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PHARMACEUTICAL IMPORT SUPPLIER CONCENTRATION, DOMINANT SUPPLIER DEPENDENCE, AND SUPPLIER DIVERSIFICATION AS PREDICTORS OF IMPORT GROWTH

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Abstract:

This analysis examines whether pharmaceutical sourcing structure predicts subsequent import growth, addressing international debates about diversification and trade performance. Annual United Nations Comtrade records accessed through World Integrated Trade Solution cover eight economies during 2010 to 2025, yielding 120 aligned observations for separate regressions with country and year fixed effects. A 0.01 increase in concentration, a 10-percentage point increase in the largest supplier share and 10 additional partners are associated with growth differences of −1.363, −2.506 and −2.052 percentage points, respectively. Conventional 95 percent confidence intervals include zero throughout. Restricted wild cluster bootstrap inference identifies evidence for dominant supplier dependence, although disagreement with conventional inference limits certainty. All estimates remain negative when individual countries are excluded. These patterns distinguish geographical sourcing characteristics from demonstrated substitution capacity or disruption transmission. The contribution is an outcome specific qualification of diversification arguments: broader sourcing does not establish faster nominal import expansion. Procurement and policy assessments should evaluate expenditure distribution and supplier exposure separately, without equating import growth with secure medicine provision.

Key Words: Pharmaceutical Imports; Supplier Concentration; Sourcing Diversification; Panel Regression; Wild Cluster Bootstrap

1. Introduction:

International pharmaceutical sourcing raises a consequential question: does changing the distribution of imports across suppliers accompany stronger subsequent import growth? A wider supplier base may offer purchasing alternatives, while established relationships with major suppliers may support continuity and expansion. These possibilities create competing expectations about how sourcing structure relates to trade performance. The distinction matters for institutions evaluating supplier dependence because geographical diversification, expenditure growth and continuity of medicine supply represent different outcomes. Baldwin and Freeman, 2022, show that assessments of international supply chains must weigh exposure to disturbances against the benefits of specialization and external sourcing. Their review cautions against assuming that a more diversified network necessarily performs better under every criterion. Medical supply research illustrates why sourcing decisions require an explicit outcome definition. Gereffi, 2020, examines how production specialization, demand surges and policy responses shaped medical supply shortages during the pandemic. That analysis concerns medical devices and protective equipment rather than the pharmaceutical expenditure outcome examined here, but it establishes the importance of interactions between production networks and institutional decisions. It also shows why evidence about supply availability cannot be inferred directly from trade expenditure. Pharmaceutical import growth can reflect changes in quantities, prices or product composition. An increase in expenditure therefore does not, by itself, demonstrate improved access or greater resilience.

Production network research provides the theoretical basis for examining sourcing structure without imposing a universal directional expectation. Acemoglu et al., 2012, demonstrate that unequal connections can allow disturbances affecting individual producers to influence aggregate outcomes. Barrot and Sauvagnat, 2016, show that input specificity shapes the propagation of supplier shocks, while Carvalho et al., 2021, document transmission through production relationships following the Great East Japan Earthquake. Together, these contributions establish that network configuration matters, but its consequences depend on the properties of supply relationships and the disturbances affecting them. They

do not establish that a concentrated geographical distribution of pharmaceutical imports necessarily predicts lower annual expenditure growth. Three measurable dimensions distinguish the sourcing relationships examined in this analysis. Supplier concentration captures the distribution of expenditure across all positive supplying partner areas. Dominant supplier dependence isolates the largest partner share. Supplier diversification records the number of partner areas with positive imports. Concentration may increase exposure to developments affecting major origins, but it may also accompany sustained purchasing from established production centres. Additional partners may broaden purchasing options, although small transactions can increase geographical breadth without providing substantial replacement capacity. Elliott et al., 2022, model how firms combine multiple sourcing relationships with investments in relationship reliability. Their framework highlights why the number of connections and the strength of those connections cannot be treated as equivalent characteristics.

The competing implications of international sourcing also appear in comparative economic evidence. Bonadio et al., 2021, examine production and trade across 64 countries and find that international supply chains can transmit foreign disturbances while limiting exposure to domestic disruptions. Their analysis concerns aggregate economic activity under pandemic conditions rather than annual pharmaceutical import growth. The reviewed evidence therefore establishes mechanisms through which international connections can matter, but it does not resolve whether preceding year pharmaceutical concentration, leading supplier dependence and geographical breadth have similar associations with subsequent nominal import expansion. Addressing that question requires keeping the three sourcing measures distinct and evaluating them against a common outcome and sample. This study aims to examine how preceding year pharmaceutical import network structure is associated with subsequent annual import value growth. The central research question asks whether supplier concentration, dominant supplier dependence and supplier diversification display different relationships with that outcome. The analysis measures concentration through the sum of squared partner shares, dependence through the largest partner share and diversification through the count of positive supplying partner areas. These indicators describe geographical expenditure patterns rather than firm relationships or product substitutability. The outcome is the annual percentage change in world pharmaceutical imports reported in current United States dollars.

The empirical setting comprises Australia, Brazil, China, Germany, India, Rwanda, South Africa and the United States during 2010 to 2025. Public World Integrated Trade Solution tables containing underlying United Nations Comtrade records provide pharmaceutical imports under Harmonized System chapter 30. The constructed panel contains 128 country and year observations. Alignment of annual growth with preceding year sourcing measures produces a balanced analytical sample of 120 observations covering 2011 to 2025. This setting permits comparison across economies with different recorded sourcing distributions, while purposive selection limits population wide generalization. Separate models relate each sourcing measure to annual import growth while accounting for country and year fixed effects. The design examines changes within countries after allowing for common annual conditions. Country clustered inference, a restricted wild cluster bootstrap and repeated estimation after individual country exclusions assess uncertainty and sensitivity. Preceding year timing establishes temporal ordering of the recorded measures without identifying causal effects. The design consequently supports associational interpretation rather than claims that changes in sourcing structure cause changes in expenditure.

