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Systemic Shocks and Topological Reconfiguration in Complex Trade Networks: Evidence from ASEAN–EU Free Trade Agreements

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Highlights

Please indicate how your work links to systems science via your contributions to systems practice, theory, and/or methodology.

- We combine PageRank and difference-in-differences to track the prominence of individual export links in goods and services networks.
- Separate supply, demand, and brokerage measures identify prominent buyers, sellers, and countries that connect otherwise weakly linked partners.

What are the main findings and/or the implications of the main findings?

- Covered links gained prominence after FTA entry. The association was positive and significant for EU exports to ASEAN.
- Link prominence increased for both intermediate and consumer goods. Their estimated increases did not differ significantly.

Abstract

Trade between ASEAN and the EU accounted for 7.9% of goods trade recorded in their network in 2010 and 13.1% in 2023. As cross-regional trade expanded, which export relationships gained prominence? We construct annual goods and services networks for 2010–2024 and allocate each exporter's PageRank across destinations according to their shares of its exports within the network. Using a staggered difference-in-differences design, we examine how the prominence of covered links changed around the entry into force of the EU's free trade agreements (FTAs) with Singapore and Viet Nam. In the baseline sample of 10,132 observations, FTA entry was associated with a 0.14-standard-deviation increase in the directed PageRank edge score. The association was positive and statistically significant for exports from the EU to ASEAN. Estimates were also positive for both intermediate goods and consumer goods, extending the finding to production inputs and final goods. We examine how trade composition, institutional distance, and exporters' network positions relate to these changes. Tracking the network weight carried by each export relationship complements measures of regional integration based on trade volumes.

Keywords: complex trade networks; bilateral free trade agreements; directed PageRank edge score; multi-period difference-in-differences

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Academic Editor: Maurice Yolles

Received: 3 October 2026
Revised: 5 November 2026
Accepted: 13 November 2026
Published: 18 November 2026

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1. Introduction

Research on trade agreements has linked a country's position in the network of agreements to domestic value added in exports [1] and to economic complexity [2]. We ask what happens to an individual export link when a free trade agreement (FTA) enters into force. Does the covered link gain weight in the wider trade network, and does the association differ between goods and services? To answer these questions, we use PageRank [3] to measure each country's prominence and allocate its score across destinations according to their shares of its exports.

Trade between the Association of Southeast Asian Nations (ASEAN) and the European Union (EU) spans economies with different levels of development, industrial capabilities, and trading relationships. In 2024, merchandise trade between the two blocs reached USD 292.8 billion, making the EU ASEAN's third-largest trading partner [4]. Members of the same bloc also play different roles. Singapore is a major trade and services hub, while manufacturing figures prominently in Viet Nam's trade. A regional total can conceal which export links gained weight, in which trade layer and in which direction.

The agreements cover only part of this regional network. After region-to-region negotiations were suspended in 2009, the EU pursued bilateral agreements with individual ASEAN members [5]. The EU–Singapore FTA entered into force in November 2019 and the EU–Viet Nam FTA in August 2020 [6,7]. These dates allow us to trace changes around legal entry for partners with different initial trade structures. Because the score of each link depends partly on trade elsewhere in the network, the surrounding links also matter when interpreting changes on covered links.

We construct annual directed, weighted goods and services networks covering up to 38 ASEAN and European economies from 2010 to 2024. For each ordered country pair, we calculate a PageRank edge score and examine its association with FTA entry in a staggered difference-in-differences design. The unit of analysis is therefore an export link in a given year and trade layer. Sections 2 and 3 review the literature and develop the hypotheses. Section 4 describes the data and methods, Section 5 reports the results, and Sections 6 and 7 discuss the findings and their implications.

2. Literature Review

2.1. Network Position and Trade Network Reconfiguration

Bilateral trade values enter a network through individual links, but a country's position also depends on how those links fit together. Borgatti and Everett [8] formalize discrete and continuous core–periphery models that characterize the position of individual nodes. Using weighted trade networks, Fagiolo et al. document persistent asymmetries in both connectivity and the strength of links [9]. Countries with similar trade volumes can occupy different positions in the trading system.

Smith and Sarabi find that trade links form differently in core and peripheral economies [10]. In the ASEAN–EU setting, a related question concerns existing links. When policy improves access to a partner market, does the link to that destination become more prominent relative to the exporter's other links?

Burt's structural-hole theory explains why the pattern of an exporter's other connections may matter. A country that connects otherwise weakly connected partners may obtain information or exercise influence through its brokerage position [11]. Effective size and constraint describe the extent to which the country's contacts are redundant or concentrated among interconnected partners. We use these country-level measures to characterize the exporter's network environment and a directed PageRank edge score to measure the prominence of each export relationship. Economic autonomy would require separate evidence.

2.2. Institutional Integration and the Reorganization of Trade Links

An agreement changes market access within a trading system that already contains other agreements. Sopranzetti finds stronger bilateral trade effects when a new agreement increases network centrality or reduces constraint in the existing FTA network [12]. This finding motivates examining a covered trade link in relation to the other destinations available to its exporter.

In structural gravity models, bilateral trade depends on economic size and on the cost of reaching a partner relative to alternative markets [13]. Baier and Bergstrand show that accounting for countries' selection into agreements changes estimates of their trade effects [14]. Agreement content also matters. Mattoo et al. find greater trade creation and less trade diversion under deep agreements than under shallow ones [15]. For services, Guillin et al. find that the association with trade depends on agreement depth and institutional conditions [16]. In our analysis, the destination's share of the exporter's sales connects these changes in relative market access to the weight of a particular link.

Maggi and Ossa show that incentives for regulatory cooperation depend on the interests of producers in the partner countries [17]. An agreement gives goods and services a common legal entry date, but its sectoral commitments and the timing of firms' responses can differ.

2.3. Distributional Consequences of Trade Agreements

Caliendo and Parro show that sectoral specialization and input–output linkages matter when quantifying the trade and welfare effects of tariff changes [18]. This distinction motivates our separate treatment of final goods and production inputs. For each product group, we measure how much network weight an export relationship carries. Quantifying the welfare consequences of a tariff change requires additional information.

Prebisch places international specialization in a center–periphery framework in his analysis of Latin American development [19]. Wallerstein emphasizes the historical division of labor in the world economy [20]. Both perspectives motivate an examination of uneven network positions. Economies such as Singapore and Viet Nam illustrate why assigning a single role to an entire bloc can obscure that variation. Directed links allow us to compare trade relationships both within and across the two regions.

These distinctions guide our comparisons within the ASEAN–EU system. Separating exports from the EU to ASEAN from exports in the opposite direction reveals which bloc is the source of the links that gain weight. Comparing goods with services, and final consumer goods with intermediate inputs, allows us to see whether the patterns differ across markets and stages of production.

2.4. Research Gap and Theoretical Contribution

Existing research establishes that network hierarchy, institutional cooperation and sectoral specialization matter for trade. Less is known about how the entry into force of an FTA relates to the weight of an individual export link in the ASEAN–EU system. We address this question in three ways.

First, we compare changes in trade links relative to the rest of the goods or services network. An exporter's sales to a destination can rise while that destination's share falls if sales to other markets grow faster. The edge score captures this distinction and also reflects the exporter's own network position. We examine its association with agreement entry under the DID specification and assess its sensitivity to alternative specifications.

Second, we examine whether trade composition and bilateral institutional distance change around entry. We also test whether the association between entry and link prominence varies with the constraint and effective size of the exporter's network.

Third, we compare the estimates across goods and services, exporter groups and product categories. These comparisons identify where changes in link prominence are concentrated within the ASEAN–EU system. Assessing technological autonomy or domestic value creation would require direct measures of those outcomes.

3. Theoretical Analysis and Research Hypotheses

3.1. Direct Effects of Cross-Regional FTAs on Directed Trade-Link PageRank

In the gravity framework, bilateral trade depends on economic size and trade costs, including the costs of crossing a policy border [13]. An FTA can reduce tariffs and simplify regulatory or administrative procedures. If selling to a covered partner becomes less costly relative to selling elsewhere, that partner may receive a larger share of the exporter's sales. The resulting change in link prominence also depends on other connections in the network and on the balance between trade creation and diversion [14,15]. Comparative advantage and factor endowments help determine which industries can expand when access improves. In services, where regulatory barriers can be substantial, commitments that ease entry may be especially important [16]. These arguments motivate the following predictions.

H1a. *Entry into force of a cross-regional FTA is associated with a higher PageRank edge score for directed trade links between the contracting countries.*

H1b. *The positive association between cross-regional FTA entry and the directed PageRank edge score is stronger in services trade than in goods trade.*

3.2. Economic Channels Linking FTAs to the Prominence of Directed Trade Links

3.2.1. Import Reallocation and Export Specialization

A preferential trade agreement changes the relative cost of buying from covered and alternative suppliers [13,15]. Whether the importing country's product mix changes depends on which products receive meaningful preferences and which the partner can supply competitively. An importer might switch its machinery purchases to the agreement partner yet spend the same share of its budget on machinery. The bilateral link could then gain weight even if the national import basket were unchanged. If spending also shifts across products, the basket changes. The import diversification index measures the distance between national and world import shares by product [21]. Shifting expenditure toward products already overrepresented in the national basket can widen that distance, whereas shifting it toward underrepresented products can narrow it.

H2a. *Following cross-regional FTA entry, the destination country's import composition is expected to shift relative to the world import basket as changes in market access differ across products.*

On the export side, a preference gives established producers a reason to expand sales of products in which they already have a cost advantage. Differences in productivity and factor endowments help determine those advantages. Firms can draw on existing capacity, distribution channels, and expertise without incurring all the fixed costs of launching a new product. Mayer et al. show that competition in a destination market can shift a multiproduct exporter's sales toward its best-performing products [22]. Entry by new products can broaden the national export basket, while faster growth in established products can concentrate it. We expect concentration to increase when a disproportionate share of additional sales accrues to products that already account for a substantial share of exports.

Although market access changes for a particular destination, the prediction concerns the source country's total export basket.

H2b. *Cross-regional FTA entry is expected to be associated with greater concentration in the source country's export basket as additional sales accrue disproportionately to products in which it already specializes.*

3.2.2. Regulatory Cooperation and Institutional Distance

Firms often invest in a foreign market before they earn revenue there. They may adapt a product, obtain certification, or establish a distribution relationship. Uncertainty about how the partner applies its rules lowers the expected return on these investments. Published procedures and regular consultation between regulators can make compliance more predictable and encourage firms to maintain a trading relationship. The scope for such cooperation depends in part on whether producers and regulators on the two sides have compatible interests [17].

A change in one administrative procedure can lower compliance costs for the transactions it covers. Broader convergence would require the agencies implementing an agreement to coordinate repeatedly and to extend those practices beyond individual transactions. Where this occurs, firms may face increasingly similar operating conditions in the two markets. We examine that possibility using bilateral differences across six Worldwide Governance Indicators [23]. Because these indicators describe broad governance conditions, sustained domestic administrative adjustment is more likely to register in the index than a change affecting only one tariff line or procedure.

H2c. *Measured institutional distance is expected to fall more after FTA entry for covered country pairs than for comparison pairs.*

3.3. How the Exporter's Network Position Conditions Adjustment

Exporters receiving similar trade preferences may differ in their ability or incentive to redirect sales. Drawing on Burt's structural-hole framework [11], we measure each source country's network constraint and effective size separately by year and trade layer. We use these measures to examine whether the exporter's existing relationships condition the association between FTA entry and the weight of a particular link.

Network constraint is high when an exporter relies heavily on a group of partners that also trade with one another. Such partners may provide overlapping market information, inputs, and distribution channels. If entering a newly accessible market requires different suppliers or new commercial contacts, an exporter with few independent connections may have less scope to adapt. We would then expect a smaller gain in the covered link's prominence.

H3a. *Within a trade layer, the positive association between cross-regional FTA entry and the PageRank edge score is expected to weaken as the source country's network constraint increases.*

Effective size measures the breadth of an exporter's nonredundant contacts. These contacts can provide information and complementary inputs that help firms serve an FTA partner. They can also give firms attractive alternative markets, reducing the incentive to direct additional sales to any one destination. The second consideration matters for an outcome that depends on a particular destination's share of exports. If the availability of

alternative markets dominates, exporters with fewer nonredundant contacts may redirect a larger share of sales to the newly accessible partner.

