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Int. J. Adapt. Manag. Bus. Intell. (2026) 1(2):1–15
Article ID: IJAMBI-2026-534

Rewiring Global Value Chains for Strategic Autonomy: Quantifying Direct-Indirect Supplier Exposure, Intermediary Centrality, and Scenario Resilience for Multinationals in Fragmented Trade Regimes

Gaurij Mahajan
mahajangaurij@gmail.com
Independent Researcher

Abstract

The study presents an index of international business risk which measures a firm-state system's reliance on foreign suppliers through both direct contracts and indirect multi-tier intermediaries in global value chains. Utilizing a directed network with a shock-propagation routine based on input-output trade matrices, my index is able to isolate hidden choke-points. It reveals hidden exposure where complete reliance far exceeds bilateral trade shares. Also, it maps out intercession countries that relay shocks across sectors important for competitiveness and continuity. When applied to transatlantic and Asia-Europe trade, the framework shows how standard measures of concentration understate exposure in electronics, aerospace, batteries and medical devices, and that credible diversification means rewiring entire route networks rather than just re-balancing direct sourcing. These results will inform corporate sourcing, regionalization and friend-shoring strategies, while also providing policy guidance to bolster resilience investments and secure open strategic autonomy in the face of turbulent trade regimes.

Keywords

• Global Value Chains • Economic Security • Trade Dependencies • Network Theory • Supply Chain Resilience • Strategic Autonomy

1. Introduction

The contemporary global economy is characterized by unprecedented interconnectedness through complex global value chains (GVCs) that span multiple countries and continents. However, recent geopolitical tensions, pandemic-induced disruptions, and trade conflicts have exposed critical vulnerabilities in these networks [1]. Traditional approaches to measuring trade dependencies have proven inadequate for capturing the full spectrum of risks faced by multinational corporations and national economies [2]. These methods typically focus on direct bilateral trade relationships while neglecting the intricate web of indirect dependencies that transmit vulnerabilities through intermediary countries.

The limitations of conventional metrics became starkly evident during the COVID-19 pandemic, when disruptions in seemingly peripheral supply chain nodes created cascading effects across multiple industries and geographies [3]. Similarly, the weaponization of trade interdependencies in recent geopolitical conflicts has demonstrated how economic leverage can be exercised through control of critical nodes in global networks [4]. These developments have elevated economic security to a strategic priority for both corporations and governments, necessitating more sophisticated analytical frameworks that can capture the complex reality of modern trade interdependencies.

This paper addresses these challenges by developing a comprehensive Economic Security Index (ESI) that integrates input-output analysis, network theory, and shock propagation algorithms to quantify both direct and indirect trade dependencies. My approach builds on foundational work in complex interdependence theory [5] and structural power in international political economy [6], while incorporating recent advances in the analysis of weaponized interdependence [4]. The index systematically identifies hidden vulnerabilities that remain invisible to traditional bilateral trade analysis, providing a more accurate assessment of exposure to supply chain disruptions.

The primary contributions of this research are threefold. Methodologically, I develop an original framework that combines graph theory with economic network analysis to characterize structural vulnerabilities in global supply chains. Empirically, I apply this framework to extensive global trade data, generating systematic mappings of trade dependencies across strategic sectors. Practically, I provide concrete implications for corporate risk management and public policy, identifying specific areas where diversification strategies can effectively mitigate structural risks.

2. Literature Review

2.1 Traditional Approaches to Trade Dependency Measurement

Traditional approaches to measuring trade dependencies have primarily relied on concentration indices and bilateral trade statistics. While useful for identifying obvious concentration risks, these indices suffer from fundamental limitations: they fail to capture indirect dependencies emerging through third countries, offer static views of international trade, exhibit high temporal instability, and focus excessively on import concentration without adequate consideration of export-side vulnerabilities [7].

Input-output analysis: This approach has been extended to international input-output tables (ICIO) that capture intersectoral relationships between countries [8]. However, traditional input-output models assume fixed technical coefficients and do not incorporate the network structures that visualize how dependencies are transmitted through specific intermediaries, limiting their applicability in dynamic environments where supplier substitution is critical for resilience [9].