The completed analysis contributes by showing that the three sourcing dimensions have negative adjusted point estimates, including geographical breadth, whose anticipated benefits do not translate into a precisely estimated positive association with import growth. Every individual country exclusion preserves the negative coefficient directions, but statistical interpretation remains uncertain. Conventional confidence intervals include zero for all three measures, and bootstrap inference changes the significance conclusion for dominant supplier dependence. These findings qualify a simple interpretation of diversification as an expenditure growth advantage. They also demonstrate why stability of coefficient direction must be distinguished from stability of statistical evidence. The practical contribution is an outcome specific basis for interpreting pharmaceutical sourcing indicators. The results support monitoring expenditure concentration, leading partner exposure and geographical breadth separately, rather than treating any single indicator as a sufficient benchmark of performance. They do not justify prescribing broader sourcing as a proven route to faster import growth or interpreting expenditure expansion as improved medicine availability. The international relevance lies in this distinction between sourcing configuration and the outcome it is used to evaluate, with empirical conclusions bounded by the selected economies and observed trade measures.

2. Theory, Conceptual Framework and Research Question Development:

This analysis applies production network theory to examine how pharmaceutical import network structure relates to subsequent import value growth across eight economies during 2010 to 2025. International sourcing connects importers to suppliers whose contributions differ in size and substitutability. These relationships create access to external production while transmitting disturbances across borders. Acemoglu et al., 2012, establish theoretically that unequal network connections can prevent individual shocks from averaging out. This provides a foundation for examining the distribution of

pharmaceutical imports across supplying partner areas, without assuming that concentration necessarily reduces growth. The framework comprises three observed dimensions of import network structure: supplier concentration, dominant supplier dependence and supplier diversification. Supplier concentration measures the distribution of import value through the sum of squared partner shares. Dominant supplier dependence measures the largest partner share. Supplier diversification measures the number of partner areas recording positive imports. The outcome is annual growth in pharmaceutical import value, calculated from successive world import totals in current United States dollars. Each network measure precedes the outcome by one year. These measures describe geographical sourcing patterns rather than relationships between individual firms.

Network theory supports competing expectations about import growth. Concentrated sourcing may expose importers to disruptions affecting major suppliers, but established sourcing relationships may also support reliable deliveries and expansion. Broader sourcing may provide alternatives while introducing coordination costs and exposure to disturbances across more locations. Baldwin and Freeman, 2022, explain that supply chain risk must be assessed alongside the benefits of international specialization and the dependence between exposures. Consequently, the analysis uses research questions rather than imposing a common directional prediction across countries and years. Supplier concentration captures how unevenly pharmaceutical import expenditure is distributed across partner areas. A higher concentration index indicates that fewer partners account for a larger share of expenditure. The theoretical concern is that imports become more sensitive to developments affecting those partners. However, concentration can also accompany expansion in imports from established production centres. Its association with subsequent growth therefore depends on whether supplier continuity or supplier disruption dominates during the observation period. Barrot and Sauvagnat, 2016, find that input specificity strengthens the propagation of supplier shocks through production networks. Their evidence identifies substitutability as an important boundary condition for interpreting concentration. In the present analysis, concentration measures expenditure distribution across pharmaceutical partner areas; it does not establish whether products from different origins are interchangeable. The feasible empirical question concerns the association between observed concentration and subsequent import value growth.

RQ1: How is supplier concentration in the preceding year associated with annual pharmaceutical import value growth?

Dominant supplier dependence isolates the contribution of the largest supplying partner. Unlike the concentration index, which incorporates the full distribution of partner shares, this measure identifies exposure to a single leading origin. Two importers can have similar largest supplier shares while differing in how their remaining imports are distributed. The measure therefore captures a distinct feature of sourcing structure, although it may overlap empirically with overall concentration. A leading partner can support import expansion through sustained supply, while a disturbance affecting that partner can constrain purchases. Carvalho et al., 2021, document the propagation of earthquake disruptions through direct and indirect supply relationships. Their findings establish that supplier connections can transmit shocks, but they do not establish a uniformly negative relationship between the largest supplier share and annual pharmaceutical import growth. This analysis therefore examines the observed association without treating supplier dominance as evidence of disruption.

RQ2: How is dominant supplier dependence in the preceding year associated with annual pharmaceutical import value growth?

Supplier diversification captures the geographical breadth of positive import relationships. Additional partner areas may offer alternative purchasing channels and access to products unavailable from existing origins. However, a greater partner count does not necessarily imply meaningful replacement capacity. Small transactions can increase the count while contributing little to total imports, and different partner areas may depend on common upstream production. Bonadio et al., 2021, show that international sourcing can transmit foreign disturbances while also insulating economies from domestic disruptions. Their findings indicate that the consequences of sourcing breadth depend on the distribution of shocks across locations. Applied here, diversification could accompany import expansion, remain unrelated to growth, or reflect purchases spread across smaller suppliers. The recorded partner count supports examination of these patterns without establishing operational substitutability.

RQ3: How is supplier diversification in the preceding year associated with annual pharmaceutical import value growth?

The conceptual framework links each preceding year network measure separately to current annual pharmaceutical import value growth. These links represent temporal associations rather than identified causal effects. The workbook contains 128 country and year observations, including 120 observations with the consecutive values required for these comparisons. Separate assessment preserves the distinction between expenditure concentration, leading partner exposure and geographical breadth without treating them as an unconstructed composite index. Interpretation remains specific to nominal import value: changes can reflect prices, quantities and product composition. The analysis can therefore resolve the three research questions while retaining positive, negative, negligible or inconclusive associations as admissible outcomes.

3. Data:

This analysis establishes the provenance of pharmaceutical import records, documents sample construction and defines the observed measures of sourcing structure and import growth. The accompanying workbook preserves source records, extraction metadata and calculation formulas, allowing each analytical observation to be traced to its underlying trade values.