H3b. *Within a trade layer, the positive association between cross-regional FTA entry and the PageRank edge score is expected to weaken as the effective size of the source country's network increases.*

3.4. Consumer Goods and Intermediate Inputs

For final consumer goods, importers choose among finished products on the basis of delivered prices and product characteristics. A tariff preference that lowers the price of a competitive product can prompt distributors to increase purchases from the covered supplier when orders are renewed. If the destination comes to account for a larger share of the supplier country's sales, the link can gain weight in the consumer-goods network. This reasoning applies in either trade direction.

H4a. *After a cross-regional FTA enters into force, covered export links are expected to gain PageRank weight in the pure consumer-goods network relative to comparison links.*

For intermediate goods, purchasing decisions also depend on how an input fits the buyer's production process. A component may need to meet technical specifications, pass qualification tests, or work with equipment already installed. These requirements can slow a switch to a new supplier. At the same time, lower prices for an approved input can increase its use across several downstream industries. Production linkages can therefore amplify a tariff preference even when switching suppliers is costly [18]. The two forces motivate a comparison with consumer goods without implying that either group must always respond more strongly.

H4b. *For the same directed country-pair observations, the change in PageRank edge weight associated with FTA entry is expected to differ between the intermediate-goods and pure consumer-goods networks.*

Figure 1 brings these hypotheses together. It shows how agreement entry may relate to directed-link prominence through changes in trade composition and institutional distance, and how the exporter's network position may condition that association.

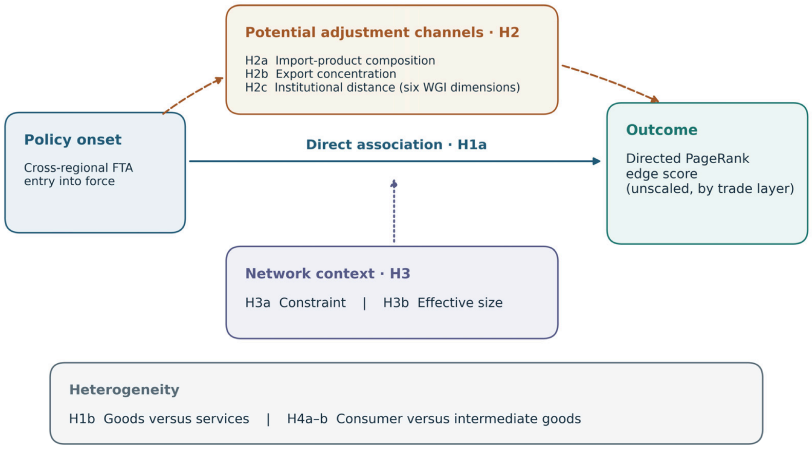


Figure 1. Conceptual pathways and hypotheses. Dashed arrows represent proposed adjustment channels.

4. Materials and Methods

This section specifies the regressions, describes how we construct the annual networks, and defines the variables used to test the hypotheses. Table A1 in Appendix A defines the network measures. Supplementary File S1 provides enlarged goods and services network figures. Supplementary File S2 documents data processing, diagnostic tests, and sensitivity analyses.

4.1. Econometric Model Specification

We estimate the association between FTA entry and the PageRank edge score of a directed trade link using the multi-period DID model in Equation (1), estimated in Stata/MP 18.0.

$$Y_{ij\ell t} = \alpha + \beta D_{ijt} + \gamma' X_{ij\ell t} + \mu_{ij\ell} + \lambda_t + \varepsilon_{ij\ell t} \quad (1)$$

The indices i and j denote the exporter and importer, ℓ denotes the goods or services layer, and t denotes the calendar year. Y is the PageRank edge score, D is the FTA indicator, and X contains the five controls. We absorb fixed effects for each directed country-pair–layer combination and each year. With staggered entry, the two-way fixed-effects coefficient combines comparisons across groups and periods [24]. We interpret β as a pooled conditional association and report heteroskedasticity-robust standard errors.

We use an event study to examine differences before entry and to trace how the association changes over time.

$$Y_{ij\ell t} = \alpha + \sum_{k=-7, k\neq -1}^{5} \beta_k E_{ij\ell t}^{(k)} + \gamma' X_{ij\ell t} + \mu_{ij\ell} + \lambda_t + \varepsilon_{ij\ell t} \quad (2)$$

Equation (2) uses the event_time variable stored in the panel. For treated links, index 0 denotes the year before legal entry, +1 the entry year, and −1 the omitted reference period. The first bin pools indices ≤ -7 and the last pools indices $\geq +5$. The supplied program includes the event indicators, five controls, directed pair-layer and year fixed effects, and heteroskedasticity-robust standard errors. Supplementary File S2 separately examines dependence among links that share a country [25].

4.2. Variable Definitions

We represent trade in year t as a directed weighted graph $G_t = (V, E_t, W_t)$, where $W_t = [w_{ijt}]$ is the matrix of export values. $w_{ijt} \geq 0$ denotes the recorded export flow from source i to destination j, and self-links are excluded ($w_{iit} = 0$). We omit the trade-layer index when referring to a single layer.

4.2.1. Variable Measure

We use PageRank [3] to construct the directed link score and structural-hole measures to describe the exporting country's partners. For institutional distance (KAS), we apply a standardized distance formula to governance data from the Worldwide Governance Indicators (WGI).

1. Trade Network Construction

We construct separate annual trade networks for goods and services over 2010–2024. Countries are nodes. A directed edge from country i to country j represents exports from i to j. Its weight is the bilateral export value. Each annual network includes the countries in that year's sample and retains trade both within and between the two regions.

We use Python 3.12.14 to process the bilateral matrices, calculate network indicators, and draw the figures. NetworkX 3.5 provides an independent check on selected measures [26,27]. For visual comparisons across 2010–2024, we use the same 37 countries in

every year. For the regressions, we calculate scores using the countries in each original annual matrix. Supplementary File S1 gives further details on network construction and visualization.

2. Dependent Variable

Directed PageRank Edge Score (PageRank). We first calculate each country's node PageRank [3]. We then allocate the exporter's score across destinations according to their shares of its available exports. Equations (3)–(5) give the calculation for each observed or interpolated directed link. Reversing the direction generally changes both the exporter's score and the relevant trade share.

Step 1. For an exporter with positive available exports, the transition probability to destination j is that destination's share of the exporter's total available exports in layer ℓ and year t. If the row has no positive available exports, the random walk assigns a uniform probability of $1/N_t$ to each node. This convention applies to the node calculation. A missing trade flow still has no observed edge score.

$$P_{ij\ell t} = \frac{w_{ij\ell t}}{\sum_{k\neq i} w_{ik\ell t}}, \sum_{k\neq i} w_{ik\ell t} > 0 \tag{3}$$

Step 2. Node PageRank is the stationary distribution of the weighted transition matrix with teleportation. We use a damping parameter of $d = 0.85$ and stop the power iteration when the L_1 change falls below 10^{-14}. N_t is the number of nodes in the annual network used to calculate the regression outcome.

$$\pi_{j\ell t} = \frac{1-d}{N_t} + d\sum_{i} \pi_{i\ell t} P_{ij\ell t} \tag{4}$$

Step 3. Equation (5) gives the raw edge score. It is the portion of the exporter's node PageRank allocated to a particular destination by its share of exports.

$$g_{ij\ell t}{}^{0} = \pi_{i\ell t} P_{ij\ell t} \tag{5}$$

We treat off-diagonal zeros and blanks as missing. For the same directed link and trade layer, we fill a one-year gap with the mean of the immediately preceding and following years' flows only if both are observed and positive. Of 16,440 records, 9987 have observed flows, and 150 qualify for interpolation. The remaining 6303 have no edge score. We apply the archived rounding rule and winsorize scores at the pooled 1st and 99th percentiles. Of the 10,137 observations with a score, five are the only observations in their pair-layer groups. Removing these singletons leaves 10,132 observations in the baseline regression.

3. Core Explanatory Variable

Bilateral Free Trade Agreement (FTA). The treatment indicator records the start of legal coverage under either the EU–Singapore or the EU–Viet Nam agreement. We pool the two agreements to estimate the association between entry and directed-link prominence over the observed implementation period. Equation (6) defines the indicator for country pair (i, j).

$$D_{ijt} = 1_{\{t\geq T_{ij}\}} \tag{6}$$

Here, T_{ij} denotes the entry year of the relevant EU–ASEAN agreement. For pairs without an agreement in force during the sample period, T_{ij} is set to infinity. Covered links take the value 1 from 2019 for the EU–Singapore FTA (in force on 21 November 2019) and from 2020 for the EU–Viet Nam FTA (in force on 1 August 2020). The annual indicator gives the same value to a partial entry year and a subsequent full year. Agreements that have been signed but have yet to enter into force are coded 0. Table A2 in Appendix A documents the coverage and distinguishes legal entry from phased implementation [6,7].

We exclude intra-ASEAN and intra-EU agreements from the treatment indicator because the research question concerns agreements between the two regions. Trade within each region still contributes to the network scores. The annual networks and regression panel include the United Kingdom in 2010–2019 and exclude it from 2020 onward. For comparison across years, Figures 2–7 use the 37 countries present throughout 2010–2024.

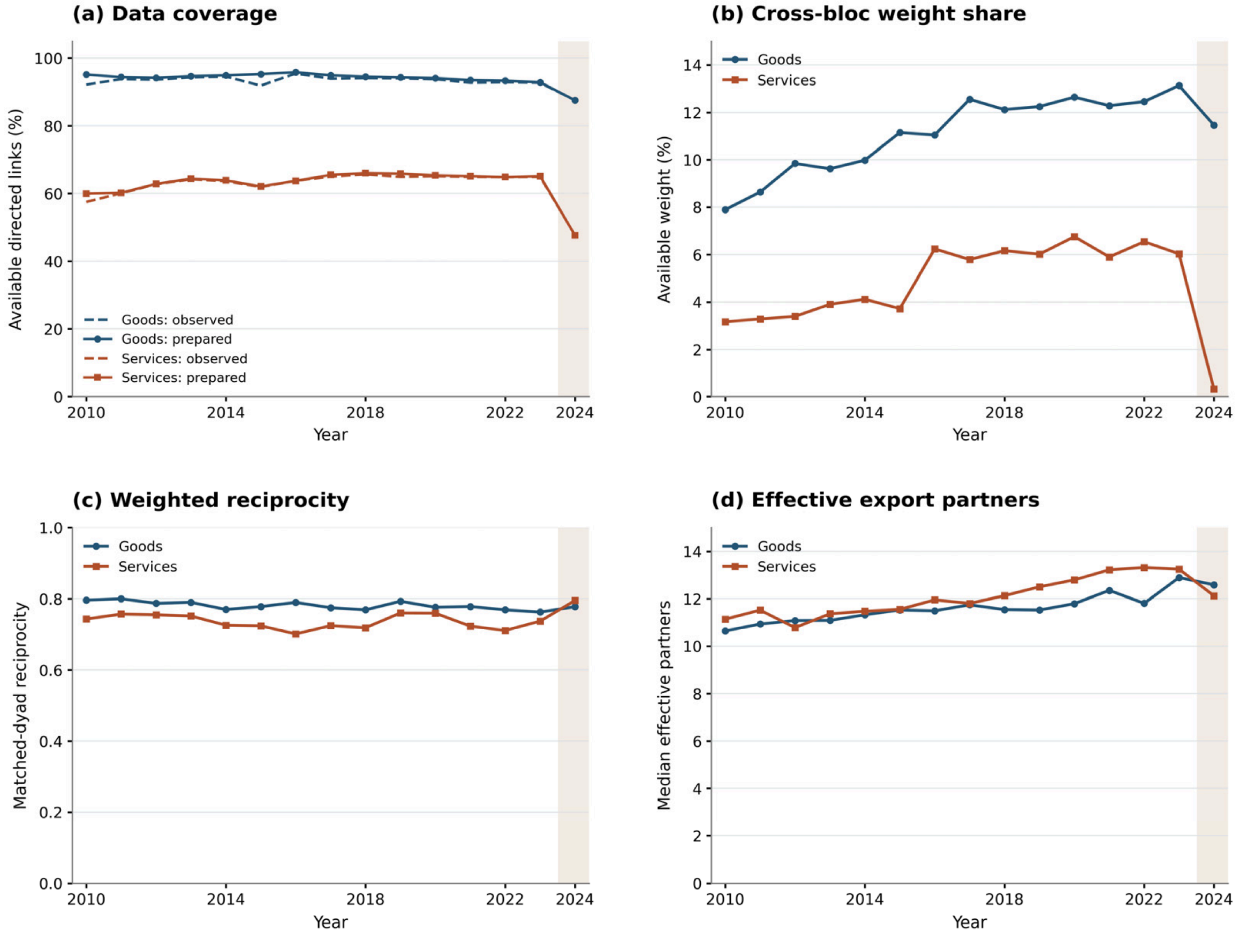


Figure 2. Coverage and weighted connectivity of the goods and services networks. The shaded band marks 2024, when services data coverage fell.

