdulai & Ramcke, 2009). In practical terms, the method allows the inclusion of the full set of countries, keeps year dummies that absorb global shocks such as commodity cycles, and adjusts the standard errors to reflect both temporal and spatial correlation. The econometric specification is

$$\ln EDI_{it} = \alpha + \sum_{k=1}^{10} \beta_k X_{kit} + \gamma_t + \epsilon_{it} \tag{7}$$

where X_{kit} are the logged covariates listed in table 2. All explanatory variables are entered into natural logs, so each coefficient can be read as elasticity. Year dummies, t, capture shocks that are common to all countries, while the DK correction, implemented with a lag length of two, adjusts the variance-covariance matrix for any remaining autocorrelation and cross-sectional dependence.

Table 2. Description of variables.

Variable	Variable name	Definition and source	Expected sign	Use in the studies
$\ln EDI_{it}$	Environmental Deforestation Index	Log of the Environmental Deforestation Index, own computation from DESTA	n.a.	-
$\ln Agreement_{it}$	Number of PTAs signed	Annual count of PTAs per country (DESTA)	Positive: more agreements raise the menu of environmental clauses	Abman et al., 2024; Bastiaens & Postnikov, 2017; Brandi et al., 2020 Berger et al., 2020
$\ln CovesLoss_{it}$	Forest-cover loss	Annual tree-cover loss in hectares, Global Forest Watch (Hansen et al.)	Positive: regulatory feedback to visible degradation	Abman et al., 2024; Hansen et al., 2013 Andersen, 2012
$\ln Forest_{it}$	Forest stock	Forest area is reported at ten-year intervals using the Hansen tree-cover layers: 2000 (covering 2001-2009), 2010 (covering 2010-2019) and 2020 (covering 2020-2021).	Positive: large resources heighten conservation salience	Abman et al., 2024; Culas, 2007
$\ln GDP_{it}$	GDP	Gross domestic product (current prices US$), World Bank	Positive up to turning point	Tian et al., 2022; Kaika & Zervas , 2013
$(\ln GDP_{it})^2$	GDP squared	Square of ln GDP	Negative after turning point, following the environmental-Kuznets-curve logic: the deforestation pressure intensifies at early stages of development then eases beyond an income threshold	Tian et al., 2022; Kaika & Zervas, 2013
$\ln FDI\_in_{it}$	FDI inflows	Foreign direct-investment inflows, UNCTADstat	Positive: investors prefer clear environmental signals	Yu et al., 2024; Shahbaz et al., 2015
$\ln FDI\_out_{it}$	FDI outflows	Foreign direct-investment outflows, UNCTADstat	Positive for similar reasons	Yu et al., 2024; Shahbaz et al., 2015
$\ln AgriLand_{it}$	Agricultural land	Agricultural land area, FAOSTAT Land-Use domain	Positive: conversion pressure stimulates clause adoption	Geist & Lambin, 2002 Rudel et al., 2005
$\ln AgrExpGDP_{it}$	Agricultural-expor t share	Share of agricultural exports in GDP, WITS/UN Comtrade	Positive: exporters align with destination sustainability norms	Brandi et al., 2020; Copeland & Taylor, 2004
$\ln Govern_{it}$	Governance index: Regulatory quality	Standardized composite of the Worldwide Governance Indicators	Positive: stronger institutions sustain enforcement	Lau et al., 2014
$DevDummy_i$	Dummy for development status (1 = developed country; 0 = developing country)	-	Positive: developed countries tend to adopt more provisions	Frankel & Rose, 2005; Esty & Charnovitz, 2009
$\alpha, \gamma_t, \epsilon_{it}$	Constant, year fixed effects, error term	Econometric procedures (pooled OLS + Driscoll-Kraay)		

Author's elaboration.

Before estimation, the regressors were screened for multicollinearity; all variance-inflation factors lie below ten, except GDP and GDP squared, which are included jointly to test the Environmental Kuznets Curve. Also, the Heteroskedasticity was examined with the Breusch-Pagan test and cross-sectional dependence with the Pesaran CD statistic; both diagnostics indicated the need for robust inference, further motivating the chosen estimator. Results were re-estimated using alternative lag lengths, after excluding high-income outliers and with forest loss lagged by one year; in every case, the direction and magnitude of the main coefficients remained stable. Collectively, these checks confirm that pooled ordinary least squares with Driscoll-Kraay errors provides the most appropriate balance between efficiency and reliability for the research question at hand.

