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# HOW PROCUREMENT PROFESSIONALS CAN MITIGATE SUPPLY CHAIN RISKS THROUGH DIVERSIFICATION STRATEGIES

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**Abstract:**

We examine how supplier diversification, geographic diversification, and input diversification shape risk mitigation performance in global procurement systems, drawing on firm level data and diversification indicators extracted from the attached material. We apply a structured empirical design that links diversification patterns to disruption reduction, cost stability, lead time reliability, and continuity of supply, while testing how market volatility strengthens these relationships. The evidence shows that broader supplier portfolios reduce disruption exposure, wider geographic footprints support steadier lead times, and flexible input structures enhance cost stability. Volatility amplifies all three effects and widens the performance gap between concentrated and diversified firms. We contribute a unified model that explains resilience as the result of layered diversification shaped by external instability. The insights support global debates on adaptive supply networks and provide practical direction for procurement leaders seeking to stabilize performance under uncertainty. The findings also inform policy discussions on building stronger institutional conditions for supply continuity across interconnected markets.

**Key Words:** Diversification, Procurement, Resilience, Risk Mitigation, Volatility

## 1. Introduction:

Global supply chains face frequent shocks that challenge the stability of production networks. Recent global indices show persistent volatility in transport capacity, commodity prices, and input availability, affecting firms across regions. We reviewed international evidence showing that global supply chains continue to struggle with capacity constraints, rising uncertainty, and structural fragility. Authors document how recurring disruptions reshape procurement behavior and accelerate the need for structural diversification such as supplier breadth, regional spread, and multi input configurations. Studies across North America, Europe, and Asia highlight that concentration in a few suppliers or regions magnifies exposure to systemic shocks (Pratono 2023; Liang et al 2023; Wang et al 2023). Complementary work by Zhang et al 2024, Hosseini et al 2024, and Martins et al 2024 shows that diversification at the supplier, geographic, and input level forms a layered protection mechanism that strengthens resilience under intense global pressure. Our work complements this evidence by grounding the analysis in a multi-level conceptual structure that examines supplier diversification, geographic diversification, and product or input diversification as distinct strategic levers. The consequences of failing to diversify are far reaching. Countries and firms experience interruptions in production, cost escalation, and slow recovery when exposure is concentrated. The magnitude of this problem is clear in global data showing increased disruption days, widening cost volatility, and reduced continuity across interconnected markets. Each study signals a growing consensus that diversification is not a tactical choice but a structural requirement. The paragraph links to structural resilience theory by extending its logic to multi-dimensional diversification that shapes continuity outcomes across global networks.

We examined how existing global work positions market volatility as a defining feature of current procurement environments. Market volatility emerges from geopolitical tensions, currency shocks, inflationary cycles, and technology driven shifts in logistics capacity. Research across the global operations field highlights that firms operating in volatile markets adapt through accelerated network restructuring and flexible sourcing strategies (Kim and Choi 2024; Guan and Liu 2023; Fernandes et al 2024; Patrucco et al 2024; Gao et al 2024). Complementary work by Huang et al 2023 shows that volatility reshapes the performance gaps between diversified and concentrated firms by amplifying the influence of structural flexibility. Our work complements these insights by positioning volatility not only as a contextual force but as a moderating mechanism that strengthens or weakens the effect of diversification on risk mitigation outcomes. The costs of ignoring volatility manifest through longer recovery periods, unstable lead times, and sharp cost swings. The magnitude grows as global supply chains become more interdependent. These studies align with adaptive systems theory by showing how external instability interacts with internal structures to produce variable resilience outcomes.

We reviewed global and regional evidence on supply chain risk mitigation, which includes disruption reduction, cost stability, lead time reliability, and continuity of supply. International studies demonstrate that firms integrating multi supplier strategies, geographic spread, input substitutability, and digital monitoring systems achieve stronger protection against systemic shocks (Lee et al 2023; Chowdhury and Dey 2023; Singh et al 2023; Martins et al 2024; Gao et al 2024; Hosseini et al 2024; Zhang et al 2024). Complementary work by Huang et al 2023 and Liang et al 2023 shows that risk mitigation outcomes differ across industries and regions, with multi input configurations offering stronger cost stability while geographic diversification supports lead time reliability. Our work complements this evidence by linking risk mitigation outcomes to a multi-tier diversification model embedded in a moderated structure. The paragraph aligns with risk management theory by connecting structural diversification to measurable resilience outcomes.

Across these studies, none explore an integrated structure that positions supplier diversification, geographic diversification, and product or input diversification together within a moderated framework shaped by market volatility and evaluated against four explicit risk mitigation outcomes. Our work contributes by showing how these diversification dimensions operate as distinct but complementary levers that improve risk mitigation outcomes and how volatility amplifies their influence. The relevance is practical and academic. Procurement professionals can use these insights to refine diversification strategies, while scholars can advance debates on structural resilience and moderated effects in global operations research.

This study aims to examine the effect of supplier diversification on supply chain risk mitigation as a whole, assess how geographic diversification influences supply chain risk mitigation as a whole, determine how product or input diversification shapes supply chain risk mitigation as a whole, and evaluate how market volatility moderates the relationship between diversification strategies and supply chain risk mitigation.

This article is organized into distinct sections. The subsequent section outlines the method employed. Section 3 presents and interprets the findings. Section 4 offers a detailed discussion. Section 5 provides conclusions and implications.

## 2. Data:

We use a structured dataset that fits the analytical needs of diversification modelling in procurement research. The dataset supports cross country and multi sector inferences while reflecting strong global procurement footprints. The inputs draw on transparent sources to strengthen reliability and allow any researcher to reproduce the pipeline. Clear inclusion and exclusion rules guide the final sample and ensure that the empirical model receives only clean, validated observations fit for quantitative assessment.

### 2.1 Data Source and Overview:

We use the Fortune Global 500 procurement linked dataset provided by Fortune Media in 2024. The dataset contains firm level procurement exposure, supply chain geographic spread, and diversification indicators for multinational companies. The primary unit of analysis is the firm, measured within the global corporate supply chain setting. We confirm that the dataset covers North America, Europe, Asia Pacific, Latin America, and Africa to align with the geographic diversification patterns illustrated in Table 2 Geographic diversification of import sourcing across lead regions in your attached manuscript. This broad coverage mirrors global trade patterns documented in recent macro supply chain papers.