The agreements differ in their timing and content. Their goods schedules include immediate and phased tariff reductions, and their services commitments vary by sector and reservation [6,7]. We document these differences but code only the start of legal coverage. The event study traces changes over time without assigning them to a particular provision. With only two agreements, differences in their terms are also difficult to distinguish from differences between Singapore and Viet Nam.

4. Mechanism Variables

Product concentration (H). We use UNCTAD's normalized product-concentration index [21]. For country c, year t, and trade direction f, x_{pct} is product p's trade value, X_{ct} is total trade, and N is the number of products. Equation (7) gives the normalized index.

$$H_{ct} = \frac{\sqrt{\sum_{p=1}^{N}\left(\frac{x_{pct}}{X_{ct}}\right)^2} - \sqrt{\frac{1}{N}}}{1 - \sqrt{\frac{1}{N}}} \quad (7)$$

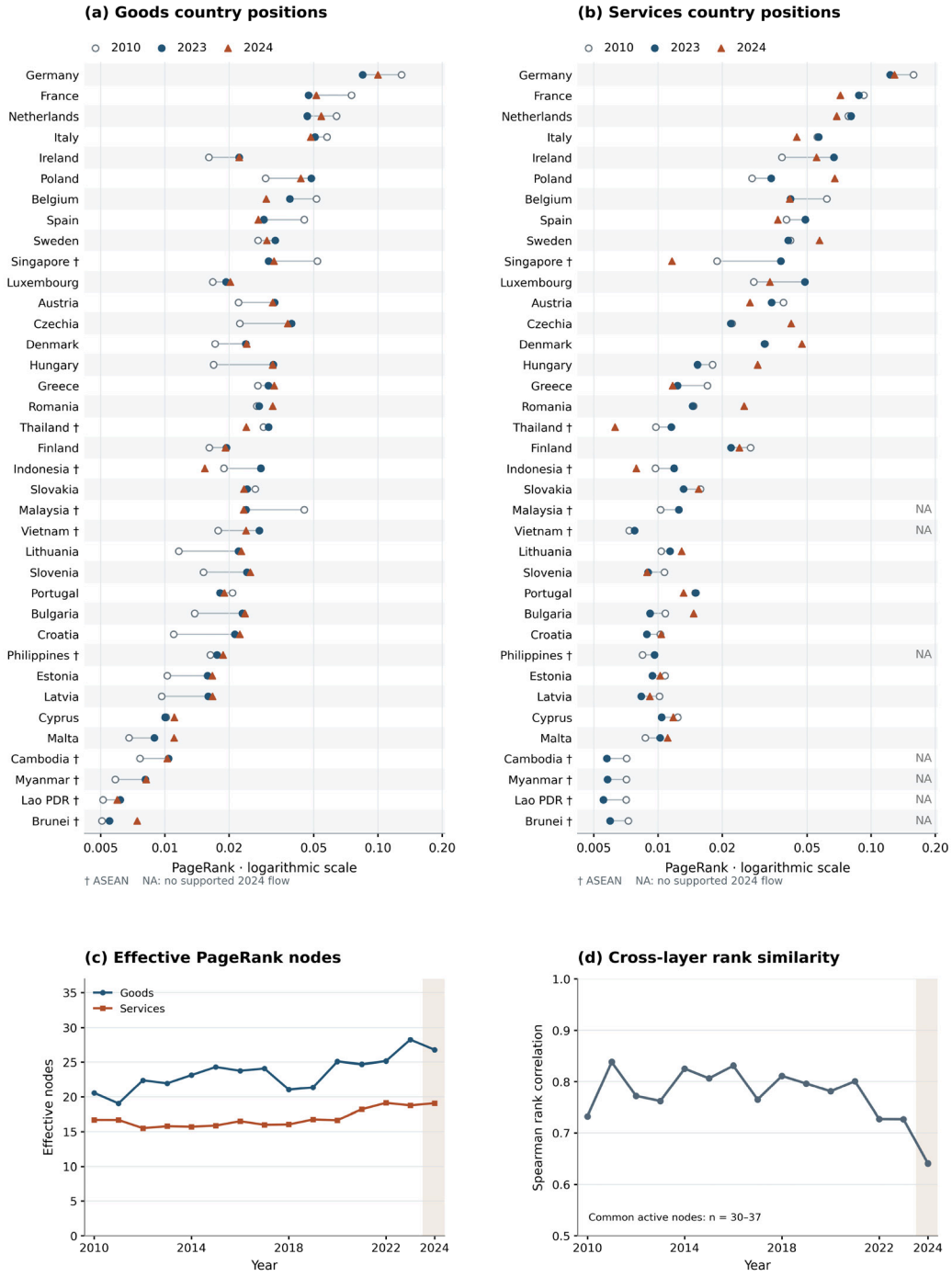


Figure 3. Country prominence and its evolution. Alternating row shading in (**a**,**b**) separates countries. The shaded band in (**c**,**d**) marks 2024.

We use the same definition separately for the export and import baskets. A higher value means that a larger share of trade is concentrated in fewer products.

Product diversification index (DIV). Following UNCTAD [21], Equation (8) takes half the sum of the absolute differences between a country's product shares and the corresponding world shares. A higher value means that the country's product mix differs more from the world mix. The number of products or partners can remain unchanged.

$$\mathrm{DIV}_{ct} = \frac{\sum_{p} \left| h_{pct} - h_{pt} \right|}{2} \tag{8}$$

Here, h_{pct} is the product's share in country c, and h_{pt} is its world share for the same year and trade direction. The measure ranges from zero to one.

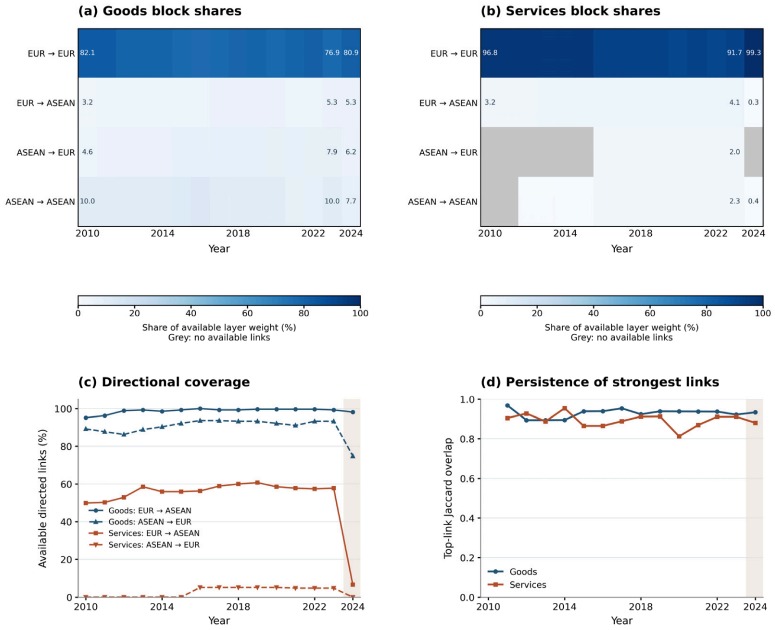


Figure 4. Regional structure and persistence of trade links. Gray cells in (**a**,**b**) indicate that no links were observed for that bloc pair and year. The shaded band in (**c**,**d**) marks 2024.



Figure 5. Comparable snapshots of goods and services network topology. Arrows point from exporters to importers.

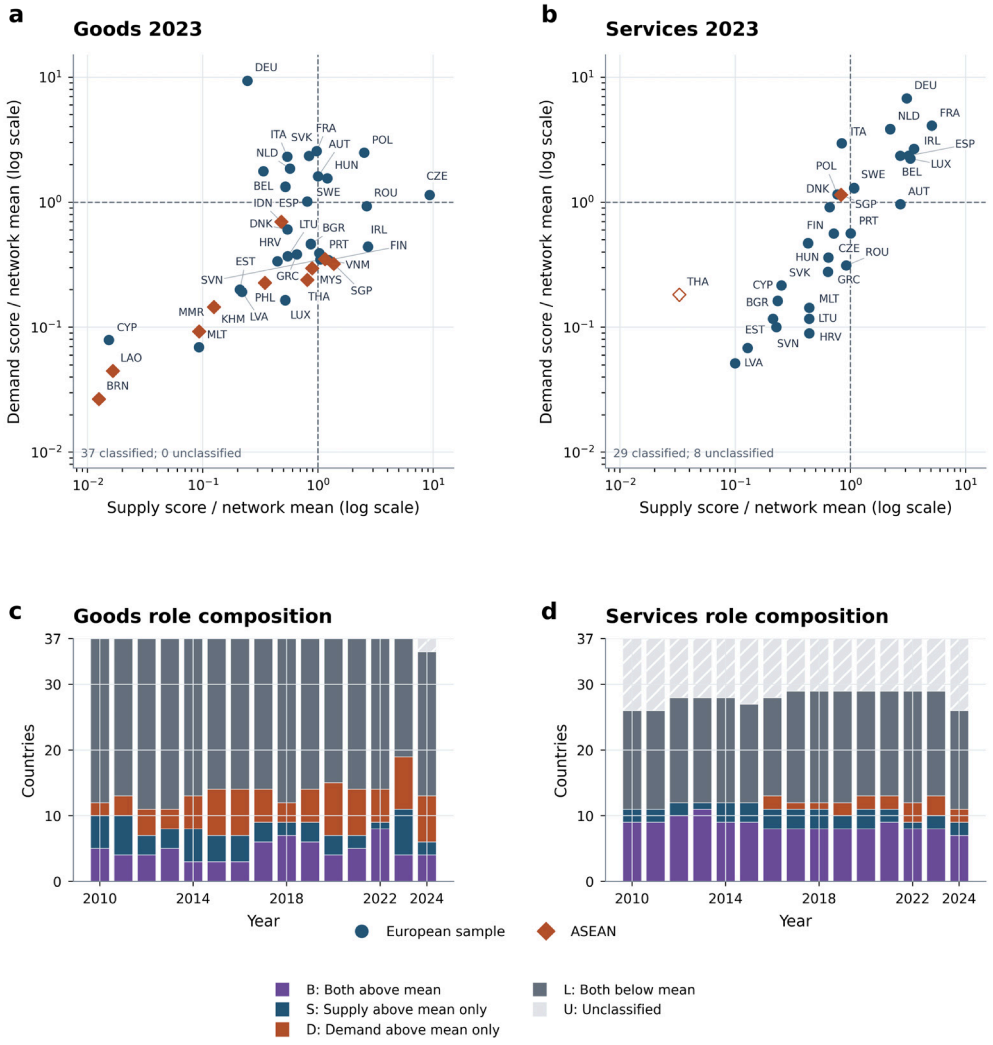


Figure 6. Country supply and demand roles in the observed networks. Supplementary Figures S19 and S20 show the goods and services panels separately. The country-role tables in Supplementary File S1 list the scores for each country. In panel (**b**), a hollow marker indicates that export or import data were available for fewer than half of a country's possible partners in the network in at least one of the two trade directions.

Institutional Distance Index (KAS). We adapt Kogut and Singh's standardized distance formula [28] to the six dimensions of the World Bank's Worldwide Governance Indicators (WGI) [23]. I_{kit} and I_{kjt} are the source- and destination-country scores on dimension k in year t. The denominator ${s_{kt}}^2$ is the variance for that dimension and year across the same 38 economies, computed with the sample denominator $n - 1$. Equation (9) averages the six standardized squared differences.