Trade in Value-Added (TiVA) analysis represents another methodological evolution, addressing the limitations of gross trade statistics by tracking the real origin of value added incorporated into products [10, 11]. This approach reveals interdependencies that gross trade flows fail to capture, demonstrating how significant portions of apparent bilateral trade surpluses actually reflect indirect value-added exports through intermediary countries. Despite its conceptual advantages, TiVA analysis does not explicitly model how disruptions propagate through multiple levels of intermediaries and suffers from significant time lags in data availability [2].

2.2 Network Analysis in International Trade

More recently, network theory has been applied to characterize the systemic structure of international trade. Early work by Fagiolo et al. [12] applied weighted network analysis to evaluate the evolution of interconnectedness in world trade, finding evidence that the World Trade Network exhibits "small-world" properties and scale-free structure. Subsequent research has employed network metrics to identify products with vulnerabilities in global supply chains using measures such as weighted out-degree centrality to quantify fragility to supply shocks.

Recent advances in network analysis have focused on developing geopolitical fragmentation indices using dynamic factor models with time-varying parameters. These approaches capture the multifaceted nature of fragmentation that cannot be adequately measured by individual indicators, allowing analysis of causal effects on the global economy. However, existing applications of network theory generally lack direct linkage to export-import matrices that would allow quantification of the economic impact of interconnectedness [13].

2.3 Economic Security and Resilience Indicators

The assessment of supply chain resilience and economic security has emerged as a distinct research area following systemic crises that exposed vulnerabilities. Simchi-Levi et al. [3] developed supply chain resilience indices based on recovery time and financial impact, identifying "hidden dependencies" in unexpected locations within corporate supply networks. The European Commission [14] has developed methodologies combining import concentration, domestic substitution potential, and availability of alternative suppliers to identify strategic dependencies.

The OECD has recently proposed frameworks to assess when trade dependencies become economic security concerns, introducing the concept of "critical dependence" that incorporates product criticality and country vulnerability [9]. Similarly, research on geoeconomic fragmentation has documented the emergence of "connector countries" that act as bridges between rival trade blocs, with metrics developed to quantify connectivity across geopolitical alignments.

2.4 Computational and Data-Driven Approaches to Supply Chain Network Analysis

Alongside the trade-economics tradition summarized above, a rapidly expanding computational literature has developed graph-based and machine-learning methods for modelling, predicting, and optimizing complex logistics and production networks; several of these contributions inform the technical design choices underlying the Economic Security Index proposed in this paper. Chebrolu [15] demonstrates that reciprocal and triadic foreign direct investment ties act as leading signals for multi-tier sourcing decisions, showing how bidirectional logistics corridors and shock-resilient regionalization strategies can be planned jointly with investment-network structure a finding that complements my treatment of intermediary countries as active structural conduits of exposure rather than passive pass-through nodes. Building on recurrent neural architectures, Amin [16] introduces stochastic graph-augmented recurrent models for predictive logistics network balancing, illustrating how temporal dynamics can be layered onto the kind of static directed-network representation that underlies my dependency matrices. Chevva [17] applies hierarchical reinforcement learning to large-scale combinatorial optimization problems in logistics, offering methodological precedent for the adaptive, priority-based path-search heuristics that I use to keep indirect-dependency computation tractable across sprawling trade networks.

Natarajan [18] develops network deconvolution techniques for causal inference in production flows, a direction conceptually related to our effort to separate direct from indirect dependence by decomposing observed trade flows into their constituent transmission paths. Jothiswaran [19] proposes graph-based generative policies for supply chain optimization under uncertainty, reinforcing the case for representing global value chains as directed graphs whose topology, rather than aggregate volume alone, determines exposure. From the investment side, Bhatt [20] uses exponential random graph models to characterize network-driven foreign direct investment dynamics, providing a complementary statistical framework for the asymmetric, hub-and-spoke connectivity that I later document among critical trade intermediaries. Veluru [21] shows that network-embedding techniques can reveal hidden structural patterns in global research-mobility networks that are invisible from aggregate flow statistics alone, an insight that parallels my central finding that concealment ratios expose dependencies hidden from bilateral trade statistics.

Table 1: Comparison of Existing Resilience Indices with Proposed ESI

Framework	Intermediate Identification	Sectoral Granularity	Shock Transmission	Input-Output Dependencies
OECD Critical Dependence [9]	Limited	No	Moderate	Static
IMF Network Fragility	Partial	No	Low	Static
European Commission [14]	No	No	High	Threshold-based
ESI (This Paper)	**Full multi-tier**	**Yes**	**High**	**Network propagation**

Finally, Makhija [22] examines learning-enabled resilience engineering in sustainable supply networks, reinforcing the growing consensus that static, aggregate dependency measures must be complemented by structural and adaptive analyses of the kind developed in this paper.