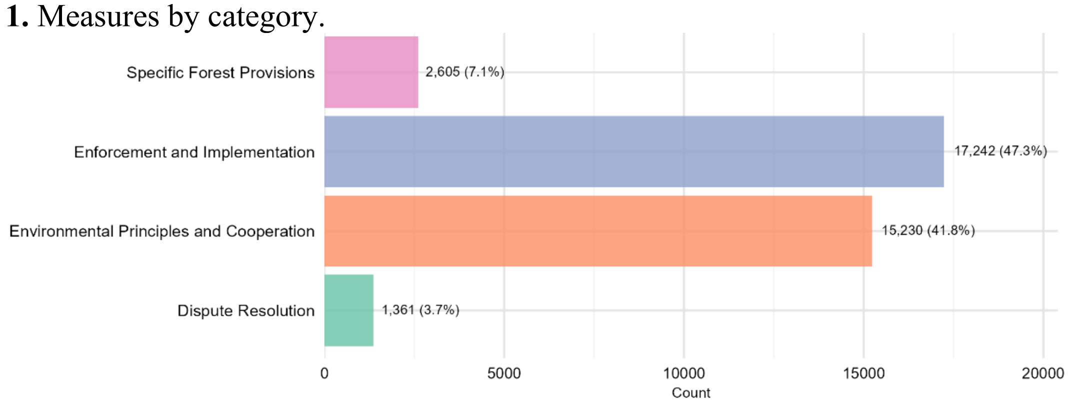
4. Results

4.1 Descriptive statistics and data overview

Category 2 provisions (Enforcement and Implementation) are the most common, appearing in approximately 78 % of agreements that contain environmental provisions (figure 1). This high frequency reflects the adoption of general institutional mechanisms for environmental governance, even in agreements that lack specific forest commitments, and partly results from the fact that categories 2 and 3 encompass a larger number of individual provisions than categories 1 and 4. Category 3 provisions (Environmental Principles and Cooperation) appear in approximately 65 % of agreements with environmental content, suggesting acceptance of broad environmental principles in trade policy. Category 1 provisions (Specific Forest Provisions) appear in only 23 % of agreements, highlighting their relative rarity and the challenge of securing targeted forest commitments in trade negotiations. Category 4 provisions (Governance and Dispute Resolution) appear in approximately 45 % of agreements, indicating moderate adoption of procedural mechanisms for environmental governance.

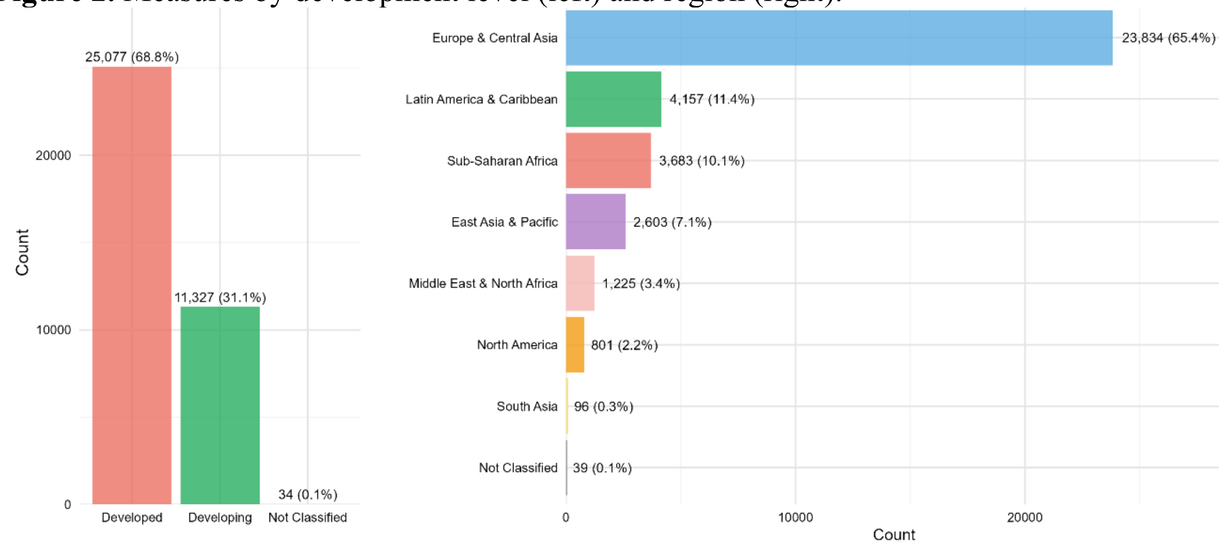
The geographical distribution highlights distinct patterns reflecting differences in environmental priorities, institutional capacity, and negotiating power. Among developed countries, 89 % are involved in at least one agreement containing environmental provisions, compared to 56 % of developing countries (figure 2, left). Regional analysis shows that North American and European countries have the highest participation (figure 2, right), followed by countries in East Asia and the Pacific. Sub-Saharan African countries have the lowest participation rates, reflecting limited engagement in PTAs generally and lower prioritization of environmental issues in trade negotiations.