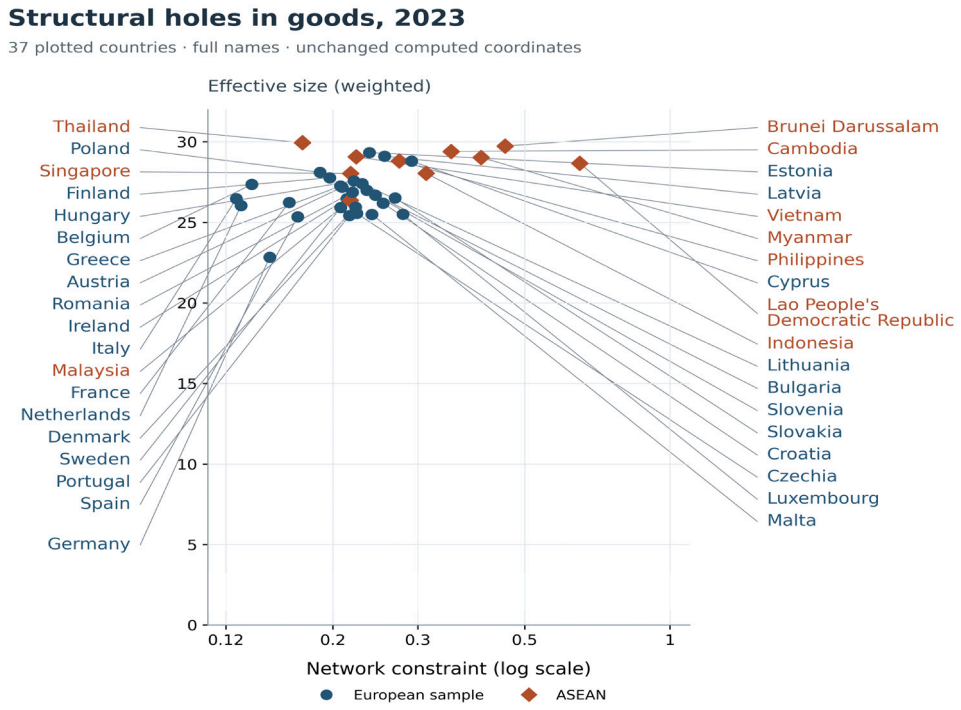
$$\mathrm{KAS}_{ijt} = \frac{1}{6}\sum_{k=1}^{6} \frac{\left(I_{kit} - I_{kjt}\right)^2}{{s_{kt}}^2} \tag{9}$$

The six dimensions are voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption. A higher KAS indicates a wider measured governance gap between the two countries.

Network Constraint (STR). Following Burt [11], we first sum trade in the two directions to obtain the symmetric tie strength $s_{ij} = w_{ij} + w_{ji}$ for each country pair. $p_{ij} = s_{ij}/\Sigma_k\, s_{ik}$ gives partner j's share of country i's total tie strength, and N_i is the set of i's supported neighbors. Equation (10) adds the direct and indirect proportions for each partner, squares that total,

and sums across partners. Constraint rises when a country concentrates its ties among partners that are themselves closely connected [27].

$$\mathrm{STR}_{i/t} = \sum_{j \in N_i} \left(p_{ij} + \sum_{k \in N_i} p_{ik} p_{kj} \right)^2 \quad (10)$$



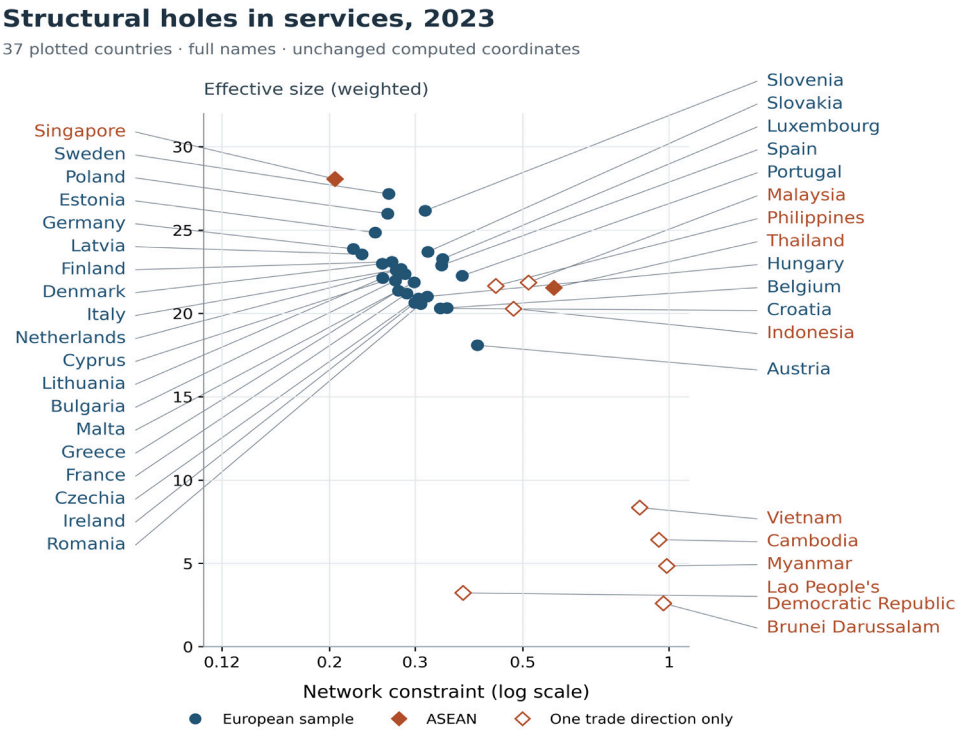


Figure 7. Constraint and effective size in goods and services networks in 2023.

We retain all countries in each annual source matrix when calculating the structural-hole indicators. We apply the stated missing-data rule to directed trade and assign missing values to nodes with no supported ties. We do not cap the constraint at one.

Network Effective Size (EEF). Following Burt [11], Equation (11) counts *i*'s supported neighbors after discounting redundancy [27]. In addition to p_{ij}, $m_{jk} = s_{jk}/\max_h s_{jh}$ expresses the strength of *j*'s tie to *k* relative to *j*'s strongest tie. A larger effective size indicates more nonredundant contacts. Measuring welfare or bargaining power would require separate outcomes.

$$EEF_{i/t} = \sum_{j \in N_i} \left[1 - \sum_{k \in N_i} p_{ik} m_{jk} \right] \quad (11)$$

We calculate both measures for each year and trade layer from the same symmetrized network. We match them to directed observations by exporter, year, and layer. All destinations of the same exporter therefore receive the same exporter-level measure within that year and layer.

5. Control Variables.

We control for five exporter characteristics. Log population (POP) captures the size of the domestic market, and log real GDP per capita (PGDP) captures the level of development. The log of one plus the number of secure Internet servers per million people (INT) measures an aspect of digital infrastructure relevant to cross-border transactions. The real effective exchange rate (EXR) captures changes in price competitiveness, and logistics performance (LOG) reflects the capacity to deliver goods reliably. Both indices enter in levels.

4.2.2. Data Sources and Processing

The 2010–2024 panel contains 16,440 directed country-pair–layer–year records covering up to 38 economies. Of these records, 10,137 have a PageRank edge score. The scores reflect trade within and between the regions, while treatment records only cross-regional agreements. Supplementary File S2 reports the diagnostics and sensitivity analyses.

The goods and services matrices were supplied as UN Comtrade data [29]. For services, the original query and data vintage are unavailable. For the product-specific networks, we use CEPII BACI HS2007 bilateral data, release V202601 [30], and the UN HS2007–BEC concordance [31]. Tracing the prepared product-composition indices and some other inputs back to individual source records requires the original provider extracts. Institutional distance uses the World Bank's six Worldwide Governance Indicators [23]. The World Development Indicators provide the source series for the five baseline controls [32].

4.3. Descriptive Statistics

Table 1 describes the 10,132 observations used in the baseline regression. For each mechanism variable, it reports the observations with a value within that sample. Statistics are rounded to six decimal places. The PageRank edge score is right-skewed, with skewness of 4.59 and Pearson kurtosis of 26.03. Supplementary File S2 (Tables S2.1–S2.3) gives missing counts, quantiles, skewness, Pearson kurtosis, and the Jarque–Bera diagnostic [33].

Table 1. Summary Statistics.

Variable	Symbol	*N*	Mean	Minimum	Maximum	SD
Directed PageRank edge	PageRank	10,132	0.000260	0.000000	0.004718	0.000697
FTA	FTA	10,132	0.078859	0.000000	1.000000	0.269532
Log population	POP	10,132	16.429790	14.089000	18.417500	1.394376
Log GDP per capita	PGDP	10,132	9.577641	7.166460	11.014900	1.167965
Log internet	INT	10,132	7.857232	0.548149	12.267400	2.953465

Table 1. *Cont.*

Variable	Symbol	*N*	Mean	Minimum	Maximum	SD
Exchange rate index	EXR	10,132	98.783019	82.238200	117.772000	8.332623
Logistics performance	LOG	10,132	3.395394	2.477140	4.043110	0.476929
Import product diversification	IM_DIV	9982	0.347304	0.156792	0.607187	0.097924
Import product concentration	IM_CON	9982	0.132354	0.046876	0.560032	0.068546
Export product diversification	EX_DIV	9891	0.500698	0.292415	0.867358	0.139721
Export product concentration	EX_CON	9891	0.169885	0.051688	0.661425	0.107942
Institutional distance	KAS	10,132	3.394777	0.096832	17.796313	2.818049
Network constraint	STR	10,132	0.301153	0.113974	0.815394	0.105541
Effective size	EEF	10,132	26.825547	15.799366	31.506361	2.890829

Note: Statistics use the 10,132-observation baseline estimation sample; mechanism measures use available observations within that sample. IM_DIV and IM_CON refer to destination-country import indices; EX_DIV and EX_CON refer to source-country export indices. Values are rounded to six decimals; the minimum PageRank score is 4.01×10^{-9}.

5. Results

5.1. Evolution of the ASEAN–EU Trade Network

Figures 2–7 show how trade is distributed among partners, which countries are prominent as buyers or sellers, and which connect otherwise weakly linked partners. They cover the 37 economies present throughout 2010–2024. All shares refer to recorded trade within this network. We interpret 2024 separately because services coverage declines sharply that year. Appendix A defines the measures. Supplementary File S1 provides the individual panels and annual services maps.

5.1.1. Partner Diversification and Country Prominence

Figure 2 shows that trade between the two blocs gained weight as exporters spread their sales more evenly across destinations. From 2010 to 2023, the cross-bloc share rose from 7.89% to 13.13% for recorded goods trade and from 3.16% to 6.03% for services. Over the same period, the median effective number of export partners rose from 10.64 to 12.89 in goods and from 11.14 to 13.24 in services. This measure weights partners by their export shares [34]. It can rise when smaller destinations account for more sales, even if the destinations stay the same. Weighted reciprocity declined modestly, meaning that a smaller share of trade was matched by flows in the opposite direction [35]. In services, coverage fell from 65.17% of possible directed links in 2023 to 47.75% in 2024, limiting comparisons with the final year.

Germany ranked first in both trade layers in 2010 and 2023, even as prominence became more widely distributed (Figure 3). Its goods PageRank fell from 0.1289 to 0.0848. The effective number of prominent nodes increased from 20.55 to 28.24 in goods and from 16.69 to 18.76 in services. Singapore moved from fifth to twelfth in goods but from fifteenth to tenth in services, where its PageRank rose from 0.0189 to 0.0377. Because links run from exporter to importer, this increase reflects Singapore's growing prominence as a destination in the recorded services network. Goods and services rankings remained positively correlated in 2023 (Spearman's $\rho = 0.727$).

5.1.2. Regional Composition and Persistence of Trade Links

Between 2010 and 2023, a larger share of recorded goods trade crossed the regional boundary (Figure 4). The intra-European share fell from 82.08% to 76.90%, while ASEAN-to-EU trade rose from 4.64% to 7.88% and EU-to-ASEAN trade from 3.25% to 5.25%. The intra-ASEAN share stayed near 10%. The strongest goods links also persisted. For links observed in both adjacent years, the Jaccard similarity of the two top-decile sets ranged from 0.894 to 0.969. This measure divides the number of links in both sets by the number in either set [36]. The pattern is consistent with firms expanding cross-regional trade while

maintaining established distribution relationships. Services coverage was less even. In 2023, 156 of 270 possible EU-to-ASEAN links were recorded, compared with only 13 in the reverse direction. The recorded service shares therefore offer limited information about the relative size of the two flows.

Figure 5 keeps countries in fixed positions and displays the 40 largest recorded directed flows in each panel. These links accounted for 48.61% of goods-network weight in 2010 and 31.72% in 2023. The two largest goods flows in 2023 were Czechia to Germany and Singapore to Indonesia, both within their respective blocs. France to Singapore was the only cross-bloc goods link among the top 40. Together, Figures 4 and 5 show that 96.4% of recorded cross-bloc goods trade that year was carried by links outside the top 40. Services trade was more concentrated in the displayed links, which carried 46.22% of recorded services weight in 2023. Supplementary File S1 provides the annual services maps.