3.1 Data Sources, Population, and Sample Construction:

The dataset contains annual pharmaceutical merchandise imports obtained through the World Bank World Integrated Trade Solution platform using underlying United Nations Comtrade records. The extraction uses public country, year, partner and product tables rather than combining independent trade databases. The World Bank identifies World Integrated Trade Solution as an access platform for merchandise trade statistics compiled by the United Nations Statistics Division. Access remains subject to the dissemination arrangements of the underlying provider, as explained in World Bank, 2010. The source selection comprises annual imports, all partner areas and pharmaceutical products classified under Harmonized System chapter 30. The workbook records nomenclature code H0, annual frequency A and import flow M. H0 identifies the source classification rather than a publication release. No immutable database release identifier is supplied. Each extraction log entry records its exact source URL, extraction date, returned record count and corresponding raw worksheet rows. The observation period is 2010 to 2025; the extraction date describes retrieval of those historical observations and is preserved separately in the workbook. The unit of analysis is the importing country in a calendar year. The empirical setting comprises Australia, Brazil, China, Germany, India, Rwanda, South Africa and the United States. These eight economies contribute 16 annual observations each, forming a balanced panel of 128 observations. Import values represent flows accumulated during each year rather than stocks or values measured at year end. Annual frequency permits construction of successive import growth rates and alignment with sourcing characteristics observed in the preceding year.

The target population comprises economies participating in international pharmaceutical import networks during the observation period. The accessible sampling frame consists of the eight selected economies and their retrievable chapter 30 import tables. The workbook documents purposive selection before extraction to obtain geographical coverage rather than statistical significance. It does not enumerate a global eligible population or establish inclusion probabilities. Accordingly, the sample supports comparisons across the selected economies without providing a representative estimate for all pharmaceutical importing countries. The extraction contains 11,682 source rows, including 128 world total rows and 11,554 partner rows. All 128 requested country and year tables returned records. The raw worksheet retains every displayed row. Construction of the analytical measures excludes world totals from partner calculations and includes only positive partner values in the sourcing distribution. Two rows labelled Unspecified for China in 2023 are combined into one residual partner category when calculating network indicators.

Table 1: Sample construction and analytical coverage

Stage	Countries	Observations or Records	Implemented Rule
Selected accessible frame	8	128 country and year combinations	Eight economies observed annually from 2010 to 2025
Retrieved source tables	8	128 tables containing 11,682 rows	Every requested table returned records
World totals identified	8	128 rows	Retained for import levels and growth; excluded from partner calculations
Partner records retained	8	11,554 raw rows	All displayed partner records preserved
Zero partner values	Within selected countries	78 rows	Preserved in raw data; excluded from positive supplier counts
Repeated residual partner label	1	2 rows combined into 1 category	Unspecified entries for China in 2023 aggregated before calculating indicators
Constructed annual panel	8	128 observations	One unique record per importer and year
Initial observations without preceding year values	8	8 observations excluded from temporal comparisons	First observation for each country lacks an observed growth denominator and preceding year predictors
Sample with aligned growth and predictors	8	120 observations	Fifteen consecutive annual comparisons per country, covering 2011 to 2025

The analytical sample retains all eight countries after temporal alignment. No additional observations are lost through missing current import values or network indicators. The resulting comparison panel remains balanced, with 15 observations per country. These counts describe data availability and construction; they are not regression estimation counts.

3.2 Data Integration, Cleaning, and Quality Assurance:

Integration uses importer identity, reporter M49 code and year. The query identifier links each annual panel record to its extraction log entry and associated partner records. Every panel query identifier appears in both the extraction log and the raw worksheet. The panel contains no duplicate importer and year keys, and the extraction log contains no duplicate query identifiers. The raw data contain no

completely identical rows. Partner identity follows the displayed area name rather than relying exclusively on embedded hyperlink codes. The workbook documents cases in which hyperlink codes do not identify the displayed partner correctly. World totals are therefore identified by the displayed name World. The two Unspecified records for China in 2023 remain separate in the raw worksheet but contribute to one residual category in the calculated sourcing distribution. This preserves the source evidence while preventing the repeated label from being counted as two distinct suppliers.

The annual panel follows a rectangular structure with one observation per row and one variable per column. Raw records, calculated measures and metadata occupy separate worksheets. This organization corresponds to the observational structure described by Wickham, 2014, and the spreadsheet practices discussed by Broman and Woo, 2018. These references explain the organization of the delivered data rather than provide external validation of the trade values. Source values are reported in thousands of current United States dollars and are multiplied by 1,000 to construct dollar values. This operation changes the reporting scale; it does not convert between currencies. No exchange rate series, inflation adjustment or deflator enters the calculations. All observations retain their reported calendar years, and no frequency conversion is applied.

Quality assurance independently reconstructs partner totals, largest partner values, positive partner counts, sums of squared values, concentration indices and largest supplier shares from the raw worksheet. Every reconstructed indicator matches the corresponding panel value within numerical precision. Partner totals are also compared with reported world totals using a tolerance equal to the larger of USD 1,000 and one millionth of the world total. All 128 observations satisfy this rule. The largest absolute discrepancy is USD 80, consistent with rounding of source values reported to two decimal places in thousands of dollars. The 11,682 raw records contain no missing values in their recorded fields. Seventy-eight partner values equal zero, and no import values are negative. Zero values remain in the raw worksheet but do not identify positive sourcing relationships. Current annual world imports, concentration, largest supplier shares and positive partner counts are complete for all eight countries throughout 2010 to 2025.

Missing analytical values arise exclusively from temporal construction. Each country has one undefined growth rate and one unavailable value for each preceding year measure in 2010. These eight initial observations are excluded together from the aligned sample. No observations are imputed, interpolated or replaced by synthetic values. No trimming, winsorization or deletion based on statistical extremity is applied. The audit also checks that sourcing shares lie between zero and one, supplier counts are positive and growth denominators are positive. Annual growth recalculated from successive world totals reproduces all 120 recorded values. These checks establish internal numerical consistency. They do not constitute independent confirmation against a second trade provider. The dataset is a retrospective extraction rather than a sequence of historical publication vintages. The workbook does not establish what information was publicly available at each original observation date. Preceding year alignment orders the recorded trade periods but does not eliminate later revisions to historical records. No cleaning rule based on regression results is documented or applied.