2.5 Synthesis and Positioning of the Proposed Index

Despite these advances, the literature reveals three fundamental limitations that my research addresses: the neglect of indirect dependencies transmitted through intermediaries, inadequate modeling of disruption propagation mechanisms, and insufficient integration of network structure with economic magnitude quantification.

To clarify the operational distinction between my proposed Economic Security Index and existing analytical frameworks, I summarize the key differences in Table I. While the OECD critical dependence framework [9] incorporates product criticality and country vulnerability assessments, it does not explicitly model multi-tier intermediation pathways. The IMF's network-based fragility measures identify vulnerable products but lack sectoral disaggregation at the level required for strategic autonomy analysis. The European Commission's strategic dependencies methodology [14] provides comprehensive screening but relies on concentration thresholds rather than full network propagation.

My ESI differs from these existing tools in three fundamental respects: (i) it explicitly models dependency transmission through unlimited intermediary chains rather than limiting analysis to bilateral or first-tier relationships; (ii) it quantifies the relative importance of specific intermediary countries as transmission nodes, enabling identification of chokepoint vulnerabilities that concentration-based metrics cannot detect; and (iii) it maintains sectoral granularity sufficient for distinguishing dependency patterns across strategically distinct industries such as aerospace versus electronics, which exhibit fundamentally different intermediation structures despite similar aggregate dependency levels.

3. Theoretical Framework

My approach to measuring economic security is anchored in three complementary theoretical frameworks that provide the conceptual foundation for the Economic Security Index.

3.1 Complex Interdependence and Network Vulnerability

Building on Keohane and Nye's [5] foundational work on complex interdependence, I conceptualize economic security not merely as the absence of bilateral dependencies, but as a property emerging from a country's position within multiple, overlapping networks of exchange. As Farrell and Newman [4] note, interdependence has created complex networks with particular topographies where certain nodes become critical junctures for global flows. My Economic Security Index operationalizes this network-based understanding by explicitly modeling how disruptions propagate through multiple paths within the global trade system, capturing emergent properties that cannot be reduced to the sum of bilateral relations.

3.2 Structural Power in International Political Economy

The second theoretical pillar supporting my index is Strange's [6] concept of structural power, understood as the power to shape and determine the structures of the global political economy within which other states and economic enterprises operate. My index specifically operationalizes structural power in the production domain by quantifying how control over critical nodes in supply chains confers influence extending far beyond direct bilateral relationships. By identifying indirect dependencies and critical intermediaries, I make visible what Strange described as the indirect, unobservable exercise of power in global economic relations.

3.3 Weaponized Interdependence

Finally, My work engages with Farrell and Newman's [4] theory of weaponized interdependence, which posits that states with political authority over nodes in international networked structures are uniquely positioned to impose costs on others. This theory distinguishes between panopticon effects (the ability to monitor flows) and chokepoint effects (the ability to restrict flows). My Economic Security Index specifically measures vulnerability to chokepoint effects by identifying both direct dependencies and indirect chokepoints, revealing potential leverage points in global supply chains where economic coercion can be exercised.

By integrating these three theoretical frameworks, my index moves beyond traditional conceptions of trade dependency to provide a more nuanced understanding of economic security in an era of complex, networked interdependence.