5.1.3. Supply and Demand Roles and the Scope for Brokerage

Figure 6 uses weighted hub and authority scores to distinguish two roles. A high supply score identifies an exporter serving prominent destinations, while a high demand score identifies a buyer served by prominent suppliers [37,38]. In 2023, Germany's goods demand score was 9.33 times the network mean, and its supply score was below the mean. Poland exceeded both benchmarks in goods, as did Germany in services. Singapore exceeded only the supply benchmark in goods and only the demand benchmark in services. Its services scores lay close to both cutoffs. Eight ASEAN economies could not be classified in services because their outgoing flows were unavailable. The figure shows these economies separately from those with measured scores below both benchmarks.

Figure 7 sums trade in both directions to assess each country's scope for brokerage. Constraint measures dependence on overlapping partner relationships, while effective size discounts contacts that duplicate access to the same partners [11,27]. In the 2023 goods network, Italy had the lowest constraint (0.126), while Thailand had the largest effective size (29.94). In services, Singapore combined the lowest constraint (0.205) with the largest effective size (28.06), although its supply score in Figure 6 was below the network mean. Its observed partner network thus offered potential access to distinct buyers, suppliers, or sources of information. Of Singapore's 35 recorded services partners, 21 had flows observed in only one direction. The subsequent regressions examine whether this partner structure conditions the association between FTA entry and link prominence.

5.2. Baseline Regression Results

Table 2 shows that the estimated association between FTA entry and link prominence changes little when we add the exporter controls. The FTA coefficient falls from 0.000096 to 0.000095, and both estimates are significant at the 1% level on the same 10,132 observations. The adjusted estimate amounts to about 0.14 standard deviations in the directed PageRank edge score. One possible explanation is that lower costs of serving a covered destination encourage exporters to allocate a larger share of sales to it. The score also depends on the exporter's own network prominence, so the estimate captures the change in the weight carried by the link.

Table 2. Benchmark Regression Results of the Difference-in-Differences Model.

Variables	No Controls	Controls
	(1) PageRank	**(2) PageRank**
FTA	0.000096 *** (0.000018)	0.000095 *** (0.000018)

Table 2. *Cont.*

Variables	No Controls	Controls
	(1) PageRank	(2) PageRank
POP		0.000376 ***
		(0.000095)
PGDP		−0.000075 **
		(0.000030)
INT		0.000009 ***
		(0.000002)
EXR		−0.000004 ***
		(0.000001)
LOG		−0.000032 ***
		(0.000012)
Constant	0.000252 ***	−0.004782 ***
	(0.000003)	(0.001609)
Observations	10,132	10,132
R-squared	0.903858	0.904722
Controls	No	Yes
pair-layer FE	Yes	Yes
Year FE	Yes	Yes

Note: Parentheses contain heteroskedasticity-robust standard errors. *** and ** denote significance at the 1% and 5% levels, respectively.

5.3. Parallel Trends

As shown in Figure 8, the event study uses 10,132 observations and the event-time coding described in Section 4.1. Five of the six negative-index estimates have 95% confidence intervals that cross zero. The coefficient at −4 is positive ($p = 0.048070$), and the joint test of the six leads rejects zero ($p = 0.010014$). These earlier differences are compatible with anticipation or with differences in prior trends; the estimates do not distinguish the two. The coefficients at 0 and +1 (the legal entry year) are not individually significant. From +2 through ≥+5, they are positive and significant at the 5% level. The rise in link prominence thus appears with a lag, from the first full calendar year after entry. Table S2.9 in Supplementary File S2 examines how the interpretation changes if the untreated trends would have differed.

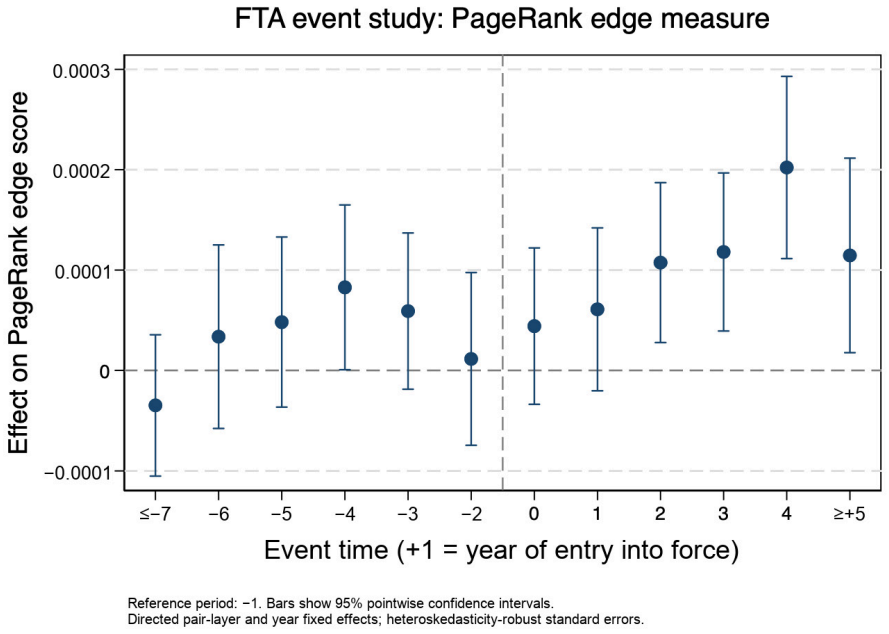


Figure 8. Event-study estimates of the FTA coefficient. The horizontal dashed line marks zero. The vertical dashed line marks the omitted reference period (−1).

5.4. Placebo and Robustness Tests

5.4.1. Placebo Comparison

As shown in Figure 9, the placebo coefficients cluster around zero. None of the 1000 simulated coefficients reached the observed FTA coefficient (0.000095) under the placebo assignment procedure.

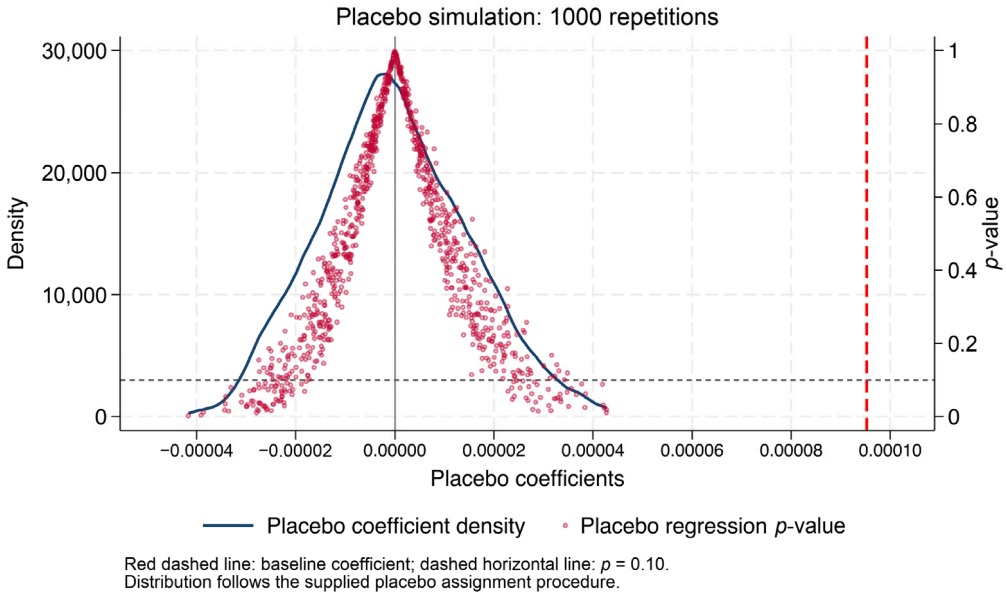


Figure 9. Placebo comparison using 1000 archived simulation results.

5.4.2. Robustness Tests

Table S2.5 in Supplementary File S2 shows how sensitive the result is to extreme scores. On the same 10,132 observations, the FTA coefficient is 0.000095 after winsorization and 0.000115 before winsorization (both $p < 0.0001$). Capping the tails reduces the estimated magnitude, while the association remains positive. The following checks examine how the result varies with sample weighting, model specification, and PageRank construction.

1. Robustness to Sample Weighting, Model Specification, and PageRank Construction

Entropy Balancing. Following Hainmueller [39], we use each directed pair-layer unit's available observations in 2010–2017 to calculate its mean for each of the five controls. We then weight the never-treated units to match the five means in the eventually treated group (Table 3). Only the construction of the weights uses the earlier period. Applying the weights to the 2010–2024 estimation sample, including 2018–2024, gives an FTA coefficient of 0.000101 (Table 4, column 1).

Table 3. Comparison of Covariate Means Before and After Entropy Balancing.

Variables	Treatment	Control (Unadjusted)	Control (Adjusted)
POP	16.206630	16.427017	16.206629
PGDP	9.915948	9.403481	9.915948
INT	7.056313	6.323490	7.056313
EXR	101.118821	98.544319	101.118820

Table 3. *Cont.*

Variables	Treatment	Control (Unadjusted)	Control (Adjusted)
LOG	3.573068	3.306132	3.573068
N	164	590	590
Control ESS	—	590	341.01

Note: Means are calculated from each eligible directed country-pair–trade-layer unit's available 2010–2017 control variables. The baseline sample includes 164 treated and 590 control units (730 units contribute eight pre-signature years and 24 contribute four). Entropy balancing targets five covariate means, with treated units retaining a weight of 1 and control weights normalized to the number of treated units; Control ESS denotes the control-group effective sample size based on these unit weights. Note that these pre-treatment unit means may differ from the means across all weighted panel observations.

Table 4. Robustness Tests for PageRank.

Variables	Entropy Balancing	Layer-Year FE	Exclude Entry Year	Quadratic Controls	Pre-Entry Means × Year	PageRank $d = 0.75$	PageRank $d = 0.95$
	(1) PageRank	(2) PageRank	(3) PageRank	(4) PageRank	(5) PageRank	(6) PageRank	(7) PageRank
FTA	0.000101 ***	0.000091 ***	0.000108 ***	0.000104 ***	0.000097 ***	0.000095 ***	0.000094 ***
	(0.000019)	(0.000018)	(0.000020)	(0.000018)	(0.000017)	(0.000017)	(0.000019)
Constant	−0.002572	−0.005820 ***	−0.004776 ***	−0.003100	0.000671	−0.005149 ***	−0.004406 ***
	(0.002472)	(0.001661)	(0.001622)	(0.002047)	(0.000432)	(0.001570)	(0.001632)
Observations	10,132	10,132	9971	10,132	10,132	10,132	10,132
R-squared	0.896423	0.905262	0.904405	0.905518	0.907076	0.907307	0.901423
Controls	Yes	Yes	Yes	Yes	Pre × year	Yes	Yes
pair-layer FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Layer-year FE	No	Yes	No	No	No	No	No

Note: The outcome is the directed PageRank edge score. Column (1) uses entropy weights based on 2010–2017 covariate means. Column (2) absorbs year effects through layer-year fixed effects. Column (3) omits each treated cohort's entry-year records and retains the controls. Column (4) adds the centered squares of the five baseline controls. In column (5), year indicators interacted with each unit's 2010–2017 covariate means replace the contemporaneous controls. Columns (6) and (7) vary the PageRank damping parameter from its baseline value of 0.85. Parentheses contain heteroskedasticity-robust standard errors. *** denotes significance at the 1% level. These standard errors do not adjust for dependence among observations that share a country.

Layer-Year Fixed Effects. We allow goods and services to face different shocks in each year by including trade-layer-by-year fixed effects. The FTA coefficient is 0.000091, close to the baseline estimate of 0.000095 (Table 4, column 2).

Excluding the Entry Year. Both agreements entered into force partway through a calendar year. We omit 2019 for the EU–Singapore links and 2020 for the EU–Viet Nam links, retaining all never-treated links in the baseline sample. The estimate remains positive at 0.000108 across 9971 observations when the post-entry period starts with the first full year of coverage (Table 4, column 3).

Quadratic Controls. We add the square of each mean-centered control to the five baseline controls. Allowing for this curvature in the relationship between the controls and the edge score yields an FTA coefficient of 0.000104 (Table 4, column 4).

Pre-Entry Covariate Means × Year. We replace the contemporaneous controls with interactions between year indicators and each unit's mean controls in 2010–2017. This allows annual changes in link prominence to vary with a unit's pre-agreement characteristics. The FTA coefficient is 0.000097 (Table 4, column 5).