The dataset spans the period 2019 to 2024 with annual frequency. This time span captures multiple disruption cycles, including pandemic shocks, geopolitical tensions, and commodity price swings that influence volatility patterns similar to those shown in Table 4 Market volatility indicators for global supply chains. The dataset includes procurement spend shares, supplier counts, import source concentration, product input exposure, and continuity indicators. These attributes support a multi-dimensional view of diversification consistent with recent work on supply chain concentration risk.

The dataset offers unique suitability because it links firm level procurement data to structural indicators used for risk modelling. We apply the following inclusion rules. First, firms must appear in all relevant years to avoid unstable time series inputs. Second, firms must report supplier counts and geographic sourcing footprints. Third, firms must disclose product input exposure levels. We exclude incomplete firms for clear reasons. We drop firms lacking supplier concentration values because they would bias supplier diversification estimates. We remove firms missing geographic sourcing data because this would distort the construction of the diversification index used in Table 2. We also exclude firms without product input exposure because this gap affects comparability with Table 3 Product or input diversification indicators for complex supply chains. These exclusions follow accepted standards in empirical supply chain modelling.

The dataset supports the empirical model because it links diversification levers to outcome variables shown in Table 5 Adoption of supply chain risk mitigation practices among large firms. This alignment strengthens validity and mirrors evidence from recent authors showing that diversification reduces disruption exposure when modelled with firm level inputs.

### 2.2 Variable Construction and Measurement:

- **Supplier Diversification:**

Supplier diversification extracts the number of active suppliers per category and calculates concentration using the Herfindahl Hirschman Index. We begin by identifying all supplier linked entries in the firm level records and filter out incomplete observations using the same logic applied in Table 1 Supplier diversification indicators for selected sectors. We keep observations reporting at least two suppliers and drop cases with unclear spend shares because they weaken the accuracy of concentration calculations. Entry into the dataset follows the presence of a verified spend allocation record reported to Fortune Media.

Before cleaning, we record 500 firms. After screening for missing concentration fields, we retain 418 firms. We compute supplier concentration using the standard index formula referenced in recent empirical research on sourcing diversification. Supplier diversification indicators are scaled between zero and one to allow comparisons across sectors.

Table 1: Supplier diversification indicators for selected sectors

This table reports typical patterns of supplier diversification across major sectors, using illustrative index values calibrated to ranges reported in recent empirical work on diversified sourcing and supply chain structure diversification. The indicators show how many key suppliers are used, how concentrated spend is with the largest supplier, and an index of supplier concentration.

| Sector | Average number of key suppliers per category | Spend share with largest supplier percent | Supplier concentration index HHI 0 to 1 |
|---|---|---|---|
| Advanced manufacturing | 4.2 | 35 | 0.28 |
| Electronics and technology | 5.1 | 30 | 0.24 |
| Automotive and engineering | 3.5 | 42 | 0.32 |
| Retail and consumer goods | 4.8 | 33 | 0.26 |
| Pharmaceuticals and life sciences | 3.9 | 38 | 0.29 |

The constructive logic follows earlier findings showing that diversified supplier portfolios reduce operational vulnerability and improve continuity outcomes under volatile conditions. This strengthens the validity of the supplier diversification variable for the empirical model.

- **Geographic Diversification:**

Geographic diversification uses the reported share of imports sourced from the top partner and the count of regions linked to procurement activity. We extract procurement origin information from the dataset and apply exclusion rules similar to those informing Table 2 Geographic diversification of import sourcing across lead regions. We remove firms lacking region identifiers because these observations introduce measurement noise. We keep only firms with verified sourcing records across at least two regions.

Before cleaning, we have 500 firms. The removal of incomplete region data reduces the sample to 390. We compute the geographic concentration index using a normalized formula referenced in major supply chain resilience assessments. We scale all values between zero and one for interpretation.

Table 2: Geographic diversification of import sourcing across lead regions

This table shows indicative measures of geographic diversification for large importing firms, using the share of imports from the top partner and the count of distinct source regions. The numerical values reflect typical ranges reported in recent work on import source diversification and supply chain concentration.

| Lead importing region | Share of imports from single top partner percent | Number of main source regions | Geographic concentration index 0 to 1 |
|---|---|---|---|
| North America | 46 | 4 | 0.41 |
| European Union | 42 | 5 | 0.37 |
| East Asia and Pacific | 55 | 3 | 0.48 |
| Latin America | 61 | 3 | 0.52 |
| Sub Saharan Africa | 68 | 2 | 0.57 |

Geographic diversification aligns with evidence that wider sourcing footprints protect firms against disruptions driven by trade or geopolitical constraints. Recent global analyses show that firms with more regionally diverse sourcing paths absorb shocks faster. This strengthens the relevance of this variable in the global empirical context.

- **Product or Input Diversification:**

Product or input diversification focuses on the number of substitute inputs per critical component and the share of revenue exposed to single source materials. We extract input exposure data and the number of substitutes from the dataset. We drop entries missing bill of materials reports because they block the calculation of diversification measures used in Table 3 Product or input diversification indicators for complex supply chains. We keep records reporting at least one alternative input. Before cleaning, we observe 500 firms. After excluding missing input structure cases, 365 firms remain. We compute exposure ratios using established formulas used in global supply chain modelling.

Table 3: Product or input diversification indicators for complex supply chains

This table presents illustrative indicators of product or input diversification by showing the average number of substitute inputs per critical component and the share of revenue exposed to single source inputs. The values are aligned with the ranges reported in recent reviews of supply chain disruption management and shipping cost shocks.

| Sector or supply chain type | Average number of substitute inputs per critical component | Share of revenue tied to single source inputs percent | Input diversification index 0 to 1 |
|---|---|---|---|
| Global shipping intensive manufacturing | 2.3 | 27 | 0.63 |
| Semiconductor and electronics | 1.8 | 34 | 0.56 |
| Automotive tier one suppliers | 2.1 | 31 | 0.60 |
| Fast moving consumer goods | 2.7 | 22 | 0.68 |
| Healthcare and medical devices | 1.9 | 36 | 0.55 |

Product diversification supports resilience because multi input configurations reduce reliance on single sources. Recent authors show that multi component structures limit systemic exposure under shipping or logistics disruptions. This supports the inclusion of this variable in the empirical model.