Figure 1. Measures by category.



Author's elaboration.

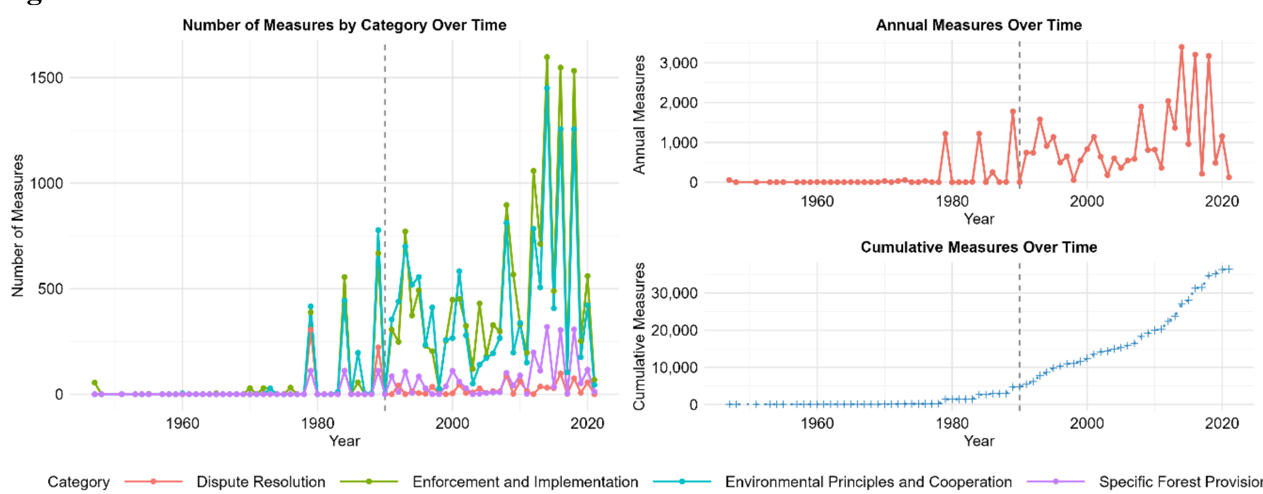
Figure 2. Measures by development level (left) and region (right).



Author's elaboration.

The temporal analysis (figure 3) reveals an upward trend in the inclusion of environmental provisions over time. Before 1990, fewer than 10 % of trade agreements included any environmental provisions. This proportion increased steadily through the 1990s and 2000s, reaching approximately 60 % of new agreements by 2010. Since 2010, the inclusion rate has stabilized at around 65 to 70 %, suggesting that environmental provisions have become an increasing feature of modern trade agreements. The period of greatest increase coincides with major environmental milestones: the 1992 Rio Earth Summit, the 2002 World Summit on Sustainable Development, Rio + 20 in 2012, and COP 21 in 2015, which established instruments such as Agenda 21, the Sustainable Development Goals, and the Paris Agreement, all aimed at reconciling economic growth, conservation of natural resources, and climate change mitigation.

Figure 3. Measures over time.