3.3 Variable Measurement, Construction, and Validation:

Pharmaceutical import network structure is operationalized through three calculated measures: supplier concentration, dominant supplier dependence and supplier diversification. All three derive from the same positive partner values but capture different distributional properties. The outcome is annual growth in reported world pharmaceutical import value. For each importer and year, a partner share is calculated as follows.

$$s_{ijt} = \frac{v_{ijt}}{S_{it}}$$

Here, s_{ijt} is the import share of partner area jfor importer iin year t, v_{ijt} is that partner's positive import value and $S_{it}$is the sum of positive partner import values. World totals are excluded from this denominator. Repeated records sharing the residual Unspecified label are combined before shares are calculated. Supplier concentration is calculated using Equation 2.

$$C_{it} = \sum_{j} s_{ijt}^2$$

Here, C_{it} is the concentration index. Squaring partner shares gives greater weight to larger suppliers. Higher values indicate a more concentrated distribution of expenditure. The index uses observed shares without normalization against an external benchmark. Dominant supplier dependence is calculated using Equation 3.

$$D_{it} = \max_{j} s_{ijt}$$

Here, D_{it} is the largest positive partner share. Higher values indicate greater expenditure dependence on the leading partner area. The measure does not require the leading partner to remain the same across years. Supplier diversification is calculated using Equation 4.

$$N_{it} = \sum_{j} 1_{v_{ijt}>0}$$

Here, N_{it} is the number of partner areas with positive imports, and 1equals one when the stated condition holds and zero otherwise. Each positive partner category receives equal counting weight regardless of its expenditure share. Annual import growth satisfies Equation 5.

$$g_{it} + 1 = \frac{W_{it}}{W_{it}^{L}}$$

Here, g_{it} is annual import value growth, W_{it} is reported world imports in the current year and $W_{it}^{L}$is reported world imports in the immediately preceding year. Growth is stored as a decimal ratio. Multiplication by 100 expresses it as a percentage change rather than a percentage point change.

Table 2: Variable dictionary

Variable or Indicator	Analytical Role	Definition and Construction	Source and Identifier	Unit and Frequency	Transformation and Direction	Missing Value Rule	Coverage and Limitation
World pharmaceutical imports	Outcome construction and scale	Reported world import total multiplied by 1,000	WITS access to UN Comtrade; H0; chapter 30; flow M; frequency A; World partner	Current USD, annual	Higher values indicate greater nominal expenditure	None missing	128 observations; affected by prices, quantities and product composition
Supplier concentration	Predictor	Sum of squared positive partner shares, Equation 2	Same source selection; positive partner rows excluding World	Index between zero and one, annual	Higher values indicate greater concentration; preceding year value used in aligned comparisons	First preceding year value unavailable for each country	128 current values and 120 aligned values; measures geographical expenditure concentration
Dominant supplier dependence	Predictor	Largest positive partner share, Equation 3	Same source selection and partner denominator	Share between zero and one, annual	Higher values indicate greater leading partner dependence; preceding year value used	First preceding year value unavailable for each country	128 current values and 120 aligned values; leading partner can change
Supplier diversification	Predictor	Number of partner areas with positive imports, Equation 4	Same source selection; repeated Unspecified labels combined	Partner count, annual	Higher values indicate broader recorded sourcing; preceding year value used	First preceding year value unavailable for each country	128 current values and 120 aligned values; includes small positive flows and residual categories
Annual import value growth	Outcome	Ratio of successive world totals, Equation 5	Same source selection; World partner	Decimal growth rate, annual	Reported as percentage change in descriptive statistics	First observation undefined for each country	120 observations; measures nominal expenditure growth
Analytical eligibility	Sample flag	One when growth and all preceding year predictors are observed; zero otherwise	Calculated panel field	Binary, annual	Identifies the common comparison sample	No missing values	120 eligible observations and eight initial exclusions

The measures represent observed trade distributions rather than latent psychological or organizational constructs. Their validation therefore rests on reproducible aggregation, denominator checks and agreement with underlying records. Factor analysis and internal consistency coefficients are not appropriate to these calculations. The sectoral boundary is pharmaceutical merchandise under chapter 30. This classification is broader than essential medicines and does not capture every pharmaceutical input classified elsewhere. The outcome also combines changes in expenditure arising from prices, quantities and the mix of imported products. The distinction between trade value and physical quantity follows the measurement framework of United Nations, 2011. Table 3 reports descriptive statistics for the common sample of 120 observations. Predictor statistics refer to preceding year values, while import levels and growth refer to the current year. Standard deviations use the sample convention.

Table 3: Descriptive statistics for the aligned analytical sample

Variable	Valid Observations	Mean	Standard Deviation	Median	Minimum	Maximum
Current pharmaceutical imports, USD billions	120	29.258	44.435	8.466	0.073	213.566
Annual import growth, percent	120	6.621	12.955	6.495	−19.879	55.628
Preceding year supplier concentration	120	0.1125	0.0397	0.0992	0.0797	0.2574
Preceding year largest supplier	120	0.2226	0.0768	0.1985	0.1243	0.4832

Variable	Valid Observations	Mean	Standard Deviation	Median	Minimum	Maximum
share						
Preceding year positive partner count	120	89.050	21.999	88.500	46	136

The mean import value exceeds the median, reflecting differences in import expenditure across the selected economies. Annual growth includes both contractions and expansions, with a mean of 6.621 percent and a median of 6.495 percent. The largest supplier accounts for an average share of 0.2226, while positive partner counts range from 46 to 136. These statistics describe the sample distribution without establishing relationships between network structure and growth. Concentration and largest supplier dependence share information because the largest share contributes to the concentration index. Supplier counts measure breadth without accounting for expenditure balance. The three variables therefore remain separate indicators rather than components of an additional composite score.

3.4 Analytical Framework, Identification, and Reproducibility:

The constructed dataset supports descriptive analysis and examination of temporal associations. Its analytical target is the relationship between each preceding year sourcing measure and current annual pharmaceutical import value growth. All three comparisons can use the same 120 observations, preventing differences in sample availability from driving comparisons across dimensions. The implemented work comprises source consolidation, indicator construction, temporal alignment, descriptive statistics and internal consistency checks. No regression coefficients, fixed effects estimates, standard errors or robustness results are contained in the workbook or established by these checks. The analytical eligibility flag identifies complete observations rather than certifying an estimated model. Preceding year timing separates the periods used to measure sourcing structure and growth. It does not establish exogenous variation. Demand changes, product composition, prices and other determinants can influence both sourcing patterns and expenditure growth. Consequently, any subsequent association requires interpretation within an observational design. The current data also do not establish information availability sufficient for evaluation of forecasts made in real time.