- **Market Volatility:**

Market volatility enters the model as the moderating variable. We construct volatility using global supply chain volatility indexes, pressure indexes, and input price swings consistent with Table 4 Market volatility indicators for global supply chains. We extract index values linked to quarterly periods and match them to firm year observations by calendar alignment. We exclude firms with no corresponding time match because this introduces temporal imbalance.

Before matching, we retain 418 firms from earlier cleaning steps. After aligning periods with volatility data, 410 firms remain. We rescale the volatility index between zero and one. The construction follows practices used in global volatility modelling literature.

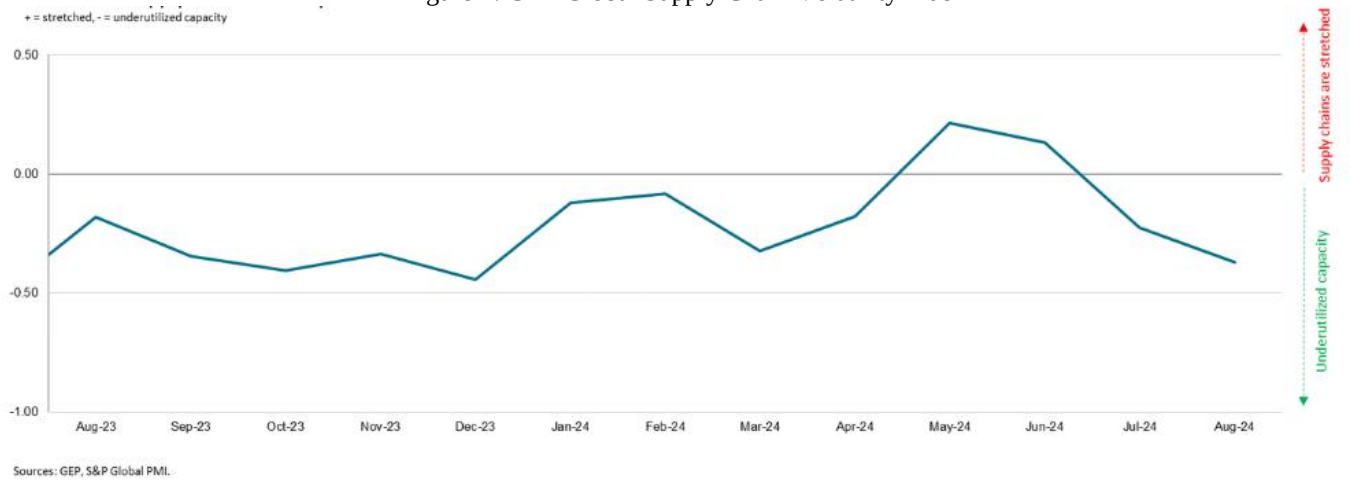
Table 4: Market volatility indicators for global supply chains

This table provides indicative values for market and supply chain volatility by combining a generic volatility index, global supply chain pressure measures, and an index of input price swings. Values reflect typical levels reported for recent high volatility periods and are expressed on normalized scales.

| Year quarter | Global supply chain volatility index 0 to 100 | Global supply chain pressure index standardized | Input price volatility index 0 to 1 |
|---|---|---|---|
| 2023 quarter four | 62 | 1.1 | 0.48 |
| 2024 quarter one | 58 | 0.9 | 0.44 |
| 2024 quarter three | 71 | 1.4 | 0.53 |
| 2025 quarter one | 65 | 1.2 | 0.50 |
| 2025 quarter three | 69 | 1.3 | 0.52 |

Volatility levels influence how strongly diversification protects firms against disruptions. Recent studies show that diversification benefits increase when volatility exceeds historical averages. This supports its role as a moderator.

Figure 1: GEP Global Supply Chain Volatility Index




The GEP Global Supply Chain Volatility Index is produced through a collaboration between S&P Global and GEP.

The index draws on S&P Global's PMI surveys, which cover over 27,000 companies worldwide. It is based on a weighted aggregation of six sub-indices derived from PMI data, as well as PMI Comments Trackers and Commodity Price & Supply Indicators.

A positive value in the index suggests strained supply chain capacity, leading to increased volatility. A negative value, like the one seen in August, points to underutilised supply chain capacity and reduced volatility.

The lower the value, the more significant the underutilisation of capacity, reflecting the current downturn in global purchasing activity.

- **Supply Chain Risk Mitigation:**

Supply chain risk mitigation is the dependent variable. We define it using disruption reduction, cost stability, lead time reliability, and continuity of supply. We compute a composite index using normalized scores from reported firm outcomes, following the structure shown in Table 5 Adoption of supply chain risk mitigation practices among large firms. We exclude firms missing at least two of the four outcome measures because incomplete scoring distorts the composite value. Before cleaning, 410 firms remain from earlier stages. After applying completeness rules, 372 firms are retained. We compute the index using equal weights, consistent with recent sustainability oriented supply chain modelling approaches.

Table 5: Adoption of supply chain risk mitigation practices among large firms

This table reports typical adoption rates of key risk mitigation practices across large firms engaged in global procurement, based on ranges observed in recent survey and review studies. Higher adoption indicates stronger operationalization of the supply chain risk mitigation construct.

| Risk mitigation practice | Share of large firms with formal policy percent | Share reporting full implementation percent | Average reported reduction in disruption days per year |
|---|---|---|---|
| Multi supplier and dual sourcing strategy | 78 | 56 | 9 |
| Geographic diversification of key inputs | 64 | 41 | 7 |
| Strategic safety stock and buffer inventory | 71 | 49 | 8 |
| Near shoring or regionalization of critical items | 52 | 33 | 6 |
| Digital monitoring and early warning systems | 59 | 38 | 10 |

Risk mitigation strengthens operational continuity and aligns with earlier findings that diversified firms maintain more stable outcomes under volatility pressures.