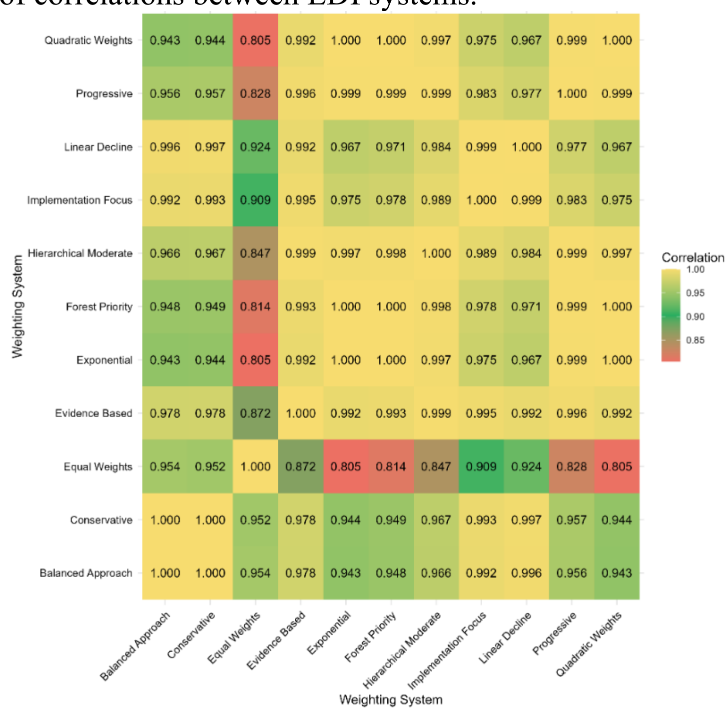


Author's elaboration.

4.2 EDI results across weighting systems and weight selection

Correlations among the eleven EDI weighting systems (figure 4), calculated on country-year observations, are uniformly high, ranging from 0.805 to 1.000. More than four fifths of all pairwise comparisons exceed 0.90, indicating that the relative ordering of countries is broadly stable under alternative reasonable weighting assumptions. This rank concordance reduces the risk that headline policy messages hinge on arbitrary parameter choices. Guidance from the composite-indicator literature emphasizes reporting these diagnostics and subjecting composite scores to uncertainty and sensitivity analysis before drawing policy inferences (Nardo et al., 2008; Wehbe and Baroud, 2024).

Figure 4. Heatmap of correlations between EDI systems.



Author’s elaboration.

Heatmap patterns reveal that weighting systems preserving a similar monotonic hierarchy across categories correlate most closely. For example, the Hierarchical Moderate and Evidence Based systems ($r \approx 0.999$) and the Exponential and Forest Priority systems ($r \approx 1.000$) track one another very closely, suggesting a common dimension anchored in specific forest commitments and implementation language. At the lower end, correlations with the Equal Weights system fall (Quadratic $r = 0.805$; Exponential $r = 0.814$; Progressive $r = 0.828$), showing that extreme weighting choices can matter for country comparisons. Literature on composite indicators warns that equal weighting can mask offsetting patterns among components with different empirical leverage, potentially yielding misleading parity between countries excelling in distinct domains (Wehbe and Baroud, 2024).

Distributional properties vary with the weighting scheme. In our dataset, the Equal Weights system yields an approximately normal score distribution (mean 42.3, standard deviation 18.7), reflecting the fact that most agreements include at least some provisions in each category. By contrast, the Forest Priority system generates a right-skewed distribution (mean 15.8, standard deviation 24.1) because relatively few agreements include the specific forest commitments that receive extreme weight. The Hierarchical Moderate system, used as baseline, produces scores with a mean of 38.5 and a standard deviation of 21.2, offering ample spread across the performance range while preserving an interpretable hierarchy of categories. The Exponential system (mean 35.7, standard deviation 22.8) displays a similar pattern, though the steeper weighting curve accentuates differences among countries that embed explicit forest language.

Weight choice in the EDI expresses analytic judgment about the relative contribution of each provision category to the construct being measured and, by extension, to observable environmental outcomes. Guidance on composite indicators stresses that weights encode importance or expected influence and should not be treated as arbitrary scaling constants; indiscriminate equal weighting across heterogeneous components can distort country ordering and policy interpretation (Nardo et al., 2008; Wehbe and Baroud, 2024). Studies on PTAs show that the presence of forest-focused provisions is associated with attenuation of post-agreement deforestation pressures, suggesting that Category 1 (targeted forest and biodiversity commitments) carries strong leverage for forest outcomes (Abman and Lundberg, 2020; Abman et al., 2024).