The completed validation addresses specific construction risks. Reconstruction from raw records checks aggregation and indicator formulas. Reconciliation with world totals checks denominator consistency. Unique panel identifiers prevent repeated annual observations. Consecutive year matching prevents growth calculations across gaps. The common eligibility flag aligns coverage across the three research questions. These procedures are data verification checks rather than alternative model estimates. Reproducibility rests on five workbook components: the annual panel, raw imports, extraction log, definitions and sources, and embedded formulas. Query identifiers connect the panel to source records. The extraction log preserves retrieval details and raw row boundaries. Original displayed values remain available alongside their conversion to dollars, while formulas expose the calculations used for concentration, largest supplier share and annual growth.

This separation of evidence, transformations and documentation follows the reproducibility principle articulated by Peng, 2011, that published numerical claims should be supported by the materials needed to evaluate their production. Sandve et al., 2013, similarly emphasize preserving the connection between source inputs, computational steps and results. Here, the workbook provides that connection for the constructed variables and reported descriptive statistics; it does not claim to supply a standalone extraction program or a versioned database archive. The data definitions remain aligned across the analytical sample: all sourcing indicators use positive partner values from the same product coverage, all preceding year measures refer to the immediately previous calendar year, and all growth rates use reported world totals. This consistency supports comparison across the selected economies while keeping interpretation specific to recorded pharmaceutical trade expenditure.

4. Methods:

4.1 Research Design and Analytical Sample:

This analysis uses an observational panel design to examine associations between preceding year pharmaceutical sourcing structure and subsequent annual import value growth. The unit of analysis is the importing country in a calendar year. The estimand is the linear association between each sourcing indicator and growth after accounting for persistent country differences and annual conditions shared across the sampled economies. The sample construction documented in Table 1 produces 120 observations across eight countries during 2011 to 2025. Each country contributes 15 observations, and every model uses the same balanced panel. The initial observation for each country supplies preceding year sourcing information but cannot contribute an observed annual growth rate within the collected period. No additional observations are excluded from the baseline models.

Identification of the conditional associations relies on changes within countries after removing country and year effects. This adjustment separates the estimated relationships from stable differences between importers and common annual variation. It does not account for all changing country characteristics, anticipated purchasing decisions or product composition. Preceding year timing

establishes the order of the recorded measures without establishing exogeneity. Estimates therefore receive an associational interpretation rather than a causal interpretation. The purposive country selection supports comparison within the observed sample. Equal observation weights ensure that larger importers do not dominate estimation solely because of their expenditure levels. The analysis does not use population weights or claim that the selected countries represent all pharmaceutical importing economies.

4.2 Model Specification and Measurement Alignment:

The variable definitions and construction rules appear in Table 2 and Equations 1 to 5. Three separate models examine supplier concentration, dominant supplier dependence and supplier diversification. Separate estimation preserves the interpretation of each measure without treating overlapping indicators as independent components of a combined effect. The implemented specification is

$$y_{it} = \alpha + \beta_k x^{L}_{kit} + \mu_i + \lambda_t + \varepsilon_{kit}, \qquad k \in \{1,2,3\}.$$

Here, y_{it} is annual pharmaceutical import growth for country iin year t, expressed in percentage points; α is the intercept; x^{L}_{kit} is the preceding year value of sourcing indicator k; β_k is its conditional association with growth; μ_i is the country fixed effect; λ_t is the year fixed effect; and ε_{kit} is the model disturbance. The indicator index identifies three separately estimated specifications. Growth stored as a decimal in the workbook is multiplied by 100 before estimation. Concentration and largest supplier dependence retain their original share scales, while diversification retains its partner count scale. Reported contrasts express a concentration increase of 0.01, a largest supplier shares increase of 10 percentage points and an increase of 10 positive partner areas. Coefficients, standard errors and confidence limits are multiplied by the corresponding scaling factors of 0.01, 0.10 and 10.

Country and year effects are implemented through an intercept, seven country indicators and fourteen-year indicators, with one reference category omitted from each set. Including the focal predictor gives 23 estimated parameters and 97 residual degrees of freedom. Each baseline design matrix has full column rank. Residualizing each predictor against the country and year indicators confirms that all three retain variation for estimation. The outcome measures nominal expenditure growth. The predictors describe geographical sourcing distributions rather than product equivalence, supplier reliability or operational replacement capacity. Interpretation remains aligned with these observed measures.

4.3 Estimation and Statistical Inference:

Ordinary least squares estimate Equation 6 separately for each sourcing indicator. Pearson correlations summarize unadjusted linear associations and overlap among the predictors. These correlations describe the pooled observations; they are not interpreted as independent observation significance tests. Calculations use Python 3.12.14, pandas 2.2.3, NumPy 2.3.5 and SciPy 1.17.0. NumPy least squares routines estimate coefficients directly from the design matrices. SciPy supplies Student t probabilities and critical values. Estimation uses no optimization initialization or convergence criterion because the linear coefficients are obtained by least squares.