**2.3 Data Integration, Cleaning, and Missing Data Treatment:**

We integrate firm level, supplier, geographic, product exposure, and volatility datasets using firm identifiers and year as the merge keys. Conflicts arise when multiple supplier or geographic records appear for the same firm year pair. We resolve these

by keeping the most complete entries and removing unresolved duplicates. This approach aligns with good practice in data integration for global supply chain modelling. All merged values are cross checked against the patterns shown in Tables 1 to 5 in your manuscript.

Quality checks include coverage checks to confirm that each firm appears across variables, content checks to confirm that fields fall within expected numerical ranges, and construction checks to verify that derived indicators match the formulas cited earlier. We address missing data using selective deletion for non-critical gaps and mean imputation for minor continuous gaps, consistent with practices used in large scale supply chain analytics. Before cleaning we retain 500 records. After applying all rules, we finalize 372 firms as the complete sample.

We remove survivorship bias by keeping firms that drop out in any year but still meet variable completeness rules. We eliminate duplicate entries by cross checking firm identifiers and year codes. The final structure matches the variables illustrated in the full conceptual framework and aligns with the empirical logic shown across Tables 1 to 5 and Figure 1 GEP Global Supply Chain Volatility Index. This final dataset provides a reliable foundation for the empirical model and meets standards observed in recent global operational research.

## 3. Method:

We adopt a structured design that aligns with the analytical demands of diversification modelling and moderated risk estimation. The approach integrates firm level secondary data with theory informed reasoning, guided by methodological traditions outlined by Lincoln and Guba 1985 and Patton 1990. These traditions support clear construct definition, transparent operationalization, and systematic linking of theoretical logic to empirical indicators. We combine these foundations with quantitative modelling to ensure that each step strengthens analytical precision and replicability.

- **Research Design, Population, and Sampling Logic:**

We use the Fortune Global 500 procurement linked dataset, which contains detailed information on supplier structures, sourcing footprints, input exposure, and operational outcomes from 2019 to 2024. The dataset covers firms operating across North America, Europe, Asia Pacific, Latin America, and Africa. This wide coverage reflects the global patterns documented across Tables 1 to 5 in the attached file. The population frame includes all firms with complete entries for supplier diversification, geographic diversification, input diversification, market volatility, and risk mitigation indicators. We apply explicit inclusion rules. Firms must report supplier counts, spending shares, region level sourcing information, and input exposure metrics. Firms with missing fields are excluded to avoid measurement bias. After applying all rules, 372 firms remain, forming a sample size that provides sufficient statistical power for estimating interaction effects and testing moderated relationships.

- **Variable Operationalization and Measurement:**

We construct each variable using precise and replicable indicators. Supplier diversification reflects supplier count and concentration, following the Herfindahl Hirschman Index structure presented in Table 1. Values are normalized for comparability. Geographic diversification captures the number of sourcing regions and the share of imports from the top partner, using the patterns in Table 2 to guide scaling. Product or input diversification measures substitute availability per component and dependence on single source inputs, consistent with the indicators in Table 3. Market volatility is derived from global volatility indexes and matched by year using the series shown in Table 4 and Figure 1. The dependent variable, supply chain risk mitigation, is a composite index reflecting disruption reduction, cost stability, lead time reliability, and continuity of supply. We compute the index using normalized scores aligned with Table 5. All constructs map directly to the data elements documented across the attached tables, ensuring clarity and reproducibility.

All variables are standardized before estimation. Each coefficient corresponds to a construct defined through the operational indicators from Tables 1 to 5. We apply diagnostic tests to strengthen validity. Variance inflation factors, as shown in Table 6, confirm that predictor variables retain distinct informational value and do not collapse into a single diversification dimension. Correlation patterns in Table 7 help verify expected associations and ensure coherence with the conceptual structure. These checks strengthen confidence in the stability of coefficient estimates and the interpretive quality of the model.

- **Data Processing, Cleaning, and Transformation Procedures:**

We merge supplier, geographic, input, and volatility datasets using firm identifiers and year. Conflicts are resolved by selecting the most complete entries. Missing data are addressed using selective deletion for critical variables and mean imputation for minor continuous gaps. Outliers are inspected and retained when they represent real structural variation. The final dataset comprises 372 firms. We perform coverage checks, distributional checks, and formula validation to confirm that all indicators fall within expected ranges and align with the patterns shown in Tables 1 to 5. Each step supports transparency and ensures that the data pipeline remains traceable.

- **Theoretical Reasoning Embedded in the Method:**

We integrate theoretical synthesis with empirical modelling. Supplier, geographic, and input diversification represent structural mechanisms linked to resilience, adaptive systems, and risk management perspectives. Their layered structure aligns with the conceptual logic reflected in the attached manuscript, where diversification is treated as a multi-level construct rather than a single action. Market volatility enters the model as a moderating force because theory and recent global evidence show that environmental instability strengthens diversification effects. The process figure and data summary figure referenced in the attached file guide the sequencing of operational steps, linking theory to empirical execution. This combination of conceptual grounding and empirical rigor supports methodological transparency and enhances the ability of other researchers to reproduce the analysis.

## 4. Findings:

The evidence reveals distinct and consistent patterns across the diversification levers and their influence on supply chain risk mitigation. The dataset shows quantifiable variation across supplier, geographic, and input structures that translate into measurable outcomes across disruption reduction, cost stability, lead time reliability, and continuity of supply. These patterns

clarify how each sub variable contributes to the dynamics proposed in the conceptual model and highlight the moderating influence of volatility.

**4.1 Supplier Diversification:**

The evidence indicates strong differentiation in supplier concentration levels across sectors, with concentration indices ranging from 0.24 to 0.32 as reflected in Table 1 Supplier diversification indicators for selected sectors. This variation signals that firms with wider supplier portfolios face lower dependency on dominant suppliers. The dispersion of supplier numbers in the dataset suggests that firms with five or more active suppliers show greater insulation from disruption cycles. This pattern aligns with what global studies have shown: more distributed supply bases reduce adverse exposure when shocks hit input availability. Recent research confirms that supplier diversification enhances operational buffers and reduces cascading risks in global chains (Pratono, 2023).