PageRank with $d = 0.75$. Lowering the damping parameter from 0.85 to 0.75 gives less weight to longer paths through the trade network. With this recalculated edge score, the FTA coefficient is 0.000095 (Table 4, column 6).

PageRank with $d = 0.95$. Raising the damping parameter to 0.95 gives longer paths more weight. The FTA coefficient is 0.000094 (Table 4, column 7). Both alternative damping parameters give estimates close to the baseline.

2. Omitted Variable Bias Bounding Inference

Table 5 reports Oster's sensitivity analysis [40]. With the same directed pair-layer and year fixed effects, adding the five macroeconomic controls changes the FTA coefficient from 0.000096 to 0.000095. Under the two assumptions about maximum explanatory power shown in the table, the critical values of δ needed to reduce the coefficient to zero are 29.645 and 8.899, respectively. The positive estimate is therefore stable under the proportional-selection assumptions examined here.

Table 5. Oster Sensitivity Analysis.

Parameters and Settings	1.3 × Controlled R^2	Alternative R_{max}
Controlled β	0.000095	0.000095
Uncontrolled β	0.000096	0.000096
Controlled within R^2	0.016468	0.016468
Uncontrolled within R^2	0.007553	0.007553
Assumed maximum R^2	0.021409	0.050000
Adjusted β ($\delta = 1$)	0.000095	0.000093
Critical δ ($\beta = 0$)	29.645359	8.898561
Baseline p-value	1.17×10^{-7}	1.17×10^{-7}
Observations	10,132	10,132

Note: The baseline p-value refers to the FTA coefficient in the controlled model.

3. Stacked DID Method

Following Cengiz et al. [41], we compare the 2019 and 2020 entry cohorts separately with never-treated links and stack the two comparisons. Each stack has its own directed pair-layer and year fixed effects, and the model includes the baseline controls. Reusing the never-treated links in both comparisons gives 18,074 stacked rows from 10,132 distinct observations. The static FTA coefficient is 0.000097, significant at the 1% level using observation-level robust standard errors (Table 6).

Table 6. Stacked difference-in-differences and double machine learning estimates.

Variables	Stacked DID	K-Folds		Alternative Machine Learning Algorithms		
	(1) PageRank	(2) K-Folds = 3	(3) K-Folds = 5	(4) Lasso CV	(5) Grad Boost	(6) N Net
FTA	0.000097 ***	0.000295 ***	0.000253 ***	0.000109 ***	0.000339 ***	0.000095 *
	(0.000018)	(0.000029)	(0.000026)	(0.000018)	(0.000031)	(0.000050)
Constant	−0.005614 ***	0.000022 ***	0.000016 ***	0.000000	0.000003	−0.000001
	(0.001147)	(0.000004)	(0.000004)	(0.000002)	(0.000004)	(0.000003)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Pair-layer FE	Yes	Yes	Yes	Yes	Yes	Yes
N	18,074	10,132	10,132	10,132	10,132	10,132
R^2	0.908006	—	—	—	—	—

Note: All six columns use the baseline PageRank edge score in its original units, after rounding and winsorization. Parentheses contain heteroskedasticity-robust standard errors. *** and * denote significance at the 1% and 10% levels, respectively. In column (1), each entry cohort has its own directed pair-layer and year fixed effects. The 18,074 stacked records represent 10,132 distinct observations because 7942 never-treated records appear in both stacks. Columns (2)–(6) use observation-level cross-fitting with seed 56. The nuisance models include the five baseline controls, their squares, and directed pair-layer and year indicators. Columns (4)–(6) use five folds. The DML constant is the intercept from the final regression of the outcome residual on the treatment residual. A dash denotes an unreported model-wide R^2.

4. Double Machine Learning (DML)

We use partialling-out double machine learning (DML) to examine how the estimate changes when the controls can have nonlinear relationships with both the outcome and treatment. Let Y denote the unscaled PageRank edge score, D the FTA indicator, and Z the five controls, their squares, and directed pair-layer and year indicators. Equation (12) gives the partially linear model.

$$Y_a = \theta_0 D_a + g_0(Z_a) + \varepsilon_a, D_a = m_0(Z_a) + v_a \quad (12)$$

DML cross-fits the outcome nuisance $\ell_0 = \mathrm{E}(Y \mid Z)$ and treatment nuisance $\mathrm{m}_0 = \mathrm{E}(D \mid Z)$. Unlike structural g_0 in Equation (12), ℓ_0 is the conditional mean of Y. The estimate of θ_0 follows from the orthogonal score in Equation (13):

$$\frac{1}{n}\sum_{\mathrm{a}=1}^{\mathrm{n}} \left[D_a - \hat{\mathrm{m}}_{-\mathrm{k(a)}}(Z_a)\right]\left[Y_a - \hat{\ell}_{-\mathrm{k(a)}}(Z_a) - \theta\left[D_a - \hat{\mathrm{m}}_{-\mathrm{k(a)}}(Z_a)\right]\right] = 0 \quad (13)$$

Following Chernozhukov et al. [42], we use three- and five-fold cross-fitting with random forests. We also compare five-fold estimates from cross-validated Lasso, gradient boosting, and a neural network. All five specifications use the same 10,132 observations, a random seed of 56, and heteroskedasticity-robust standard errors. All five coefficients are positive. Four are significant at the 5% level, while the neural-network estimate has $p = 0.057$. Cross-fitting assigns individual observations to folds. The models use pair-layer and year indicators as predictors. Because the pair and year determine legal treatment, differences between observed and predicted treatment depend on the learner. The comparison assesses sensitivity to that choice and provides no independent source of policy variation.

5. Additional Specification Sensitivity

Uncertainty about the baseline estimate depends on which observations can have correlated errors. Allowing links that share either country to have correlated errors [25] gives a standard error of 0.000022 for the FTA coefficient of 0.000095 ($p = 0.000020$, Supplementary File S2, Table S2.6). Only two ASEAN partners entered agreements, and a wild cluster bootstrap at the ASEAN-country level gives $p = 0.0606$. The residual cross-sectional dependence test [43] and the CIPS unit-root diagnostic [44] use complete series. For services, CIPS does not reject a unit root at 5%. For goods, the available critical values do not cover the sample size. A joint test of the FTA and five control slopes rejects stability at the prespecified 2020 break [45] ($F = 16.21$, $p < 0.001$, Table S2.8).

Following Rambachan and Roth [46], we use a separate event study with year 0 set to legal entry and average the estimates for years 0–4. The 95% interval stays above zero at relative-magnitude bounds of 0 and 0.05. At 0.05, the interval is [0.000008, 0.000148]. At 0.10, it includes zero [−0.000004, 0.000158] (Supplementary File S2, Table S2.9). The evidence for a positive average therefore depends on the size of the departure allowed. We also use the group–time estimator of Callaway and Sant'Anna [47] to compare each entry cohort with never-treated pairs. The pooled average treatment effect on treated links is estimated at 0.000069 ($p = 0.030$). The joint test rejects the pre-entry restrictions ($p = 0.00115$), which limits a causal interpretation of that estimate (Supplementary File S2, Section S2.6).

5.5. Mechanism Analysis

To examine how trade relationships change around FTA entry, we first estimate the association between entry and each measure of trade composition or institutional distance. We then test whether the association with the directed PageRank edge score varies with the exporter's network position. These regressions describe possible adjustment channels but do not identify causal mediation.

$$M_{\mathrm{ij}\ell\mathrm{t}} = \alpha + \rho D_{\mathrm{ijt}} + \gamma' X_{\mathrm{ij}\ell\mathrm{t}} + \mu_{\mathrm{ij}\ell} + \lambda_t + \nu_{\mathrm{ij}\ell\mathrm{t}} \quad (14)$$

In Equation (14), M denotes the relevant outcome. We use the destination country's import-product indices, the source country's export-product indices, or the institutional distance between the two countries. In each case, the FTA coefficient measures the conditional difference associated with agreement entry.

5.5.1. Concentration and Diversification Mechanism Test

In Table 7, the destination country's import diversification index rises by 0.005347 around entry ($p < 0.01$). Its import basket thus moves farther from the world product mix, consistent with H2a. The estimate for import concentration is 0.001923 and is statistically imprecise. On the export side, the source country's diversification index falls by 0.001569 ($p < 0.10$), while its product concentration rises by 0.009313 ($p < 0.01$), supporting H2b. One possible explanation is that exporters can expand sales of established products more readily than they can introduce new ones. These country-level measures describe the composition of trade. They do not quantify how much of the change in a particular link's PageRank score passes through that channel.

Table 7. Mechanism Test Results of Concentration, Diversification, and Institutional Distance.

Variables	Import Diversity	Import Concentration	Export Diversity	Export Concentration	Institutional Distance
	(1) IM_DIV	(2) IM_CON	(3) EX_DIV	(4) EX_CON	(5) KAS
FTA	0.005347 ***	0.001923	−0.001569 *	0.009313 ***	−0.111669 ***
	(0.000887)	(0.001632)	(0.000859)	(0.001535)	(0.022010)
Constant	−0.897393 ***	2.036538 ***	2.469700 ***	−0.471631 *	8.093683 **
	(0.161305)	(0.281492)	(0.137722)	(0.279356)	(3.643373)
Observations	9982	9982	9891	9891	10,132
R-squared	0.959105	0.645609	0.984453	0.900291	0.953519
Controls	Yes	Yes	Yes	Yes	Yes
pair-layer FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Notes: Parentheses contain heteroskedasticity-robust standard errors. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

5.5.2. Institutional Distance Convergence Mechanism

The FTA coefficient for bilateral institutional distance is −0.111669 ($p < 0.01$) in Table 7, column (5). The narrower measured governance gap is consistent with H2c. More predictable procedures could help firms plan investments in product adaptation, certification, and distribution. The index, however, covers six broad governance dimensions. It cannot show which provisions or domestic reforms account for the smaller gap, or distinguish adjustment after entry from convergence that may already have influenced partner selection.

5.5.3. Moderating Effect of Network Topological Characteristics

Equation (15) tests whether the association between FTA entry and link prominence varies with the exporter's network position. We estimate separate interactions with network constraint (STR) and effective size (EEF).

$$Y_{ij\ell t} = \alpha + \beta_1 D_{ijt} + \beta_2 (D_{ijt} \times Z_{i\ell t}) + \beta_3 Z_{i\ell t} + \gamma' X_{ij\ell t} + \mu_{ij\ell} + \lambda_t + \varepsilon_{ij\ell t} \quad (15)$$

For each directed trade link, Z is the source country's constraint or effective size in the same year and trade layer. The annual network used in the regressions includes the United Kingdom through 2019. In 2023, its membership coincides with the 37-country set plotted in Figure 7.

Table 8 provides little evidence for H3a. The FTA–constraint interaction is negative (−0.000217) but imprecisely estimated. The interaction with effective size is also negative (−0.000030) and is statistically significant, consistent with H3b. When an exporter has more

nonredundant contacts, the estimated gain in the covered link's score is smaller. Access to a wider range of alternative markets offers one possible explanation.

Table 8. Moderating Effects on PageRank.

Variables	Structural Constraint	Network Effective Size
	(1) PageRank	(2) PageRank
FTA	0.000147	0.000870 ***
	(0.000093)	(0.000235)
STR	−0.000478 ***	
	(0.000098)	
EEF		−0.000002
		(0.000004)
FTA × STR	−0.000217	
	(0.000361)	
FTA × EEF		−0.000030 ***
		(0.000009)
Constant	−0.002999 *	−0.006099 ***
	(0.001770)	(0.001829)
Observations	10,132	10,132
R-squared	0.905104	0.905206
Controls	Yes	Yes
pair-layer FE	Yes	Yes
Year FE	Yes	Yes

Note: Parentheses contain heteroskedasticity-robust standard errors. *** and * denote significance at the 1% and 10% levels, respectively.

5.6. Heterogeneity Analysis

5.6.1. Heterogeneity by Exporter Network Position

Table 9 divides the baseline sample separately by network constraint and effective size, using the sample mean of each indicator as the cutoff. The estimated FTA coefficient is positive and significant in both constraint groups. For effective size, the estimate is 0.000174 in the low group and −0.000012 in the high group. Only the former is statistically significant. The pattern is consistent with the negative effective-size interaction in Table 8 and with the possibility that exporters with fewer alternative contacts direct more trade toward a covered partner. The groups describe the exporter's network in the year of observation.

Table 9. Heterogeneity by Network Constraint and Effective Size.