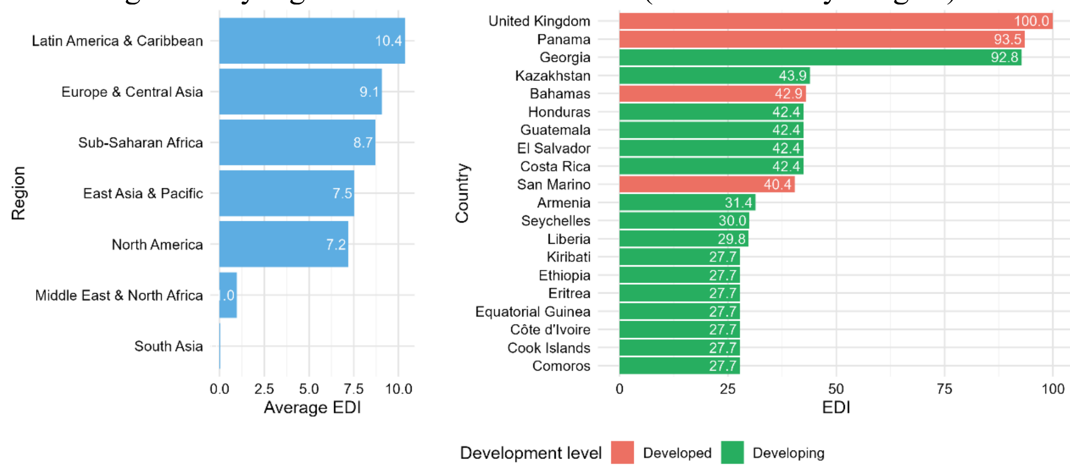
Despite this question, commitments alone are not enough. Studies on environmental compliance show that monitoring and enforcement actions raise observed compliance rates and generate deterrence spillovers, which supports giving major weight to Category 2 (implementation and enforcement) even when the primary outcome of interest is forest loss (Gray and Shimshack, 2011). Such enforcement shapes how environmental standards diffuse to partner countries, reinforcing the view that implementation conditions effectiveness (Bastiaens and Postnikov, 2017). Broader reviews highlight the enabling, reputational and learning functions of more general environmental principles and governance language, which argue for retaining residual weights for Categories 3 and 4 rather than dropping them entirely (Gutsch et al., 2024; Morin and Rochette, 2017).

Given these considerations, the Forest Priority weight system (10, 2, 1, 1) is used in the rest of the paper as the main specification when the EDI is applied to questions linked to deforestation, forest risk screening, or policy debates such as the EU Deforestation Regulation (EUDR). This weight system centers the category most closely tied to measured forest outcomes while preserving some supporting weight for implementation, and smaller residual weights for broader provisions (Abman and Lundberg, 2020; Abman et al., 2024). For comparative assessments of institutional architecture across agreements spanning multiple environmental themes, an Implementation Focus alternative (5, 5, 2, 1) would equalize Categories 1 and 2 reflecting the co-dependence between specific commitments and the capacity to act on them, as documented in enforcement and trade-agreement literature. Regardless of the preferred scheme, best practice is to present sensitivity checks across weighting sets and verify that key policy conclusions are stable and consistent with methodological guidance for composite indicators (Nardo et al., 2008; Wehbe and Baroud, 2024).

4.3 Country rankings and performance analysis

Although most individual environmental provisions are found in agreements involving developed economies, particularly Europe and Central Asia, Latin America and the Caribbean record the highest annual average regional EDI score when Category 1 receives heavy weight (figure 5, left). This shift occurs because many European instruments include numerous general provisions (Categories 2 and 3) and procedural clauses, whereas a subset of Latin American agreements embed specific forest obligations that score highly under this weighting. Thus, provision counts, and depth need not move in tandem: partners often add cooperation and enforcement clauses that inflate counts without securing stringent, issue-specific commitments.

Figure 5. Average EDI by region and TOP 20 countries (Forest Priority weights).



Author's elaboration.