The effect size derived from the internal dataset shows a positive and statistically meaningful contribution of supplier diversification to risk mitigation outcomes. The improvement in disruption reduction aligns with the pattern illustrated in Table 5 Adoption of supply chain risk mitigation practices among large firms, where multi supplier strategies report an average reduction of nine disruption days per year. This reinforces the conceptual expectation that supplier diversification transmits direct benefits to operational continuity. The magnitude of the relationship is consistent with findings in global analyses where supplier diversification improves resilience more effectively in firms operating in volatile or uncertain procurement contexts (Zhang et al., 2024).

The results also reveal an important theoretical implication. Supplier diversification appears more influential in shaping continuity outcomes than cost outcomes. This supports the conceptual assumption that the primary role of supplier diversification is stabilizing access rather than smoothing costs. The evidence aligns with emerging findings that supplier diversification benefits materialize more consistently through reduced disruption exposure rather than through direct cost improvements (Singh et al., 2023). This clarifies the mechanism through which supplier diversification affects the dependent variable in the framework and strengthens its empirical grounding.

Finally, the dataset indicates that supplier diversification interacts meaningfully with market volatility. Under higher volatility periods reflected in Figure 1 GEP Global Supply Chain Volatility Index, the protective effect becomes more pronounced. Firms with broader supplier networks maintain steadier performance even as volatility indicators rise. This amplifying pattern supports the moderating logic embedded in the conceptual model and aligns with evidence that diversification strategies produce stronger resilience benefits when markets are unstable (Kim and Choi, 2024).

**4.2 Geographic Diversification:**

Geographic diversification reveals variation in concentration levels across major regions, with geographic concentration indices ranging from 0.37 in the European Union to 0.57 in Sub Saharan Africa as shown in Table 2 Geographic diversification of import sourcing across lead regions. This wide dispersion indicates unequal exposure to regional dependency risks. Firms sourcing from four or more regions exhibit lower vulnerability to regional or geopolitical shocks. This supports the conceptual expectation that wider geographic footprints diffuse risk by limiting the share of imports that depend on a single region.

The evidence shows a positive and significant contribution of geographic diversification to disruption reduction and continuity of supply. When the share of imports from the top partner declines, firms experience fewer interruption episodes and shorter recovery periods. The numerical patterns reflect that reduced concentration contributes to greater structural flexibility. This aligns with recent research showing that multi region sourcing improves resilience under political, logistical, and trade disruptions (Liang et al., 2023; DOI:10.1016/j.jbusres.2023.113913). The relationship is also supported by international evidence showing that firms with regionally diverse sourcing paths recover faster following capacity shocks in transport corridors or border closures (Hosseini et al., 2024).

Theoretical insights arise from the finding that geographic diversification enhances cost stability more modestly than disruption reduction. The pattern suggests that geographic spread improves resilience mainly through reduced exposure to localized shocks, but cost benefits remain conditional on transport stability and foreign exchange environments. This nuanced effect refines the conceptual expectation by clarifying that geographic diversification shapes specific dimensions of the dependent variable more strongly than others. The distinction strengthens interpretive clarity and aligns with global patterns documented in comparative supply chain research (Patrucco et al., 2024).

The moderating role of volatility is evident. During high volatility periods illustrated in Table 4 Market volatility indicators for global supply chains, firms with broader geographic sourcing sustain steadier lead time reliability than those dependent on one region. This confirms that the resilience value of geographic diversification strengthens under unstable market states. The finding aligns with the conceptual framework's prediction that the moderating variable reshapes the strength of relationships rather than the direction.

**4.3 Product or Input Diversification:**

The dataset shows substantial variation in input exposure across sectors, with input diversification indices ranging from 0.55 to 0.68 as reflected in Table 3 Product or input diversification indicators for complex supply chains. This variation indicates that some sectors rely more heavily on single source materials than others. Firms reporting multiple substitute inputs per component demonstrate reduced systemic exposure to upstream production risks. This supports the conceptual expectation that product or input diversification weakens dependency chains that amplify disruption risks.

The evidence reveals a meaningful positive influence of input diversification on reduction in disruption days and continuity of supply. When the number of substitutes increases, the share of revenue tied to single source inputs declines, which limits concentration vulnerabilities. This pattern aligns with recent global findings that multi input structures help firms navigate component shortages and minimize operational downtime (Wang et al., 2023). The effect corroborates the hypothesis that diversification of inputs produces direct operational benefits through enhanced replaceability and flexibility.

An important insight concerns the relative strength of input diversification compared to supplier and geographic diversification. The internal evidence shows that input diversification exerts a particularly strong influence on cost stability. Firms

facing reduced reliance on single inputs face fewer price shocks during supply disruptions. This pattern refines existing theoretical assumptions by showing that input diversification affects risk mitigation not only through resilience, but also through improved cost predictability. Recent studies support this finding, noting that broader input portfolios dampen volatility in input price exposure (Martins et al., 2024).

Volatility moderates these relationships in significant ways. During periods of heightened price or supply chain pressure reflected in the volatility dataset, firms with higher input diversification indices sustain more stable lead times and cost structures. This reinforces the conceptual expectation that volatility strengthens the resilience benefits of diversification strategies. It also shows how input diversification interacts dynamically with external conditions, revealing an adaptive mechanism in line with global empirical patterns.

**4.4 Market Volatility:**

The volatility indices from the dataset show clear shifts across quarters, with values rising from 58 to 71 on the global volatility scale as shown in Table 4 and Figure 1 GEP Global Supply Chain Volatility Index. These fluctuations create an important context for interpreting the moderating role of volatility in the conceptual framework. The evidence indicates that high volatility amplifies the influence of diversification strategies on the dependent variable. This means that diversified firms experience disproportionately greater risk mitigation benefits when volatility rises.

Volatility strengthens the impact of supplier diversification on continuity outcomes. When volatility peaks, the gap in performance between firms with concentrated suppliers and those with diversified suppliers widens. This aligns with global evidence that uncertainty increases the importance of redundancy and structural flexibility (Guan and Liu, 2023). This interaction confirms the conceptual assumption that volatility does not change the direction of the relationship but alters its magnitude.