The baseline covariance estimator clusters disturbances by country, permitting heteroskedasticity and dependence across observations within each country. Cameron and Miller, 2015, provide the methodological basis for clustering when repeated observations may share disturbances. The implemented covariance matrix is

$$\hat{V} = \frac{G}{G-1}\frac{n-1}{n-K}[X'X]^{-1}\left[\sum_{i=1}^{G} X_i' \hat{u}_i \hat{u}_i' X_i\right][X'X]^{-1}.$$

Here, $\hat{V}$ is the estimated coefficient covariance matrix; Gis the number of country clusters; n is the observation count; Kis the number of estimated parameters; Xis the complete design matrix; $X_i$contains its rows for country i; and $\hat{u}_i$ contains that country's fitted residuals. The leading factors apply the finite sample correction. Baseline calculations use eight clusters, 120 observations and 23 parameters. Conventional two sided probability values and 95 percent confidence intervals use a Student t reference distribution with seven degrees of freedom. Country clustering assumes independence across country clusters. Year effects absorb common annual mean shifts but do not eliminate every possible form of residual dependence between countries. A restricted wild cluster bootstrap assesses sensitivity to inference with eight clusters. For each specification, the null imposes a zero focal slope. The restricted regression retains the country and year effects and produces fitted values and residuals. Bootstrap outcomes are constructed as

$$y^{*}_{it} = \hat{y}^{0}_{it} + w_i \hat{u}^{0}_{it}.$$

Here, y^{*}_{it} is a bootstrap outcome, $\hat{y}^{0}_{it}$ is the restricted fitted value, $\hat{u}^{0}_{it}$is the restricted residual, and $w_i$is a country specific weight taking values of negative one or positive one. Every observation within a country receives the same weight. All 256 country sign configurations are enumerated. Each bootstrap sample is estimated using the unrestricted specification and the same corrected country clustered covariance formula. The bootstrap probability value is the proportion of absolute bootstrap t statistics at least as large as the absolute observed statistic. Numerical comparison uses a tolerance of one billionth. Exhaustive enumeration removes simulation randomness, so no random seed is required. It does not make bootstrap inference assumption free. MacKinnon et al., 2023, motivate examining inference procedures explicitly when cluster structure and limited cluster counts affect reliability.

4.4 Verification, Sensitivity and Reproducibility:

Processing begins with the workbook's constructed annual panel. Records are ordered by importer and year, growth is aligned with immediately preceding year sourcing values, and the common eligibility flag restricts estimation to complete observations. No imputation, interpolation, statistical trimming or winsorization is applied. Valid extreme growth observations remain in the analysis. Verification independently reconstructs the sourcing indicators from the raw partner records and recalculates growth from successive world import totals. Checks also examine unique panel identifiers, positive denominators, permissible share ranges and agreement between partner sums and world totals. These procedures assess numerical construction and sample integrity rather than causal identification.

Eight country omission estimates are computed for each predictor. Each exercise removes all observations for one country and reestimates the same country and year adjusted specification using the remaining 105 observations. The comparison assesses whether coefficient direction and magnitude depend on a single importer. The country omission exercise and bootstrap comparison are exploratory sensitivity analyses rather than preregistered tests. Interpretation considers coefficient magnitude, interval width, country omission ranges and differences between inference procedures. A probability value above a conventional threshold is not treated as proof of no association. Conversely, a threshold crossing under one procedure does not establish a stable conclusion when another procedure yields materially different uncertainty.

The workbook documents source records, query identifiers, extraction metadata, variable definitions and construction formulas. Equations 6 to 8 specify the additional estimation and inference operations used for the findings. This distinction separates the supplied data construction materials from the analytical procedures described here. Peng, 2011, and Sandve et al., 2013, emphasize traceability between inputs, computational operations and reported results as a basis for reproducible research. The methodological contribution rests on consistent measurement, common sample comparisons and transparent uncertainty assessment using established tools. Together, these procedures answer the sourcing questions within an observational framework without attributing unmeasured mechanisms or causal effects to the estimated relationships

5. Findings:

This analysis examines whether preceding year pharmaceutical sourcing patterns are associated with subsequent annual import value growth. The findings combine sample distributions, separate country and year adjusted estimates, and sensitivity checks using the same observations. The evidence distinguishes the direction and magnitude of estimated associations from their precision and dependence on the inference procedure.

5.1 Analytical Sample and Sourcing Patterns:

The constructed panel contains 128 annual observations across Australia, Brazil, China, Germany, India, Rwanda, South Africa and the United States during 2010 to 2025. Aligning import growth with preceding year sourcing measures excludes the initial observation for each country, leaving a balanced analytical sample of 120 observations covering 2011 to 2025. Each country contributes 15 observations. All three association models use this common sample. Annual pharmaceutical import growth averages 6.621 percent, with a median of 6.495 percent and a standard deviation of 12.955 percentage points. Observed growth ranges from a contraction of 19.879 percent in Rwanda in 2018 to an expansion of 55.628 percent in Brazil in 2021. These values represent changes in nominal import expenditure and therefore combine changes in prices, quantities and product composition.

Table 4: Distribution of analytical variables

Variable	Observations	Mean	SD	Median	Minimum	Maximum
Annual pharmaceutical import growth, percent	120	6.621	12.955	6.495	−19.879	55.628
Preceding year supplier concentration	120	0.1125	0.0397	0.0992	0.0797	0.2574
Preceding year largest supplier share	120	0.2226	0.0768	0.1985	0.1243	0.4832
Preceding year positive partner count	120	89.050	21.999	88.500	46	136

Country summaries reveal differences between sourcing breadth and import expansion. Germany and South Africa record the highest average preceding year partner counts, at 117 and 115, respectively, but their mean annual import growth is below that of several economies with fewer recorded partners. Rwanda has the highest average concentration and largest supplier dependence, yet its average growth exceeds that of Australia, Germany and South Africa. These comparisons do not support a simple ranking in which broader geographical sourcing consistently corresponds to faster expenditure growth.

Table 5: Country profiles in the common analytical sample

Country	Observations	Mean Annual Growth, Percent	Mean Preceding Year Concentration	Mean Preceding Year Largest Supplier Share	Mean Preceding Year Partner Count
Australia	15	2.838	0.0927	0.1907	86.000
Brazil	15	6.911	0.0992	0.2022	66.533

Country	Observations	Mean Annual Growth, Percent	Mean Preceding Year Concentration	Mean Preceding Year Largest Supplier Share	Mean Preceding Year Partner Count
China	15	12.802	0.1077	0.2172	78.733
Germany	15	4.591	0.1029	0.1776	117.000
India	15	8.075	0.0973	0.2015	96.200
Rwanda	15	7.035	0.2086	0.3903	56.867
South Africa	15	1.893	0.0970	0.2010	115.000
United States	15	8.823	0.0946	0.2002	96.067

Supplier concentration and largest supplier dependence are strongly correlated, with a Pearson coefficient of 0.9517. Their correlations with partner count are −0.5181 and −0.5024, respectively. This overlap supports examining the three indicators in separate models rather than interpreting them as independent contributions within a single specification. Unadjusted correlations with growth are small: −0.0149 for concentration, 0.0152 for largest supplier dependence and −0.1286 for partner count. These pooled summaries are descriptive and do not account for persistent country differences or common annual conditions.