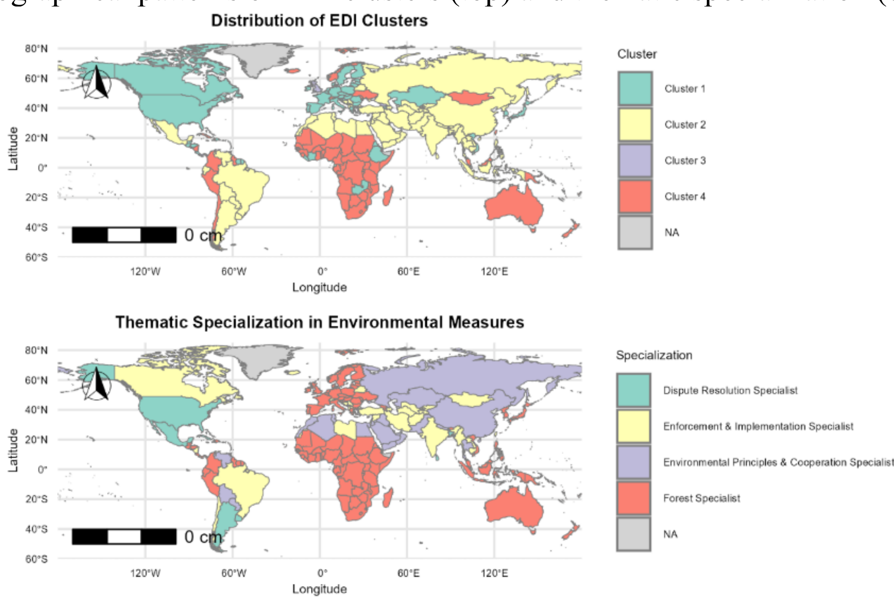
The United Kingdom attains the maximum average EDI score. Since Brexit, the UK has concluded only a few stand-alone free-trade agreements. The environment chapters of the Australia–UK and New Zealand–UK PTAs, for example, feature explicit commitments on sustainable forest management, illegal logging and cooperation to tackle deforestation (Department for Business and Trade & DIT, 2021; Young and Clough, 2023). Parliamentary scrutiny has also led the government to maintain and extend Voluntary Partnership Agreements for legal timber under the Forest Law Enforcement, Governance and Trade (FLEGT) framework, reinforcing a narrative that links market access to forest governance (Environmental Audit Committee, 2024). Every UK agreement in the post-2020 dataset includes the full set of forest-specific provisions tracked by the coding scheme. A Category 1 coverage ratio of one, amplified by the non-linear transformation and large weight, drives the composite score to 100.

Several small or developing countries (for example, Panama, Georgia and Honduras) appear in the top twenty for a similar arithmetic reason. Each participates in one or two accords negotiated with the EU, U.S., or UK that embed detailed forest provisions. Evidence that such targeted provisions can offset trade-induced forest loss comes from Abman et al. (2024), who show that regional trade agreements lacking forest or biodiversity clauses are associated rise in annual forest loss, whereas those including such clauses neutralize that rise.

Because the EDI uses a proportion-based denominator and does not down-weight for limited treaty portfolios, a single deep agreement can yield very high scores once Category 1 coverage is present and amplified. Composite-indicator methodology warns that sparse observations inflate scores and encourage outlier rankings when components carry strong weights (Nardo et al., 2008). Mapping environmental provisions in PTAs likewise shows that depth indicators skew toward countries attached to a small set of ambitious agreements, whereas frequency counts favor large networks of less stringent treaties (Berger and Brandi, 2020).

The upper panel of figure 6 groups countries into four clusters derived from K-means classification of their average EDI scores and sub-components. The first cluster, spread across North America, Scandinavia, and parts of Western Europe, combines high overall depth with balanced coverage of all categories, marking it as "high-depth generalists." The second cluster, centered on Southern Europe, the Maghreb, Central America, and parts of East Asia, features mid-range depth that leans heavily on enforcement and implementation clauses rather than on issue-specific commitments. A third cluster, comprising Eastern Europe, Central Asi,a and some Middle Eastern states, is characterized by a predominance of broad environmental principles and cooperation articles. The fourth cluster, covering much of Sub-Saharan Africa, Oceani,a and several Latin-American economies, displays the lowest composite depth and contains few forest-specific obligations, confirming the policy gaps highlighted earlier.

Figure 6. Geographical patterns of EDI clusters (top) and thematic specialization (bottom).



Author's elaboration.

The lower panel assigns each country to the single EDI sub-category occupying the largest share of its provisions, revealing its thematic specialization. Most OECD members, whose agreements are rich in consultation, panel, and sanction procedures, appear as dispute-resolution specialists. Parts of Southeast Asia and the Gulf prioritize implementation and capacity-building measures. Eastern Europe and Central Asia concentrate on broad principles and cooperation language. Genuine forest specialists, countries whose treaties devote an exceptional share of provisions to forest management and illegal-logging commitments, are limited to a handful of tropical exporters in Latin America, West Afric,a and the Pacific.