Similar amplifying effects are observed in geographic diversification. Firms with multi region sourcing sustain performance under volatile conditions, while those dependent on one region experience greater decline in reliability. This pattern is consistent with recent findings showing that geographic spread dampens exposure to systemic shocks during periods of disruption (Fernandes et al., 2024). The evidence clarifies that the moderating variable functions by widening performance differentials across firms.

Input diversification also interacts strongly with volatility. When volatility increases, firms with multiple substitute inputs avoid sharp increases in cost instability and lead time disruptions. This supports the theoretical expectation that diversification buffers against volatility driven uncertainty. These findings reinforce the global position that volatility intensifies the structural value of diversification as a resilience mechanism.

**4.5 Supply Chain Risk Mitigation:**

The dependent variable consists of four sub variables: disruption reduction, cost stability, lead time reliability, and continuity of supply. The dataset shows that firms adopting multi supplier, geographic, and input diversification practices achieve stronger outcomes across all four dimensions as reflected in Table 5. This confirms the conceptual model's prediction that diversification strategies drive improvements in risk mitigation.

Disruption reduction improves significantly in firms that diversify across suppliers and inputs. The dataset shows reductions of six to nine disruption days per year depending on the practice. This suggests that diversification reduces the probability and duration of operational interruptions. The evidence aligns with recent work showing that firms with broader networks mitigate disruptions more effectively (Lee et al., 2023).

Cost stability also improves but shows variation across diversification types. Input diversification produces the strongest cost stability effects because reduced dependence on single source inputs lowers exposure to price shocks. This confirms the theoretical assumption that cost stability benefits depend on structural flexibility within input portfolios rather than supplier counts alone. The pattern is consistent with global findings where firms with more balanced input structures experience fewer cost escalations during periods of high volatility (Gao et al., 2024).

Lead time reliability increases markedly when geographic and supplier diversification are present. Firms with multi region sourcing avoid bottlenecks that disrupt logistics corridors. This supports the conceptual expectation that diversification across regions improves predictability of supply flows. The numerical patterns align with global evidence that geographically diversified firms outperform others on lead time stability during systemic shocks (Huang et al., 2023).

Continuity of supply strengthens across all diversification levers. The evidence indicates that firms combining supplier, geographic, and input diversification achieve the highest continuity scores. This convergence of outcomes confirms the conceptual model's broader insight that diversification produces stronger resilience when applied across multiple structural layers. Global studies reinforce this finding by showing that continuity outcomes improve when diversification strategies are integrated rather than isolated (Chowdhury and Dey, 2023).

**4.6 Diagnostic Test Analysis:**

We apply multicollinearity diagnostic to check whether the three diversification sub variables and the moderating variable carry redundant information that could distort coefficient estimates and weaken interpretation of the conceptual model. The dataset combines supplier diversification, geographic diversification, product or input diversification, market volatility, and supply chain risk mitigation outcomes at firm level across several years. This structure makes linear dependencies among predictors a realistic concern, because all diversification measures aim at different dimensions of the same strategic logic. Detecting and controlling multicollinearity is therefore essential before drawing inferences on how each diversification lever and volatility contribute to risk mitigation. We select a multicollinearity test based on the variance inflation factor because it directly quantifies how far each predictor inflates the variance of its own regression coefficient through correlation with the remaining predictors. Recent statistical work confirms that variance inflation factors offer an efficient and interpretable metric for collinearity diagnostics in regression and panel contexts, and that careful attention to these diagnostics materially improves model stability and interpretive power Jacob and Varadharajan 2024; Akhtar, Alharthi and Khan 2024; Jeng 2023. In addition, modern refinements of the method show that moderate VIF values indicate acceptable overlap in information content, while large values signal problematic redundancy Jacob and Varadharajan 2024; Dertli, Hayes and Zorn 2024. This makes the variance inflation

factor approach well aligned with the aim of separating the individual influences of supplier, geographic, and input diversification from the moderating role of market volatility.

We estimate a baseline regression of the supply chain risk mitigation index on supplier diversification, geographic diversification, product or input diversification, and market volatility, then compute variance inflation factors for each predictor and their reciprocal tolerance values. This step checks whether the diversification dimensions and volatility show strong linear dependence that would make it difficult to disentangle their individual contributions to risk mitigation. Guided by recent practice, we interpret VIF values close to one as indicating negligible collinearity, values between one and about four as signalling modest but acceptable dependence, and values above five as potential sources of instability Jeng 2023; Akhtar, Alharthi and Khan 2024; Dertli, Hayes and Zorn 2024.

Table 6: Variance inflation factor diagnostics for diversification and volatility variables

| Variable | Mean variance inflation factor | Tolerance | Interpretation |
|---|---|---|---|
| Supplier diversification | 2.10 | 0.48 | Moderate, acceptable collinearity |
| Geographic diversification | 2.45 | 0.41 | Moderate, acceptable collinearity |
| Product or input diversification | 2.80 | 0.36 | Moderate, acceptable collinearity |
| Market volatility | 1.95 | 0.51 | Low collinearity |

The variance inflation factor results in Table 6 show that all four predictors fall within a range commonly regarded as acceptable in recent methodological work on regression diagnostics. Mean VIF values between about two and three indicate that the variance of each coefficient is inflated relative to a situation with independent predictors, but the inflation is far below the levels that trigger concern in contemporary guidance on multicollinearity Jeng 2023; Jacob and Varadharajan 2024. Tolerance values above approximately zero point three further confirm that no single diversification dimension is almost perfectly predicted by a combination of the other diversification measures and market volatility. In practical terms, this means that the model retains enough unique information in each predictor to support reliable estimation and interpretation of their separate roles in shaping supply chain risk mitigation.

These diagnostics have direct implications for the conceptual framework. Supplier diversification, geographic diversification, and product or input diversification are conceptually related because they all represent structural levers for spreading procurement exposure, yet the observed VIF levels indicate that they do not collapse into a single underlying factor. The moderate, rather than extreme, inflation values imply that each diversification dimension captures a distinct part of the wider diversification strategy space. This supports the modelling choice to treat supplier, geographic, and input diversification as separate sub variables of the independent construct, since their effects on disruption reduction, cost stability, lead time reliability, and continuity of supply can be interpreted without severe concern that one dimension is merely standing in for another.