Variables	Low Constraint	High Constraint	Low Effective Size	High Effective Size
	(1) PageRank	(2) PageRank	(1) PageRank	(2) PageRank
FTA	0.000049 **	0.000128 **	0.000174 ***	−0.000012
	(0.000022)	(0.000057)	(0.000026)	(0.000024)
Constant	−0.002430	−0.005524 *	−0.007558 *	−0.002100
	(0.003215)	(0.003069)	(0.004315)	(0.001796)
Observations	6191	3827	4075	5969
R-squared	0.915758	0.895605	0.935308	0.912965
Controls	Yes	Yes	Yes	Yes
pair-layer FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Note: Parentheses contain heteroskedasticity-robust standard errors. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

5.6.2. Heterogeneity by Trade Direction

Table 10 separates exports from the EU to ASEAN from exports in the opposite direction. The estimated FTA coefficient is 0.000144 for EU-origin exports and 0.000015 for ASEAN-origin exports. Only the former is statistically significant. The evidence for increased link prominence is therefore clearer for EU-origin exports.

Table 10. Heterogeneity by Trade Direction and Source-Country Technology Level.

Variables	EU as Source Node	ASEAN as Source Node	High Technology	Low Technology
	(1) PageRank	(2) PageRank	(3) PageRank	(4) PageRank
FTA	0.000144 ***	0.000015	0.000128 ***	0.000033 ***
	(0.000023)	(0.000028)	(0.000028)	(0.000012)
Constant	−0.002219	−0.003843	0.004620	−0.005314 ***
	(0.002943)	(0.003935)	(0.004332)	(0.001341)
Observations	6288	3844	5480	4643
R-squared	0.893475	0.916593	0.902854	0.905641
Controls	Yes	Yes	Yes	Yes
pair-layer FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Note: Parentheses contain heteroskedasticity-robust standard errors. *** denotes significance at the 1% level.

5.6.3. Heterogeneity by Source-Country Technology Level

Table 10 also groups observations by whether the source country's share of medium- and high-technology activities exceeds the baseline sample mean. The FTA coefficient is positive and statistically significant in both groups, with a larger point estimate in the high-technology group (0.000128 versus 0.000033). Existing technological and commercial networks may help exporters reach a covered market, but the regressions group countries by technology share and do not directly measure changes in industry costs or supply-chain integration.

5.7. Intermediate Goods and Consumer Goods

Table 11 compares links in the intermediate-goods and pure consumer-goods networks using the UN BEC classification. BEC Rev. 4 codes 111 and 121, for example, cover production inputs, while 112 and 122 cover goods for final consumption. The FTA coefficients are positive for intermediate goods (0.000031) and consumer goods (0.000039), both significant at 1%. The consumer-goods estimate supports H4a. In a direct comparison on the same 7596 observations, the consumer-minus-intermediate difference is 0.000008191 ($p = 0.607868$), providing little evidence for H4b (Supplementary File S2, Table S2.10). Gains in link prominence thus extend to both production inputs and final goods.

Table 11. Product-Group Heterogeneity in PageRank.

Variables	Intermediate	Consumer
	(1) PageRank	(2) PageRank
FTA	0.000031 ***	0.000039 ***
	(0.000010)	(0.000013)
Constant	−0.000969	−0.001825 **
	(0.001141)	(0.000863)
Observations	7596	7596
R-squared	0.925698	0.901560
Controls	Yes	Yes
pair-layer FE	Yes	Yes
Year FE	Yes	Yes

Note: Parentheses contain heteroskedasticity-robust standard errors. *** and ** denote significance at the 1% and 5% levels, respectively.

6. Discussion

6.1. Comparison with Previous Studies

Baier and Bergstrand [14] show why countries' selection into FTAs matters when estimating effects on bilateral trade flows. Selection also matters when the outcome is a

network score. Our baseline coefficient of 0.000095 is the conditional change in the amount of an exporter's PageRank allocated to a covered destination. Because this allocation depends on the destination's share of the exporter's network sales, it need not move in proportion to bilateral trade value.

Fagiolo et al. [9] document persistent differences in connectivity and core–periphery structure in world trade. Smith and Sarabi [10] show that the formation of trade links varies across core and peripheral economies and across products. In our ASEAN–EU networks, prominence is also unevenly distributed, more so in services than in goods. By tracing individual links over time, we examine how the weight of a covered export relationship changes around agreement entry within these different network structures.

Mattoo et al. [15] find that deep agreements can generate greater trade creation and less diversion than shallow ones, and that some provisions can benefit nonmembers. Such findings matter for interpreting a network outcome. A change in exports to one partner can change the shares assigned to other partners, including those outside the agreement. Our estimates cannot separate direct effects on covered links from spillovers onto comparison links, nor do they measure welfare. The trade-composition and institutional-distance results describe accompanying changes, and the network interactions identify settings in which the association is stronger or weaker.

This application adds a question to analyses of agreement content and trade volumes. Of the export relationships covered by an agreement, which acquire greater weight in the observed network? The answer depends on the definition of link weight and the links available for comparison. Inference also depends on how the analysis handles shared trading partners and trends that may already differ before entry.

6.2. Research Implications

Evaluations of regional integration can track directed trade-link prominence alongside trade volumes, product composition, domestic value added and participation in production chains. A higher edge score means that more of the exporter's PageRank is allocated to that destination. Assessing whether the exporter gains technological autonomy, retains more income or receives a larger share of the gains from trade requires measures of those outcomes.

For policymakers monitoring an agreement, the scores identify which export relationships strengthen relative to others. Comparing those changes with the timing of tariff concessions, regulatory implementation and improvements in logistics could help identify where firms take up new market access and where they face continuing barriers.

7. Conclusions

The aim of this study was to examine how the entry into force of cross-regional FTAs relates to the prominence of directed trade links in ASEAN–EU networks. We constructed annual goods and services networks for 2010–2024. The descriptive comparisons use the same 37 countries throughout, while the regression panel covers up to 38 economies and contributes 10,132 baseline observations. The EU–Singapore and EU–Viet Nam agreements define the two treatment cohorts, beginning in 2019 and 2020, respectively.

Covered links had a higher directed PageRank edge score after entry, conditional on the baseline specification. The positive association extended to trade in both intermediate and consumer goods. Changes in trade composition and institutional distance, together with differences across exporters' network positions, describe aspects of the adjustment around entry. Tracking which links gain prominence can complement measures of trade value and domestic value added, provided the network boundary, data coverage and sensitivity to the specification are taken into account.

Limitations and Future Research

The scope of the evidence reflects the two agreements studied, the trade relationships observed and the information available on implementation.

The post-entry period is short for both agreements and overlaps with the COVID-19 pandemic. The later positive coefficients in Figure 8 are consistent with delayed adjustment, but the joint pre-entry test also detects differences before entry. We therefore interpret the baseline estimate as a conditional association in these two cohorts. Additional agreement cohorts and longer post-entry histories would help distinguish adjustment paths across partners and over time.

The measured prominence of each link depends on which other links are observed in its annual network. Broader coverage, particularly in services, would improve comparisons across years. Further work could also examine alternative functional forms and methods of inference that allow for dependence among links across the network.

The binary treatment indicator records legal entry. It does not measure when individual tariffs were phased out, which services reservations applied, how provisions were enforced, or whether firms used the available preferences. Linking product-specific tariff schedules and sectoral services commitments to trade outcomes would allow future research to distinguish the timing of legal entry from the pace and intensity of implementation.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/systems14111482/s1. Supplementary File S1. Trade network construction and country roles. Figure S1. Data coverage of the goods and services networks [29]. Figure S2. Cross-bloc share of available trade weights. Figure S3. Weighted reciprocity among complete bilateral dyads [35]. Figure S4. Effective number of export partners [34]. Figure S5. Country PageRank in the goods network [3,26]. Figure S6. Country PageRank in the services network [3,26]. Figure S7. Concentration of PageRank across countries. Figure S8. Similarity of goods and services PageRank rankings. Figure S9. Regional composition of available goods weights. Figure S10. Regional composition of available services weights. Figure S11. Directional coverage of cross-bloc links. Figure S12. Year-to-year persistence of the strongest directed links [36]. Figure S13. Goods network topology in 2010. Figure S14. Services network topology in 2010. Figure S15. Goods network topology in 2023. Figure S16. Services network topology in 2023. Figure S17. Goods network topology in 2024. Figure S18. Services network topology in 2024. Figure S19. Goods supply and demand roles in 2023 [37,38]. Figure S20. Services supply and demand roles in 2023 [37,38]. Figure S21. Goods role composition over time. Figure S22. Services role composition over time. Figure S23. Country role trajectories in goods. Figure S24. Country role trajectories in services. Figure S25. Complete annual PageRank trajectories in goods. Figure S26. Complete annual PageRank trajectories in services. Figure S27. Structural holes in goods in 2010. Figure S28. European detail in goods in 2010. Figure S29. Structural holes in services in 2010. Figure S30. European detail in services in 2010. Figure S31. Structural holes in goods in 2023 [11,27]. Figure S32. European detail in goods in 2023. Figure S33. Structural holes in services in 2023. Figure S34. European detail in services in 2023. Figure S35. Structural holes in goods in 2024. Figure S36. European detail in goods in 2024. Figure S37. Structural holes in services in 2024. Figure S38. European detail in services in 2024. Figure S39. Annual services topology overview. Figure S40. Services network in 2011. Figure S41. Services network in 2012. Figure S42. Services network in 2013. Figure S43. Services network in 2014. Figure S44. Services network in 2015. Figure S45. Services network in 2016. Figure S46. Services network in 2017. Figure S47. Services network in 2018. Figure S48. Services network in 2019. Figure S49. Services network in 2020. Figure S50. Services network in 2021. Figure S51. Services network in 2022. Supplementary File S1 also reports each country's supply score, demand score, and role classification in the goods and services trade networks. Supplementary File S2. Data diagnostics and sensitivity analyses. Table S2.1. Descriptive statistics in the common baseline sample. Table S2.2. Distributional diagnostics in the common baseline sample [33]. Table S2.3. Distributional quantiles in the baseline sample. Table S2.4. Classic Pesaran CD diagnostic on complete 2010–2024 series [43]. Table S2.5. Re-estimated sensitivity specifications using robust standard errors. Table S2.6. Baseline FTA estimate allowing for correlation between links that share

a country [25]. Table S2.7. Cross-sectionally augmented panel unit-root diagnostics (CIPS) [44]. Table S2.8. Prespecified coefficient-stability diagnostic around 2020 [45]. Table S2.9. Sensitivity of the average event-study effect to departures from parallel trends [46]. Figure S2.1. Relative-magnitude sensitivity intervals for the average event-study effect. Table S2.10. Differences in the FTA coefficient by trade layer and product group. Sections S2.3 and S2.6 discuss staggered treatment timing [24] and group–time effects [47], respectively. The replication folder contains the prepared panel, code, and calculation records.

Author Contributions: Supervision, L.Z.; writing—review and editing, writing—original draft preparation, methodology, S.C.; resources and financial support, J.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the National Social Science Fund of China (grant no. 20XJL010), the 2025 ASEAN and Border Economy Series project on ASEAN—EU economic and trade cooperation (project no. 2025JK00) and the Key Research Base of Humanities and Social Sciences of Universities in Guangxi Zhuang Autonomous Region (Guangxi University Institute for Frontier Economics of China).

Data Availability Statement: The replication code and accompanying data are available on GitHub: https://github.com/martindoris614-gif/Manuscript-4637024/releases/tag/v1.0 (accessed on 3 November 2026). Download and execution instructions are provided with the Supplementary Materials.

Acknowledgments: We gratefully acknowledge the support of the ASEAN–EU economic and trade cooperation project. All authors have read and approved the final manuscript and agree to be accountable for all aspects of this work.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Definitions of core metrics in trade network analysis.