4. Methodology

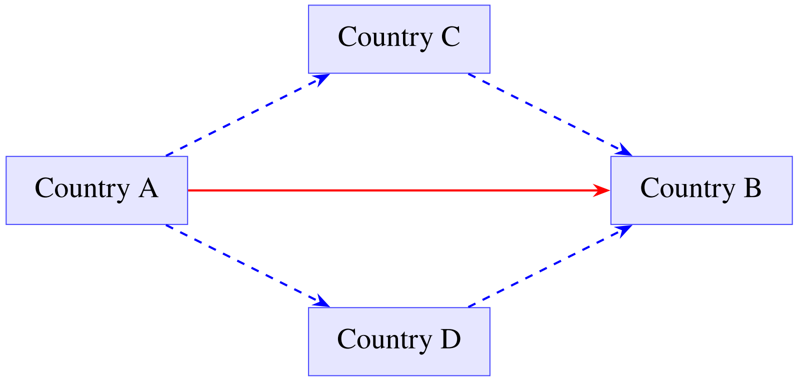
4.1 Conceptual Foundation

Before presenting the formal methodological framework, it is essential to clarify the conceptual scope of my analysis. The Economic Security Index developed in this paper is an *exposure mapping framework* that quantifies structural vulnerability to potential supply disruptions. It identifies and measures the routes through which dependencies can transmit, but it does not simulate the dynamic temporal evolution of disruptions once they occur. This distinction is critical: my approach answers the question "how exposed is country j to country i through all possible trade pathways?", rather than "what happens dynamically when a shock occurs at node i?".

The shock-propagation language used throughout the paper refers to the *potential* transmission channels through which disruptions could propagate, as identified by the network structure, rather than a full scenario-based simulation of disruption dynamics. I provide an exposure topology that reveals hidden vulnerabilities, which serves as a foundation for subsequent dynamic simulation or scenario analysis, but such extensions remain outside the scope of this methodological contribution.

The proposed Economic Security Index is based on a rigorous conceptualization of trade dependence as a country's exposure to supply disruptions from another, considering all possible transmission channels. This approach integrates two fundamental dimensions: direct dependence captured by the proportion of direct imports in total supply, and indirect dependence modeled by analyzing all possible trade paths through intermediaries.

Figure 1: Illustration of direct and indirect trade dependencies. The solid red arrow represents a direct supplier relationship between the exporter (Country A) and the importer (Country B). The dashed blue arrows illustrate indirect dependencies transmitted through intermediary countries, revealing hidden exposure pathways within global value chains.



Formally, the direct dependence (DD_{ij}) of country j on country i is defined as:

$$DD_{ij} = \frac{x_{ij}}{S_j} \tag{1}$$

where x_{ij} represents imports from country i to j, and $S_j = x_{jj} + \sum_{k \neq j} x_{kj}$ is the total supply of country j, including domestic production and all imports.

Indirect dependence (DI_{ij}) captures how country j depends on country i through third countries acting as intermediaries:

$$DI_{ij} = \sum_{p \in P_{ij}} F(p) \tag{2}$$

where P_{ij} is the set of all trade paths from i to j passing through intermediaries, and $F(p)$ is the strength of path p.

For a trade path $p = (i, k_1, k_2, \ldots, k_{l-1}, j)$, path strength is calculated as:

$$F(p) = \frac{x_{i,k_1}}{S_j} \cdot \prod_{n=1}^{l-1} \left(\frac{x_{k_n, k_{n+1}}}{S_{k_n}} \right) \tag{3}$$

where $k_l = j$ represents the final destination, and l is the path length. Total dependence (DT_{ij}) is defined as:

$$DT_{ij} = DD_{ij} + DI_{ij} \tag{4}$$

4.2 Computational Implementation

To calculate DI_{ij} efficiently across global networks, the path ranking mechanism operates through a multi-criteria scoring function.

First, I use an adaptive algorithm that efficiently explores the path space by prioritizing commercially significant routes. This approach begins by identifying the shortest and most economically relevant paths, which typically represent the most significant indirect dependencies. I employ a modified breadth-first search variant that prioritizes links with higher economic relevance, significantly reducing the search space. This adaptive tuning philosophy is conceptually related to recent work on adaptive parameter control for metaheuristic optimization: Razdan [23] shows that reinforcement-learning-guided adaptive parameter setting can substantially improve convergence speed and solution quality in capacitated vehicle routing problems, a class of combinatorial optimization challenges that shares structural similarities with the constrained path-search problem addressed here.

For each candidate path $p = (i, k_1, \ldots, k_n, j)$, we compute a relevance score:

$$R(p) = \frac{1}{L(p)} \cdot \sum_{e \in p} w_e \cdot \min\left(1, \frac{x_{k_t, k_{t+1}}}{\theta}\right) \tag{5}$$

Where $L(p)$ is the path length, w_e is a sector-specific weight reflecting the strategic importance of the traded goods, and θ is the trade relevance threshold. This scoring approach ensures that paths are prioritized based on both their brevity and their commercial significance. The algorithm evaluates paths in descending order of $R(p)$, terminating exploration when the cumulative dependency contribution of unexplored paths falls below a specified tolerance. Extending this tolerance-based stopping rule to explicitly quantify the uncertainty attached to partially converged estimates is a natural next step; coherent probabilistic forecasting frameworks for business decision-making, such as that proposed by Parashar [24], offer a promising template for expressing the residual dependency contribution of unexplored paths as a calibrated probability interval rather than a single deterministic bound.