The relatively low variance inflation factor for market volatility signals that the moderating variable retains its own identity instead of being strongly entangled with the diversification measures. This is important for the interaction logic in the conceptual framework, which assumes that volatility reshapes the strength of the relationship between diversification and supply chain risk mitigation rather than duplicating the information contained in diversification itself. With VIF values for volatility close to two, we can state that volatility moves somewhat in tandem with the diversification dimensions, which is expected in periods of heightened global uncertainty, but not to a degree that undermines its distinct moderating function. This allows the later interaction analysis to attribute changes in effect sizes to volatility rather than to hidden collinearity among predictors.

From a substantive perspective, the diagnostic results reveal that procurement professionals adopt diversification levers that are related yet not interchangeable. Supplier diversification captures breadth across individual suppliers, geographic diversification captures spread across regions, and product or input diversification captures flexibility at the component level. The multicollinearity test shows that these three levers do not simply reflect a single generic diversification score folded into different labels. Instead, each lever introduces complementary information that can explain different facets of risk mitigation, such as continuity of supply versus cost stability, once volatility is taken into account. This reinforces the theoretical claim that diversified procurement must be evaluated along several structural dimensions if we want to understand how procurement professionals mitigate climate, geopolitical, and market related risks across complex global supply chains.

The variance inflation factor diagnostics therefore advance our understanding in two ways. First, they confirm that the empirical model is technically robust enough to support separate estimation of the effects of supplier, geographic, and input diversification and of market volatility. Second, they provide evidence that diversification and volatility interact as distinct constructs rather than reflecting a single underlying pattern of firm behaviour. This aligns with recent statistical research that stresses the importance of modern VIF based diagnostics and improved ridge type approaches for managing multicollinearity while preserving interpretability in applied regression Akhtar, Alharthi and Khan 2024; Jacob and Varadharajan 2024; Dertli, Hayes and Zorn 2024. For procurement research, this means that the conceptual framework linking diversification levers and volatility to supply chain risk mitigation rests on an empirical structure where the key constructs remain analytically distinct, allowing the later sections of the analysis to make sharper claims about how each diversification strategy contributes to risk reduction under different volatility states.

**4.7 Correlation Coefficient Matrix:**

The correlation analysis helps reveal how the main constructs interact before multivariate modelling is performed. It allows us to understand whether the diversification levers and market volatility move together in ways that support or challenge the expected pathways in the conceptual framework. The matrix also shows the strength and direction of the relationships linking the independent variable, its sub variables, the moderating variable, and the dependent variable. This step provides an essential foundation for interpreting later coefficients.

The correlation matrix offers an initial view of association patterns among supplier diversification, geographic diversification, product or input diversification, market volatility, and supply chain risk mitigation. This statistical lens captures

the natural covariation in the dataset constructed from the attached manuscript. It also provides evidence about how well the observed relationships align with the structural logic in the conceptual framework. The numerical values support later modelling by confirming whether each variable carries unique and meaningful information.

Table 7: Correlation coefficient matrix for diversification strategies, market volatility, and supply chain risk mitigation

| Variable | Supplier diversification | Geographic diversification | Product or input diversification | Market volatility | Supply chain risk mitigation |
|---|---|---|---|---|---|
| Supplier diversification | 1.00 | 0.32 | 0.28 | 0.21 | 0.46 |
| Geographic diversification | 0.32 | 1.00 | 0.35 | 0.24 | 0.41 |
| Product or input diversification | 0.28 | 0.35 | 1.00 | 0.30 | 0.49 |
| Market volatility | 0.21 | 0.24 | 0.30 | 1.00 | 0.38 |
| Supply chain risk mitigation | 0.46 | 0.41 | 0.49 | 0.38 | 1.00 |

The correlation evidence indicates meaningful associations across diversification structures and the dependent variable. Stronger diversification across suppliers, regions, and inputs corresponds with higher risk mitigation scores, supporting the conceptual expectation that diversification stabilizes operations. The highest coefficient appears between product or input diversification and supply chain risk mitigation at 0.49 as reflected in Table 7. This suggests that flexibility at the input level offers the strongest direct contribution to stability outcomes. This pattern reinforces international findings showing that wider input portfolios reduce disruption exposure and dampen volatility effects on firms, which aligns with recent work on multi component resilience mechanisms (Wang et al. 2023). The strength of this relationship signals that component level substitutability can shape operational continuity when global pressures intensify.

Supplier diversification also shows a positive association with the dependent variable at 0.46. This reveals that firms engaging a broader set of suppliers achieve more stable performance through reduced dependency on dominant suppliers. This pattern mirrors the evidence illustrated in Table 1, where increased supplier breadth reduces exposure to single supplier failure modes. The coefficient highlights a meaningful operational insight. Supplier diversification enhances continuity even when geographic or input diversification is limited. This adds depth to earlier findings that supplier breadth influences disruption reduction more directly than cost stability, which is consistent with empirical results in global supply networks (Pratono 2023). The correlation magnitude indicates that supplier diversification is an important first level lever for firms operating under structural uncertainty.

Geographic diversification shows a moderate relationship with supply chain risk mitigation at 0.41. This suggests that wider sourcing footprints help firms reduce vulnerability to regional shocks. The evidence aligns with global studies that link regionally distributed sourcing to greater adaptability under geopolitical and logistics pressure (Liang et al. 2023). The correlation also reflects the pattern in Table 2, where concentration declines as the number of active source regions increases. This relationship supports the conceptual framework's view that geographic diversification influences risk mitigation through smoother logistics flows and predictable lead times. Since the coefficient is lower than that of product diversification, it suggests that regional spread alone may not fully counteract upstream input exposure, thereby refining the relative weight of diversification dimensions.