Metric	Calculation Formula	Description
Available-link coverage	Available directed links / $N(N-1)$	Share of non-self-links with observed or interpolated values; not a measure of actual network density.
Cross-bloc trade share	Σ cross-bloc w_{ij} / $\Sigma_{i\neq j}\, w_{ij}$	Available weight on links between ASEAN and European countries divided by total available network weight.
Weighted reciprocity	Σ matched $\min(w_{ij}, w_{ji})$ / Σ matched w_{ij}	Weighted reciprocity compares reciprocated weight with total weight [35]. Our sum includes dyads observed in both directions.
Effective export partners	$\exp(-\Sigma_j\, P_{ij} \ln P_{ij})$	The effective number of partners is the exponential of export-share entropy [34]. We report the median among nodes with supported outgoing trade.
Bloc shares and persistence	$\Sigma_{i\in A,\, j\in B}\, w_{ij}$ / $\Sigma_{i\neq j}\, w_{ij}$	Bloc-to-bloc shares use all available weights; year-to-year strong-link persistence uses a Jaccard index on common support [36].
Node and edge PageRank	Equations (3)–(5)	We compute weighted node PageRank [3] with damping 0.85. For each directed link, we multiply the source score by the destination's share of the source's exports.
Network constraint and effective size	Equations (10) and (11)	We calculate constraint and effective size [11,27] on supported, symmetrized weighted ties. Regression and figure samples use their respective annual node sets.
Weighted HITS	$h \propto Wa$; $a \propto W^{T}h$	We compute weighted hub and authority scores [37,38] and normalize each set to sum to one. Role categories compare each score with its network mean.

Table A2. Summary of Cross-Regional Bilateral FTAs and Treatment Assignment (2010–2024).

Agreement/Institutional Arrangement	Signature Date	Entry-into-Force Date	Contracting Parties (Treatment/Control Assignment)	Coding in FTA_{ijt}
EU–Singapore FTA (EUSFTA)	19 October 2018	21 November 2019	Directed dyads between EU member states and Singapore (both EU → SGP and SGP → EU)	Coded as 1 for 2019–2024; 0 for 2010–2018 (UK–Singapore coded in the active EU sample for 2019)
EU–Viet Nam FTA (EVFTA)	30 June 2019	1 August 2020	Directed dyads between EU-27 member states and Viet Nam (both EU → VNM and VNM → EU)	Coded as 1 for 2020–2024; 0 for 2010–2019
Other EU–ASEAN Dyads	—	Not in force during 2010–2024	Directed dyads between EU economies and the remaining 8 ASEAN members (IDN, MYS, THA, PHL, BRN, KHM, LAO, MMR)	Coded as 0 throughout 2010–2024 (Control Group)
Region-to-Region ASEAN–EU FTA	Negotiations paused in 2009	None	No bloc-to-bloc agreement in force during the sample period	Excluded from treatment; selective bilateral FTAs serve as building blocks
Intra-EU & Intra-ASEAN Arrangements	Various	In force prior to/during the sample	Intra-bloc pairs (EU–EU and ASEAN–ASEAN)	Retained in annual network construction (W_t), excluded from DID treatment

Note: The sample covers 10 ASEAN members and 28 European economies (the EU-27 and the UK). The input networks and dyadic panel include UK records for 2010–2019 and omit them from 2020 onward. This is the study's data-coverage convention.

Implementation note. Under the EU–Singapore FTA, tariff elimination combines immediate access with phase-outs extending up to five years [6]. Under the EU–Viet Nam FTA, tariff elimination is phased over up to seven years on the EU side and ten years on the Vietnamese side, with tariff-rate quotas for certain sensitive goods [7]. In both agreements, Annex 2-A sets out goods schedules. These legal schedules differ from the annual 0/1 entry indicator used in the regressions.

References

1. Yang, Y.; Liu, W. Free trade agreements and domestic value added in exports: An analysis from the network perspective. *Econ. Model.* **2024**, *132*, 106656. [CrossRef]
2. Fan, Z.; Long, R.; Anwar, S.; Wang, J. Does centrality within trade agreements network matter to economic complexity? The conditioning effects of network structure. *Int. Rev. Econ. Finance* **2025**, *98*, 103892. [CrossRef]
3. Brin, S.; Page, L. The anatomy of a large-scale hypertextual Web search engine. *Comput. Netw. ISDN Syst.* **1998**, *30*, 107–117. [CrossRef]
4. ASEAN Secretariat. ASEAN-EU Economic Relation. Available online: https://asean.org/our-communities/economic-community/integration-with-global-economy/asean-eu-economic-relation/ (accessed on 21 October 2026).
5. European Commission. EU Trade Relations with the Association of South East Asian Nations (ASEAN). Available online: https://policy.trade.ec.europa.eu/eu-trade-relationships-country-and-region/countries-and-regions/association-south-east-asian-nations-asean_en (accessed on 21 October 2026).
6. European Union; Republic of Singapore. Free Trade Agreement Between the European Union and the Republic of Singapore. Available online: https://eur-lex.europa.eu/eli/agree_internation/2019/1875/oj/eng (accessed on 3 November 2026).
7. European Union; Socialist Republic of Viet Nam. Free Trade Agreement Between the European Union and the Socialist Republic of Viet Nam. Available online: https://policy.trade.ec.europa.eu/eu-trade-relationships-country-and-region/countries-and-regions/viet-nam/eu-viet-nam-agreements/texts-agreements_en (accessed on 3 November 2026).
8. Borgatti, S.P.; Everett, M.G. Models of core/periphery structures. *Soc. Netw.* **1999**, *21*, 375–395. [CrossRef]
9. Fagiolo, G.; Reyes, J.; Schiavo, S. The evolution of the world trade web: A weighted-network analysis. *J. Evol. Econ.* **2010**, *20*, 479–514. [CrossRef]

10. Smith, M.; Sarabi, Y. How does the behaviour of the core differ from the periphery? An international trade network analysis. *Soc. Netw.* **2022**, *70*, 1–15. [CrossRef]
11. Burt, R.S. *Structural Holes: The Social Structure of Competition*; Harvard University Press: Cambridge, MA, USA, 1992. Available online: https://www.jstor.org/stable/j.ctv1kz4h78 (accessed on 30 October 2026).
12. Sopranzetti, S. Overlapping free trade agreements and international trade: A network approach. *World Econ.* **2018**, *41*, 1549–1566. [CrossRef]
13. Anderson, J.E.; van Wincoop, E. Gravity with gravitas: A solution to the border puzzle. *Am. Econ. Rev.* **2003**, *93*, 170–192. [CrossRef]
14. Baier, S.L.; Bergstrand, J.H. Do free trade agreements actually increase members' international trade? *J. Int. Econ.* **2007**, *71*, 72–95. [CrossRef]
15. Mattoo, A.; Mulabdic, A.; Ruta, M. Trade creation and trade diversion in deep agreements. *Can. J. Econ.* **2022**, *55*, 1598–1637. [CrossRef]
16. Guillin, A.; Rabaud, I.; Zaki, C. Does the depth of trade agreements matter for trade in services? *World Econ.* **2023**, *46*, 3616–3653. [CrossRef]
17. Maggi, G.; Ossa, R. The political economy of international regulatory cooperation. *Am. Econ. Rev.* **2023**, *113*, 2168–2200. [CrossRef]
18. Caliendo, L.; Parro, F. Estimates of the Trade and Welfare Effects of NAFTA. *Rev. Econ. Stud.* **2015**, *82*, 1–44. [CrossRef]
19. Prebisch, R. *The Economic Development of Latin America and Its Principal Problems*; United Nations Department of Economic Affairs: Lake Success, NY, USA, 1950. Available online: https://hdl.handle.net/11362/29973 (accessed on 21 October 2026).
20. Wallerstein, I. *The Modern World-System: Capitalist Agriculture and the Origins of the European World-Economy in the Sixteenth Century*; Academic Press: New York, NY, USA, 1974. Available online: https://archive.org/details/modernworldsyste00wall (accessed on 30 October 2026).
21. United Nations Conference on Trade and Development. Merchandise: Standard Product Concentration and Diversification Indices—Annual (Analytical): Metadata. Available online: https://unctadstat.unctad.org/datacentre/dataviewer/metadata/dimension/US.ConcentDiversIndices/indicator (accessed on 27 October 2026).
22. Mayer, T.; Melitz, M.J.; Ottaviano, G.I.P. Market size, competition, and the product mix of exporters. *Am. Econ. Rev.* **2014**, *104*, 495–536. [CrossRef]
23. World Bank. Worldwide Governance Indicators. Available online: https://datacatalog.worldbank.org/search/dataset/0038026/worldwide-governance-indicators (accessed on 27 October 2026).
24. Goodman-Bacon, A. Difference-in-differences with variation in treatment timing. *J. Econom.* **2021**, *225*, 254–277. [CrossRef]
25. Aronow, P.M.; Samii, C.; Assenova, V.A. Cluster-robust variance estimation for dyadic data. *Polit. Anal.* **2015**, *23*, 564–577. [CrossRef]
26. NetworkX Developers. PageRank. Available online: https://networkx.org/documentation/stable/reference/algorithms/generated/networkx.algorithms.link_analysis.pagerank_alg.pagerank.html (accessed on 2 November 2026).
27. NetworkX Developers. Structural Holes. Available online: https://networkx.org/documentation/stable/reference/algorithms/structuralholes.html (accessed on 2 November 2026).
28. Kogut, B.; Singh, H. The effect of national culture on the choice of entry mode. *J. Int. Bus. Stud.* **1988**, *19*, 411–432. [CrossRef]
29. United Nations Statistics Division. UN Comtrade Database. Available online: https://comtradeplus.un.org/ (accessed on 2 November 2026).
30. CEPII. BACI: International Trade Database at the Product-Level, HS2007, Version V202601. Available online: https://www.cepii.fr/DATA_DOWNLOAD/baci/doc/baci_webpage.html (accessed on 3 November 2026).
31. United Nations Statistics Division. Conversion Table Between the Harmonized System (2007 Edition) and the Classification by Broad Economic Categories. Available online: https://unstats.un.org/unsd/classifications/Econ (accessed on 2 November 2026).
32. World Bank. World Development Indicators. Available online: https://datatopics.worldbank.org/world-development-indicators/ (accessed on 27 October 2026).
33. Jarque, C.M.; Bera, A.K. A test for normality of observations and regression residuals. *Int. Stat. Rev.* **1987**, *55*, 163–172. [CrossRef] [PubMed]
34. Jost, L. Entropy and diversity. *Oikos* **2006**, *113*, 363–375. [CrossRef]
35. Squartini, T.; Picciolo, F.; Ruzzenenti, F.; Garlaschelli, D. Reciprocity of weighted networks. *Sci. Rep.* **2013**, *3*, 2729. [CrossRef] [PubMed]
36. Jaccard, P. The distribution of the flora in the alpine zone. *New Phytol.* **1912**, *11*, 37–50. [CrossRef]
37. Kleinberg, J.M. Authoritative sources in a hyperlinked environment. *J. ACM* **1999**, *46*, 604–632. [CrossRef]
38. Deguchi, T.; Takahashi, K.; Takayasu, H.; Takayasu, M. Hubs and authorities in the world trade network using a weighted HITS algorithm. *PLoS ONE* **2014**, *9*, e100338. [CrossRef] [PubMed]
39. Hainmueller, J. Entropy balancing for causal effects: A multivariate reweighting method to produce balanced samples in observational studies. *Polit. Anal.* **2012**, *20*, 25–46. [CrossRef]

40. Oster, E. Unobservable selection and coefficient stability: Theory and evidence. *J. Bus. Econ. Stat.* **2019**, *37*, 187–204. [CrossRef]
41. Cengiz, D.; Dube, A.; Lindner, A.; Zipperer, B. The effect of minimum wages on low-wage jobs. *Q. J. Econ.* **2019**, *134*, 1405–1454. [CrossRef]
42. Chernozhukov, V.; Chetverikov, D.; Demirer, M.; Duflo, E.; Hansen, C.; Newey, W.; Robins, J. Double/debiased machine learning for treatment and structural parameters. *Econom. J.* **2018**, *21*, C1–C68. [CrossRef]
43. Pesaran, M.H. *General Diagnostic Tests for Cross Section Dependence in Panels*; IZA Discussion Paper No. 1240; IZA: Bonn, Germany, 2004. Available online: https://www.iza.org/publications/dp/1240/general-diagnostic-tests-for-cross-section-dependence-in-panels (accessed on 4 November 2026).
44. Pesaran, M.H. A simple panel unit root test in the presence of cross-section dependence. *J. Appl. Econom.* **2007**, *22*, 265–312. [CrossRef]
45. Ali, M.M.; Silver, J.L. Tests for equality between sets of coefficients in two linear regressions under heteroscedasticity. *J. Am. Stat. Assoc.* **1985**, *80*, 730–735. [CrossRef]
46. Rambachan, A.; Roth, J. A more credible approach to parallel trends. *Rev. Econ. Stud.* **2023**, *90*, 2555–2591. [CrossRef]
47. Callaway, B.; Sant'Anna, P.H.C. Difference-in-differences with multiple time periods. *J. Econom.* **2021**, *225*, 200–230. [CrossRef]

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