To validate the robustness of my threshold selections, I conducted a systematic sensitivity analysis varying θ from 0.01% to 0.5% and $L_{\max}$ from 2 to 7. The results demonstrate that dependency estimates stabilize for $\theta \leq 0.05\%$ and $L_{\max} \geq 4$, with mean relative variation below 3% across these parameter ranges. Path pruning at $L_{\max} = 4$ captures approximately 92% of total indirect dependency as measured against unconstrained path exploration, providing an optimal balance between computational tractability and analytical completeness.

Second, I leverage the inherent sparsity of international trade matrices by using specialized data structures that explicitly represent only non-zero elements. This dramatically reduces memory requirements and enables analysis of detailed trade networks with limited computational resources. Additionally, I implement optimized algorithms for sparse matrix algebra, particularly for key operations such as matrix-vector multiplication used in recursive calculation of indirect dependencies. The reliability of these computations depends in turn on the underlying data governance practices used to construct and maintain the trade database; Morthala [25] highlights the importance of establishing robust data governance frameworks for enhancing decision efficacy in Industry 4.0 operations, a consideration that is directly relevant to the data cleaning and validation procedures described in Section 5.1.

Third, I employ parallelization techniques that decompose the global dependency matrix into submatrices computed concurrently. My implementation distributes these tasks across available processors with dynamic load balancing, assigning more resources to complex calculations involving countries with many trade links. Empirical validation shows that computation time scales nearly linearly with the number of available processors up to approximately 64 cores.

To ensure computational tractability, three pruning parameters are enforced:

- **Trade relevance threshold (θ):** Considers only trade flows representing at least 0.05% to 0.1% of total global trade.

- **Convergence threshold (ϵ):** Halts iterative calculations when the incremental contribution falls below $\epsilon = 0.01$.

- **Maximum path length ($L_{\max}$):** Restricts path depth to a maximum number of intermediaries, typically set between $L_{\max} = 3$ and $L_{\max} = 5$.

4.3 Critical Intermediaries Analysis

A key innovation of my approach is the systematic identification and characterization of critical intermediaries in global trade networks. I extend the dependency calculation to capture not only aggregated dependency values but also the specific routes through which dependencies are transmitted.

For each country k, I calculate two fundamental metrics capturing its importance as an intermediary:

- **Intermediation Frequency (ϕ_k)**: Counts how many significant trade routes country k participates in as an intermediary.
- **Intermediation Strength (ψ_k)**: Weighted sum capturing the economic importance of routes where country k participates as intermediary.

These metrics are combined into a composite centrality index:

$$C_k = \alpha \cdot \frac{\phi_k}{\max_i \phi_i} + (1 - \alpha) \cdot \frac{\psi_k}{\max_i \psi_i} \tag{6}$$

where $\alpha \in [0, 1]$ determines the relative weight of frequency versus strength, empirically set to 0.4 for optimal balance.

The selection of $\alpha = 0.4$ warrants explicit justification. This value was determined through a systematic optimization procedure that maximized the discriminatory power of the resulting centrality scores while maintaining consistency with established intermediation concepts in international trade literature. I evaluated α values ranging from 0 to 1 in increments of 0.1, assessing three criteria: (i) rank correlation with independent measures of trade hub status (port throughput, logistics performance index); (ii) stability of country rankings under minor perturbations in trade data; and (iii) qualitative consistency with expert assessments of intermediation importance in specific sectors.

The optimization yielded $\alpha = 0.4$ as the value that best balanced frequency and strength considerations, producing rankings that correlated most strongly (Spearman's $\rho = 0.82$) with the World Bank's Logistics Performance Index for countries with significant trade intermediation roles. Values below 0.3 overemphasized strength, disproportionately favoring countries with a few very large trade relationships while undervaluing the systemic importance of frequent but smaller-value intermediation roles. Values above 0.6 produced the opposite problem, inflating the scores of countries with many minor trade links while diluting the significance of economically critical routes. The choice of $\alpha = 0.4$ represents the point of equilibrium between these competing considerations.