5.2 Associations Between Sourcing Structure and Import Growth:

Each model regresses annual import growth, expressed in percentage points, on one preceding year sourcing indicator, country fixed effects and year fixed effects. Estimation uses ordinary least squares. Country effects absorb persistent differences between importers, while year effects absorb annual conditions shared across the sample. The reported associations therefore depend on changes within countries after accounting for common annual variation. Standard errors are clustered by country, with a finite sample correction. Conventional confidence intervals and probability values use a student t reference distribution with seven degrees of freedom. Because the sample contains only eight country clusters, these intervals require cautious interpretation. Cameron and Miller, 2015, explain why repeated observations within clusters require appropriate inference and why a small number of clusters complicates conventional approximations.

Table 6: Separate associations with subsequent annual pharmaceutical import growth

Preceding Year Predictor	Reported Increase	Estimated Growth Difference, Percentage Points	Clustered Standard Error	Lower 95 Percent Limit	Upper 95 Percent Limit	Conventional p Value
Supplier concentration	0.01 index units	−1.363	0.622	−2.834	0.109	0.065
Largest supplier share	10 percentage points	−2.506	1.629	−6.358	1.346	0.168
Positive partner count	10 partner areas	−2.052	2.053	−6.907	2.803	0.351

Source: Calculations from the supplied workbook. Each model contains 120 observations, eight countries, country fixed effects and year fixed effects. Standard errors and confidence intervals are scaled to the reported predictor increase.

For RQ1, a concentration increase of 0.01 is associated with annual import growth lower by 1.363 percentage points. The confidence interval extends from 2.834 percentage points lower growth to 0.109 percentage points higher growth. The point estimate therefore indicates a negative association, but its conventional 95 percent interval includes zero. The direction is compatible with the proposition that reliance on a narrower expenditure distribution can accompany weaker subsequent expansion. However, the estimate does not identify supplier disruptions or product substitution as the operative mechanism. Barrot and Sauvagnat, 2016, demonstrate the importance of input specificity in transmitting supplier shocks; the present measure captures geographical expenditure concentration without observing that specificity.

For RQ2, a 10-percentage point increase in the largest supplier share is associated with annual growth lower by 2.506 percentage points. Its conventional confidence interval ranges from 6.358 percentage points lower growth to 1.346 percentage points higher growth. This range accommodates both a substantial negative association and a modest positive association. The estimate concerns dependence on the leading partner area, rather than an observed interruption originating from that partner. Carvalho et al., 2021, identify disruption transmission through production relationships, but that evidence does not establish that the association estimated here reflects the same process.

For RQ3, an increase of 10 positive partner areas is associated with annual growth lower by 2.052 percentage points. The confidence interval extends from 6.907 percentage points lower growth to 2.803 percentage points higher growth. Geographical breadth therefore does not display a precisely estimated positive association with subsequent expenditure expansion in this sample. This result does not establish that diversification reduces supply resilience. Partner counts do not measure replacement capacity, product equivalence or the geographical distribution of upstream dependencies. Bonadio et al., 2021, show that international sourcing can transmit disturbances while also limiting exposure to domestic shocks, reinforcing the need to distinguish sourcing breadth from a direct measure of resilience.

5.3 Sensitivity to Country Composition and Inference:

Two exploratory checks assess distinct threats to interpretation. Repeated estimation after excluding one country examines whether the direction depends on a single importer. A restricted wild cluster bootstrap examines sensitivity to the inference procedure given the small number of country clusters. Both checks retain the separate predictor specifications and their country and year effects. All three coefficients remain negative in every country omission exercise. For concentration, the estimated difference associated with a 0.01 increase ranges from −2.149 to −1.092 percentage points. For largest supplier dependence, the difference associated with a 10 percentage point increase ranges from −4.019 to −1.401 percentage points. For diversification, the difference associated with 10 additional partners ranges from −3.799 to −0.997 percentage points.

Table 7: Country omission and inference sensitivity

Predictor and Reported Increase	Lowest Estimate After Country Omission	Highest Estimate After Country Omission	Conventional p Value	Wild Cluster Bootstrap p Value
Concentration increase of 0.01	−2.149	−1.092	0.065	0.195
Largest supplier shares increase of 10 percentage points	−4.019	−1.401	0.168	0.023
Increase of 10 positive partner areas	−3.799	−0.997	0.351	0.305

The country omission results establish stability of coefficient direction across the examined sample changes. They do not establish stable statistical significance. Magnitudes vary, particularly for partner count, showing that estimated associations remain sensitive to the composition of the eight-economy sample. Inference also differs across procedures. Concentration and partner count do not reject a zero association at the 5 percent level under either reported procedure. For dominant supplier dependence, the bootstrap probability value is 0.023, whereas the conventional value is 0.168. The disagreement means that the statistical conclusion for this predictor depends on the inference method. The bootstrap result is therefore reported alongside the conventional interval rather than used to replace it selectively. Exhaustive enumeration removes simulation randomness from this particular bootstrap calculation, but it does not eliminate dependence on the bootstrap assumptions or the limited number of clusters. MacKinnon et al., 2023, emphasize that cluster structure and the choice of inference procedure can materially affect empirical conclusions.

5.4 Resolution of the Research Questions:

RQ1 yields a negative estimated association between preceding year concentration and subsequent pharmaceutical import growth. Its direction persists across every country omission, but neither reported inference procedure establishes a negative association at the 5 percent level. RQ2 also yields a negative estimate that persists across country omissions. Statistical evidence is sensitive to the inference procedure: the restricted bootstrap rejects a zero slope, while the conventional confidence interval includes zero. The defensible conclusion is a negative estimated association with method dependent precision. RQ3 yields a negative association between preceding year partner count and growth, with substantial uncertainty under both inference procedures. The evidence does not establish that broader recorded sourcing predicts faster nominal pharmaceutical import growth. Across the three questions, the clearest finding is the distinction between coefficient direction and evidential strength. Negative adjusted estimates are stable across the examined country exclusions, while their magnitudes and statistical interpretation remain uncertain. The results support an associational account of pharmaceutical sourcing structure and expenditure growth within the selected economies. They do not identify causal effects or establish that nominal import expansion measures medicine availability or supply resilience.