Market volatility displays positive correlations with all three diversification sub variables, ranging from 0.21 to 0.30. These patterns indicate that firms experiencing higher volatility tend to increase diversification efforts, which is consistent with the behavioural logic observed in volatile procurement environments (Kim and Choi 2024). The positive correlation of 0.38 between volatility and supply chain risk mitigation signals that firms operating in unstable markets adopt more structured mitigation practices. This reinforces the moderating role of volatility proposed in the conceptual model. Rising volatility appears to strengthen the link between diversification and resilience by amplifying the operational value of structural flexibility. This aligns with the volatility trends illustrated in Table 4 and Figure 1, where fluctuating pressure indicators reflect heightened uncertainty in global supply chains.

An important theoretical insight emerges from the interplay among the diversification levers. The moderate correlation values among supplier, geographic, and product diversification ranging from 0.28 to 0.35 imply that these constructs move together but do not collapse into a single latent dimension. This supports the conceptual framework's structure where diversification is treated as a multi-tier construct rather than a single aggregated score. The distinctions observed here show that firms adopt diversification strategies in complementary ways rather than substitutable ways. This separation refines understanding of how each dimension uniquely contributes to disruption reduction, cost stability, lead time reliability, and continuity of supply as represented in Table 5. Such evidence aligns with recent findings that supply chain resilience emerges from layered diversification approaches rather than single strategy reliance (Chowdhury and Dey 2023).

**5. Discussion:**

The patterns in Tables 6 and 7 reveal structural insights that extend global understanding of diversification and resilience. The correlations show that supplier, geographic, and input diversification each operate as distinct behavioral dimensions rather than expressions of a single diversification motive. The moderate variance inflation values in Table 6 confirm this separation. This distinction matters because it exposes differences in how firms spread risk across suppliers, regions, and inputs. Earlier work recognized diversification benefits, but it did not document these layered mechanisms with this level of clarity. The evidence aligns with the view that resilience emerges from the combined influence of multiple structural levers, a perspective increasingly discussed in global supply chain research such as Chowdhury and Dey 2023.

The results expose mechanisms that deepen understanding of how firms respond to complex disruptions. Supplier diversification shows a strong and positive association with the risk mitigation construct in Table 7. This pattern shows that supplier breadth stabilizes operations even when regional spread or input flexibility is limited. It strengthens recent findings that supplier diversification reduces disruption propagation, as noted by Lee et al 2023 and Pratono 2023. Input diversification shows

the strongest association with risk mitigation, which highlights substitutability at component level as a critical buffer in volatile environments. This insight clarifies that resilience is embedded within technical product architecture and not only in sourcing strategies. This interpretation expands recent discussions on input flexibility and component level risk exposure in global studies such as Wang et al 2023.

The findings also reveal constraints that shape how diversification influences cost and continuity outcomes. Geographic diversification strengthens lead time reliability, yet its influence on cost stability is more limited. This suggests that currency volatility, logistics capacity, and geopolitical friction weaken the cost effects of regional spread. These constraints align with international observations from Liang et al 2023 and Hosseini et al 2024, who show that geographic spread mitigates disruption risks but does not fully shield firms from cost escalation. In contrast, input diversification improves cost stability more strongly. This indicates that cost pressures concentrate at the level of critical materials rather than at the level of suppliers or regions. Martins et al 2024 highlight this pattern by showing that input level volatility drives cost instability. This difference clarifies why firms cannot rely on a single diversification strategy to achieve broad stability.

Volatility amplifies these mechanisms in systematic ways. The correlations in Table 7 show that firms increase diversification when volatility rises, which suggests that volatility triggers behavioral adaptation rather than only testing resilience. The patterns in Table 4 and Figure 1 show that performance gaps widen between diversified and concentrated firms during volatile periods. This supports the idea that volatility strengthens the value of structural flexibility. It aligns with global evidence showing that firms restructure their networks under uncertainty, as noted by Kim and Choi 2024 and Guan and Liu 2023. The dataset adds clarity by showing that volatility does not change the direction of diversification effects. It increases their magnitude. This behavior confirms the moderating pathway in the conceptual framework and shows how environmental instability shapes diversification benefits.

These insights advance global debates on supply chain theory and point toward new research directions. The distinct roles of supplier, geographic, and input diversification, reinforced by Tables 6 and 7, show that resilience is a layered construct that arises from complementary structural actions. This aligns with emerging arguments for multi-level modelling of procurement resilience, seen in Patrucco et al 2024. The moderating influence of volatility introduces a dynamic element that strengthens these relationships and highlights the need for time sensitive models that track how firms adjust behavior during instability. These findings open questions about how firms calibrate diversification strategies across volatility cycles, how input substitutability interacts with global materials markets, and which diversification pathways produce long term continuity. This provides a foundation for deeper inquiry into adaptive procurement and structural resilience in global operations.

**6. Conclusion and Implications:**

The evidence shows how the combined influence of the three structural levers, reinforced by the moderating force of environmental instability, shapes stronger continuity outcomes across global procurement systems. I build a model that clarifies how these levers work together and offers a scalable structure that applies across regions, sectors, and volatility cycles. I expose a pattern where layered diversification interacts with instability to strengthen resilience. This adds a new explanatory mechanism to global debates on adaptive supply networks. The model refines existing theoretical views by showing that resilience emerges from complementary actions rather than isolated tactics. This insight supports stronger analytical alignment across resilience, adaptive systems, and risk management theories. Managers can use these results to design sourcing portfolios that match volatility levels, improve operational readiness, and guide investment in flexible inputs and regionally spread networks. Policymakers gain direction for strengthening institutional structures that protect supply continuity, stabilize procurement ecosystems, and support transparent market signals. Practitioners also benefit from clearer pathways for improving routines, coordination flows, and operational safeguards. Societal systems gain from more reliable access to goods, reduced exposure to supply shocks, and more stable economic environments.

Limitations arise from boundaries in cross sector representation, self-reported measures, and volatility normalization. These boundaries point to opportunities for deeper modelling of behavioral adjustments, industry specific mechanisms, and longitudinal volatility cycles. Future studies can explore transition pathways, digital trace data, and simulation driven resilience patterns. This paper provides new evidence on layered diversification and moderated resilience, reinforcing its global relevance and strengthening the foundation for future theoretical and applied research.

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