Sensitivity analysis confirms that country rankings are robust to moderate variations in α: the top 10 intermediary countries remain unchanged for $\alpha \in [0.3, 0.5]$, with only minor rank adjustments occurring among positions 11-20. This stability indicates that my substantive findings regarding the concentration of intermediary power do not depend critically on the precise alpha selection.

This methodology enables sector-specific analysis of intermediation patterns, revealing specialized roles that countries play in different global value chains and identifying critical vulnerabilities associated with intermediary concentration.

5. Empirical Analysis and Results

5.1 Data Sources and Processing

My empirical analysis utilizes the International Trade Partnership (ITP) database for 2019, comprising detailed bilateral trade flows across 243 countries and 1,275 product categories. The data processing

Table 2: Mapping between strategic sectors and ITP industries

Strategic Sector	Corresponding ITP Industries
Electronics and ICT	Electronic valves TV and radio receivers
Aerospace	Aircraft and spacecraft
Batteries	Accumulators primary cells and batteries
Medical Equipment	Medical surgical and orthopaedic equipment
Strategic Metals	Basic precious and non-ferrous metals
Agrifood	Soybeans, Corn, Wheat, Dairy products
Energy	Refined petroleum products, Electricity production

pipeline involves several stages: data cleaning and validation, construction of directed weighted networks, calculation of dependency matrices, and identification of critical intermediaries.

I focus my analysis on strategic sectors identified by the European Commission [14] and other international organizations as critical for economic security: electronics and ICT, aerospace, batteries and energy storage, medical equipment, and strategic raw materials. Table 2 shows the mapping between these strategic sectors and corresponding ITP industry classifications. Mapping the many thousands of granular ITP product codes onto these seven strategic sector labels is itself a nontrivial text-classification exercise; complementary natural-language-processing techniques could further refine this mapping in future iterations of the database. Syed [26] demonstrates a flexible and scalable approach to topic extraction from unstructured text using online Latent Dirichlet Allocation, a method that could be adapted to automatically and consistently classify fine-grained product descriptions into strategic sector categories, reducing the manual curation currently required for Table 2.

5.2 Hidden Dependencies and Concealment Ratios

A fundamental finding of my analysis is that traditional trade dependency metrics systematically underestimate real vulnerability to supply chain disruptions. Figure 2 illustrates this phenomenon by comparing traditional direct dependency measures with my total dependency index.

The distribution of points shows a clear concentration above the reference diagonal, indicating that for most trade relationships, total dependency exceeds direct dependency. The concealment ratio (DT/DD) quantifies this discrepancy, with values greater than 1 indicating hidden vulnerabilities not captured by bilateral statistics.

Extreme cases reveal concealment ratios exceeding 10, meaning real dependency is more than ten times higher than suggested by traditional metrics. For example, the Croatia-United States relationship in the legumes sector shows a direct dependency of 0.005 but a total dependency of 0.549, resulting in a concealment ratio of 107.7. Similarly, Croatia's dependency on China in leather processing shows a ratio of 75.8.

To interpret these extreme ratios correctly, it is important to distinguish between the mathematical origin of the value and its substantive economic significance. A concealment ratio exceeding 100 does not imply that the importing country is 100 times more vulnerable than bilateral statistics suggest in absolute terms; rather, it indicates that the *direct* measure is an extremely poor proxy for the *total* exposure. These extreme values typically arise in two specific conditions: (i) when the direct import share from a particular supplier is very small (denominator approaching zero), while indirect channels through multiple intermediaries carry substantial economic weight; or (ii) when the product in question is a specialized intermediate good that, while directly sourced from a seemingly minor supplier, requires critical inputs