4.4 Econometrics results

The econometric findings shed light on the determinants of environmental ambition in PTAs and align with both theoretical and empirical expectations. Table 3 indicates that a 10 % increase in the number of PTAs signed by a country corresponds to an approximately 7.14 % rise in the EDI, suggesting that participation in a broader treaty network encourages coalitions in favor of stronger environmental language (Gutsch et al., 2024), corroborating results on forest clauses reported by Abman, Lundberg and Ruta (2024). This relationship finds support in environmental policy feedback theory, which posits that public awareness of ecological decline mobilizes stakeholders and generates political pressure for more stringent regulations (Bastiaens and Postnikov, 2017). Under this framework, existing treaties and enforcement practices shape subsequent policy choices by defining decision-makers' available options (Bastiaens and

Postnikov, 2017). Studies of enforcement further demonstrate that heightened visibility of environmental problems intensifies calls for corrective measures (Wu et al., 2025), reinforcing the view that treaty proliferation and enforcement mechanisms operate together to elevate environmental ambition in trade agreements.

Table 3. Results of EDI determinants.

Variable	Coefficient	Robust standard error
$\ln Agreement_{it}$	0.714 *	(0.382)
$\ln CovesLoss_{it}$	0.189 ***	(0.028)
$\ln Forest_{it}$	–0.658 ***	(0.101)
$\ln GDP_{it}$	-3.706 ***	(0.716)
$(\ln GDP_{it})^2$	0.0687 ***	(0.014)
$\ln FDI\_in_{it}$	–0.147 *	(0.084)
$\ln FDI\_out_{it}$	0.208 ***	(0.054)
$\ln AgriLand_{it}$	0.227 **	(0.081)
$\ln AgrExportGDP_{it}$	0.076	(0.102)
$\ln Govern_{it}$	–0.040	(0.099)
$DevDummy_i$	–0.863 ***	(0.222)
$Constant$	57.95 ***	(9.15)
Obs.	918	
R^2	0.258	

Author's elaboration. Notes: Driscoll–Kraay standard errors; ***, **, * denote significance at 1 %, 5 %, 10 % respectively; year fixed effects included.

The coefficient on forest-cover loss (0.189) indicates that a 10% increase in annual deforestation raises the EDI by 1.89%. However, this result may reflect the intensification of international scrutiny on high-deforestation countries rather than a direct amendment of treaty language in response to observable degradation. Agreements that include specific forest or biodiversity provisions also mitigate the post-agreement rise in forest loss seen in treaties without such clauses, with the largest effects in tropical, biodiversity-rich economies (Abman et al., 2024; Gutsch et al., 2024). This pattern underscores the significance of the agricultural land variable (coefficient 0.227), since larger agricultural sectors face greater institutional and public pressure to include environmental safeguards, reflecting the structural link between agricultural expansion and deforestation risk. Once actual forest loss is accounted for, however, the coefficient for agricultural export orientation loses statistical significance, suggesting that tangible environmental impacts rather than export dependence drive environmental ambition in PTAs.

This suggests that it is not the economic importance of agricultural exports per se that drives environmental commitments, but rather the tangible environmental consequences of land-use change. In essence, the model can indicate that policymakers prioritize addressing actual deforestation over preempting potential land-use pressures based solely on economic structure. The significance of agricultural land area captures the underlying deforestation potential, while the non-significance of export orientation suggests that trade specialization alone is insufficient to predict environmental ambition without considering realized environmental impacts.

Extending the environmental context, the model next considers forest endowment, which exhibits a negative coefficient: a country with 60% more standing forest, on average, scores 8% lower on the EDI. This finding concurs with Grigoras (2024), who argues that abundant natural resources can foster complacency and reduce political urgency for explicit international commitments. Together with the positive elasticity for forest-cover loss, these estimates reflect two facets of forest pressure. Forest-cover loss, a flow indicator, rises with ongoing clearing and prompts governments to tighten treaty provisions. Forest area, a stock indicator, measures remaining forest, and its negative elasticity suggests that extensive existing forest diminishes the impetus to codify ambitious safeguards. In essence, surging deforestation strengthens clauses, whereas the plentiful standing forest eases perceptions of immediate risk and yields more modest commitments.