6. Discussion:

Pharmaceutical sourcing breadth does not translate automatically into faster import expansion. Table 6 shows negative adjusted associations for concentration, dominant supplier dependence and partner count, while Table 7 distinguishes stability of direction from uncertainty about statistical significance. The contribution lies in examining these sourcing dimensions against the same subsequent expenditure outcome, rather than treating diversification as an established growth advantage. Equations 2

to 4 distinguish expenditure concentration, leading partner exposure and geographical breadth, while Equation 5 defines nominal import growth. This separation matters because network fragility concerns the functioning of interconnected production relationships, whereas import growth measures expenditure expansion. Elliott and Golub, 2022, emphasize that fragility depends on structural relationships and responses to shocks. The present evidence adds an empirical boundary to that argument: observable sourcing structure cannot be interpreted as a direct measure of either growth performance or resilience. The distinction between structural exposure and an identified transmission mechanism is central to interpreting supplier dependence. The negative estimates in Table 6 are compatible with constraints associated with concentrated sourcing, but they do not distinguish supplier disruption from demand adjustment, price changes or shifts in product composition. Equations 2 and 3 describe expenditure allocation without observing the processes through which procurement relationships affect deliveries. Gereffi, 2020, demonstrates that medical supply outcomes emerge from interactions between demand, production organization and public policy, rather than geographical sourcing alone. The contribution here is therefore a disciplined separation of measurable exposure from mechanism attribution. A leading partner share can identify where expenditure dependence resides, but its association with subsequent growth does not establish how that dependence operates. This distinction prevents aggregate trade relationships from being interpreted as evidence of a specific causal pathway.

The three indicators also provide overlapping information, which changes how their relative importance should be understood. The correlation of 0.9517 between concentration and largest supplier dependence shows that these measures largely track a shared expenditure pattern in this sample. Their separate coefficients in Table 6 cannot be added, converted into contribution shares or ranked as dominant transmission channels. Equations 2 and 3 explain the overlap because the largest supplier share contributes directly to the concentration index. By contrast, Equation 4 counts positive relationships without measuring their expenditure importance or replacement capacity. Elliott et al., 2022, model fragility through the formation and reliability of supply relationships, highlighting properties that geographical counts alone cannot capture. The present analysis sharpens the measurement implication: more recorded partners and a more balanced expenditure distribution are distinct characteristics, and neither independently establishes operational redundancy. The sensitivity results reveal that persistence of coefficient direction is a narrower achievement than persistence of statistical evidence. Table 7 shows negative estimates after every individual country exclusion, indicating that no single importer determines their signs. Nevertheless, the disagreement between conventional and bootstrap inference for dominant supplier dependence prevents a method invariant significance claim. This changes the substantive interpretation from an established supplier dependence penalty to a negative association whose precision remains sensitive to the inference procedure. Wasserstein et al., 2019, argue against reducing scientific interpretation to whether a probability value crosses a threshold. Applied here, the contribution is to retain magnitude, uncertainty and sample sensitivity together: consistent signs justify further examination of the relationship, while conflicting inference limits the strength of conclusions drawn from eight country clusters.

The international comparison further challenges the use of sourcing breadth as a universal performance benchmark. Table 5 shows that Germany and South Africa combine relatively broad partner coverage with lower average import growth than several economies with fewer partners, while Rwanda combines higher concentration with intermediate growth. These differences do not establish separate effects for advanced and emerging economies, but they demonstrate why country rankings in breadth cannot substitute for analysis of subsequent outcomes. Ivanov and Dolgui, 2020, distinguish the continued functioning of interconnected supply networks from narrower descriptions of their configuration. The practical implication is to monitor partner breadth, expenditure balance and leading supplier exposure separately, alongside an explicit definition of the outcome being managed. Table 6 does not justify prescribing either more suppliers or less concentration as a proven route to faster import growth. The broader contribution is an outcome specific framework for evaluating pharmaceutical sourcing across countries, with expenditure expansion kept distinct from continuity of medicine supply.

7. Conclusion and Implications:

More international sourcing connections do not automatically imply stronger pharmaceutical import expansion. Across the examined economies, the three dimensions of sourcing structure yield negative adjusted associations with subsequent expenditure growth, although their precision differs across inference procedures. The contribution is an empirical distinction between geographical sourcing patterns and the performance outcomes attributed to them. This analysis qualifies interpretations that equate broader international participation with improved trade performance, while showing that consistent estimate direction does not establish a causal mechanism. The theoretical implication is that network configuration requires interpretation against a clearly specified outcome rather than a universal assumption about diversification benefits. Managers should assess purchasing relationships through separate measures of expenditure distribution and supplier exposure, with explicit attention to uncertainty. Procurement reviews should distinguish changes in spending from changes in physical deliveries before reallocating resources. Policymakers should likewise avoid using geographical breadth or

import expenditure growth alone as evidence of secure medicine provision. Monitoring systems should preserve these distinctions when comparing countries or evaluating sourcing strategies. The international relevance lies in a transferable analytical discipline: align sourcing indicators with the decisions they inform. Such alignment can support more accountable procurement and clearer public reporting without assuming that the observed relationships establish improvements in health or welfare.

The purposive eight economy panel offers a basis for extending comparisons to a broader range of importing systems. More countries would improve assessment of transferability and inference with clustered observations. Product level quantities, prices and delivery records would separate expenditure changes from physical supply performance. Linking these records to supplier identities and upstream production locations would permit direct investigation of substitution capacity and shared dependencies. Designs using plausibly external supply disturbances could strengthen causal identification. Future analyses should also evaluate whether the observed associations differ across procurement arrangements and product categories, with consequential specifications established before examining results.

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