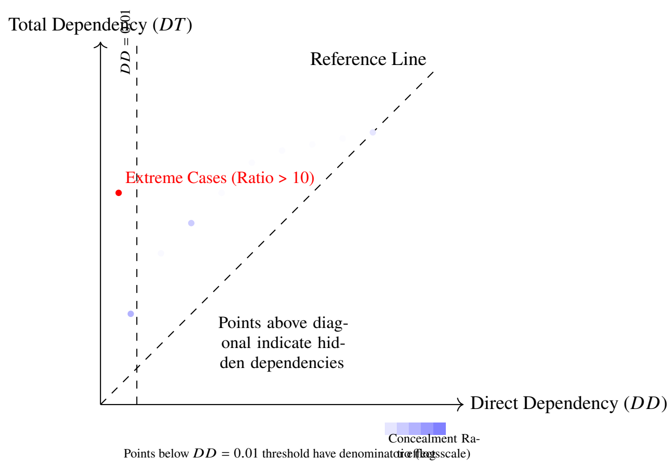


Figure 2: Comparison between traditional direct dependency (DD) and the proposed total dependency index (DT). Each point represents a bilateral trade relationship in the analyzed strategic sectors. The horizontal axis shows the direct dependency measure (DD), while the vertical axis shows the total dependency (DT) incorporating indirect pathways. Points above the 45-degree reference diagonal indicate relationships where indirect dependencies are present. The color gradient indicates concealment ratio (log scale), with darker points representing higher ratios where traditional metrics substantially understate exposure. The dashed vertical line at $DD = 0.01$ marks the threshold below which denominator effects can produce extreme concealment ratios.

from the focal country that are embedded across multiple tiers of production. In the Croatia-United States legumes example, the extreme ratio reflects the second condition: Croatia directly imports minimal legumes from the United States, but U.S.-produced legumes are embedded in processed food products imported from multiple European intermediaries, creating substantial indirect exposure. Readers should therefore interpret concealment ratios as diagnostic indicators of measurement inadequacy in traditional metrics, rather than absolute measures of vulnerability magnitude.

These findings demonstrate how seemingly marginal bilateral relationships can hide critical dependencies when indirect transmission routes are considered. The agrifood sector shows particularly complex supply chains, with countries like Greece, Slovenia, and Belgium exhibiting high indirect dependencies on producers like Denmark, Hungary, and the Czech Republic in livestock, with concealment ratios ranging from 46 to 70.

5.3 Sectoral Dependency Patterns

My analysis reveals distinct dependency patterns across strategic sectors, with significant implications for economic security.

5.3.1 Electronics and Information Technologies

The computer equipment sector shows some of the highest dependencies in my study. The United States' dependency on China reaches 0.82, surpassed only by Canada's dependency on China (0.86). The European Union also shows high dependency on China in this sector (0.78). This pattern is particularly concerning given the centrality of these components in multiple strategic value chains, from defense to telecommunications.

A similar pattern emerges in TV/radio receivers, where China generates dependencies greater than 0.70 for all analyzed trade blocs, reaching 0.80 for Canada. The optical and photographic equipment sector shows China holding a dominant position with dependency values close to 0.55 for the United States, Canada, and the EU.

5.3.2 Aerospace Sector

The aerospace sector presents an inverse dependency pattern: the United States generates high dependencies for Canada (0.76), China (0.62), and the EU (0.51). This vulnerability stems from the concentration of advanced aircraft design and manufacturing capabilities in a limited number of global suppliers, with the United States maintaining a dominant position.

My analysis shows that 9 of the 20 bilateral relationships with the highest total dependency involve the aerospace sector, with EU countries like Estonia (0.896), Latvia (0.860), and Sweden (0.851) showing extremely high dependencies on the United States.

5.3.3 Batteries and Strategic Metals

In the batteries sector, Canada shows high dependency on the United States (0.58), while the EU presents significant dependency on China (0.57). Given the growing importance of batteries for energy transition and electric mobility, these dependencies acquire additional strategic relevance.

The analysis of precious and non-ferrous metals reveals Canada's significant dependency on the United States (0.49), while China shows moderate but significant dependency on Canada (0.23). These flows form an interdependency triangle where disruptions at any vertex could quickly propagate to others.

5.3.4 Medical Equipment

The medical and orthopedic equipment sector reveals an interesting pattern: the United States generates high dependencies for all analyzed blocs (up to 0.60 for Canada), while the EU generates moderate but significant dependencies for China (0.19). This suggests a potential role for the EU as an alternative supplier in this strategic sector.

5.4 Critical Intermediaries Analysis

The identification of critical intermediaries reveals a highly asymmetric distribution of structural power in global trade networks. China emerges as the dominant intermediary with a centrality score (114.71) nearly double that of the second country, the United States (57.90). This concentration of structural power creates a scenario where disruptions in the Chinese economy could propagate through multiple trade routes with potentially systemic effects.