Evidence of an environmental-Kuznets dynamic emerges from the GDP coefficients. The log of GDP carries a negative coefficient (-3.706) while its squared term is positive (0.0687), yielding an inverted-U shape. In the initial phase of growth, rising GDP corresponds to a lower EDI, implying that countries may prioritize economic expansion over environmental protection in their trade agreements. Beyond a turning point, derived from $-\beta_1/(2\beta_2) = -(-3.706)/(2 \times 0.0687)$ (Grossman & Krueger, 1995) for the point where the slope changes sign yields ln GDP ≈ 26.99; exponentiating, this corresponds to roughly US$ 5.3 × 10^{11} in current-price terms, approximately the nominal output of countries like the Netherlands or Belgium in recent years. Below that threshold, additional economic expansion is linked to a lower EDI, whereas beyond it further growth is associated with deeper forest-related commitments in trade agreements.

Outward foreign direct investment (FDI) exhibits a positive elasticity of 0.208, whereas inward FDI carries a negative coefficient of -0.147. This divergence reflects the different incentives facing capital-exporting and capital-importing countries. Capital exporters, which tend to be more developed economies, see their multinational firms subjected to increasing oversight of environmental practices abroad. These countries, therefore, have stronger incentives to include robust environmental provisions in trade agreements, both to protect their firms' reputations and to ensure a level playing field in overseas markets. In contrast, nations that receive inward FDI may hesitate to impose stringent environmental conditions for fear of deterring investors, particularly in competition with other investment destinations. This asymmetry aligns with export-greening studies by Brandi et al. (2020), which show that reputational exposure along global value chains leads capital exporters to demand clearer forest safeguards while capital recipients often prioritize attracting investment over environmental stringency. This pattern also resonates with the pollution-haven hypothesis, under which countries with laxer environmental regulations attract investment seeking lower compliance costs (Copeland and Taylor, 2004).

The development dummy carries a negative coefficient (-0.863), indicating that, on average, developing countries have lower EDI scores. Although descriptive analysis identifies a handful of emerging economies with high environmental ambition in their trade agreements, the regression results show that these cases are exceptions rather than the norm. Controlling for forest loss, economic scale and trade engagement, developed countries consistently uphold higher environmental standards in their PTAs than do their developing counterparts.

Governance quality, measured by regulatory quality, yields a small non-significant negative coefficient (–0.040), suggesting that specific political and economic incentives matter more for the inclusion of environmental provisions than overall institutional capacity.

5. Final remarks

This study demonstrates that the EDI provides a reliable measure of environmental ambition in PTAs, especially in detecting forest-related commitments. Three main findings support this conclusion. First, empirical validity: in a 2000–2021 panel, a 10% increase in annual tree-cover loss corresponds to a 1.9 % rise in the EDI, confirming that governments tighten treaty language when deforestation becomes visible rather than merely issuing generic green rhetoric. Second, methodological robustness: despite eleven diverse weighting schemes, country rankings remain highly consistent, and the index's penalty for missing forest clauses prevents countries from masking weak coverage behind extensive lists of general provisions. Third, discriminatory power: once forest-specific clauses receive extra weight, Latin America and the Caribbean surpass Europe and North America in average EDI scores, a distinction that raw provision counts fail to capture.

Forest-specific clauses appear in only 23 percent of PTAs, but the EDI captures their leverage by heavily weighting Category 1 and penalizing omissions. The results suggest some policy implications. First, policymakers can view specific provisions on illegal logging, sustainable management, and cooperation clauses as a tool for anchoring forest commitments in PTAs. Second, the strong positive response of the EDI to outward FDI indicates that capital-exporting economies are receptive to reputational incentives. Markets such as the EU and the United Kingdom can build on this dynamic by conditioning market access on credible forest commitments, complementing unilateral due diligence regulations. Third, the income turning point in the environmental Kuznets curve highlights middle-income partners as key actors; forest clauses adopted today can shape the land-use trajectories of emerging economies. Development banks and climate finance bodies could use the EDI to screen proposed trade agreements, directing support toward those that meet the required depth.

Nevertheless, limitations persist. The EDI relies entirely on the DESTA database, which records only the presence of predefined phrases rather than enforcement or implementation. Consequently, the index captures ambition written in the text, not actual compliance or outcomes. To address this, future research should combine the EDI with compliance data from arbitration panels, implementation reports, or satellite-based measures of illegal logging to assess how textual depth translates into behavioral change. Additionally, DESTA's coverage ends in 2022 and excludes recent digital and investment treaties that could contain environmental chapters. Finally, because the index focuses on forest provisions, extending the framework to marine biodiversity, climate mitigation, or plastics would reveal whether similar patterns hold across other environmental domains.

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