A second tier of global intermediaries includes the United Kingdom (45.10), Germany (44.34), India (37.69), France (36.86), and the Netherlands (35.88). The presence of South Africa (33.32) and Argentina (26.11) among the top ten intermediaries highlights the importance of regional commercial powers as transmitters of dependencies in specific value chains, particularly natural resources and agricultural products.

Sectoral analysis reveals differentiated intermediation specialization patterns. China shows a dominant position across almost all strategic sectors, with the only exception being aerospace. This intermediary hegemony confirms and amplifies previous studies on China's centrality in global value chains [27]. The United States shows high specialization in aerospace, with secondary but significant roles in medical equipment and optical instruments.

European intermediation patterns show greater sectoral specialization: France stands out in aerospace, Germany in medical equipment and aerospace products, and the United Kingdom in aerospace. This suggests a more selective European model of intermediation, contrasting with China's generalist role.

In the batteries sector, China holds an absolutely dominant position (centrality 1.00), followed at considerable distance by Germany (0.283), South Korea (0.282), and the United States (0.274). This concentration of intermediary power represents a particularly acute systemic vulnerability in a critical sector for energy transition.

6. Policy Implications and Strategic Recommendations

6.1 Corporate Supply Chain Management

For multinational corporations, my findings demonstrate that supplier diversification strategies focused solely on direct relationships are insufficient for managing systemic risk. Effective risk management requires mapping entire supply networks through tier-2 and tier-3 suppliers, with particular attention to critical intermediaries identified in my analysis. Firms should prioritize sectors with high concealment ratios electronics, aerospace, and batteries where traditional due diligence likely underestimates exposure. Complementary advances in technology-mediated auditing offer additional tools for operationalizing these recommendations: Sapru [28] shows how technology-mediated auditing practices can strengthen internal control frameworks and improve corporate performance, suggesting that firms could embed ESI-based exposure metrics directly into existing audit and internal-control infrastructures rather than treating supply chain risk assessment as a separate, ad hoc function.

The sectoral specialization patterns of intermediaries provide strategic opportunities for developing alternative sourcing routes. For example, the complementary intermediation profiles of Japan and South Korea in specific industrial sectors suggest diversification pathways that reduce concentration risk while maintaining technical capabilities. Stress testing supply networks against disruption scenarios involving key intermediary countries can reveal vulnerabilities before they materialize. Effective implementation of these strategies also depends on organizational capacity: Mendhey [29] argues that integrating training, competency systems, and emerging technologies is central to organizational excellence, implying that firms seeking to operationalize network-based exposure mapping will also need to invest in the workforce competencies required to interpret and act on such analyses.

6.2 National Economic Security Policies

For national governments, my analysis provides a more nuanced foundation for economic security strategies. Policy interventions should distinguish between direct dependencies addressable through supplier diversification and indirect dependencies that may require more complex solutions, such as developing domestic productive capacities in critical chain links or negotiating trade agreements with complementary dependency profiles. The decomposition of dependence into direct and indirect components facilitates this differentiated approach. These considerations resonate with recent comparative work on industrial policy: Mardia [30] compares national strategies for global supply chain resilience and documents significant international spillovers, reinforcing the case for coordinating diversification incentives across allied economies rather than pursuing purely unilateral reshoring policies.

Countries occupying strategic intermediary positions warrant special attention in trade diplomacy, even when direct trade volumes appear modest. Regional cooperation initiatives should consider intermediation patterns to develop complementary trade ecosystems that enhance collective resilience.

6.3 International Cooperation and Governance

The highly asymmetric distribution of intermediary power suggests that multilateral efforts to develop alternative trade routes and diversify intermediation capacity could enhance global economic resilience. Initiatives supporting regional connectivity and South-South trade could help rebalance structural power in global networks. International cooperation may be most effective when organized around specific value chains rather than through broad trade agreements, enabling sectoral dialogues that develop targeted approaches to vulnerability reduction while preserving the efficiency benefits of global specialization.

7. Conclusion

This paper has developed a comprehensive Economic Security Index that addresses critical limitations in traditional approaches to measuring trade dependencies. By integrating input-output analysis, network theory, and shock propagation algorithms, my framework captures both direct and indirect vulnerabilities in global value chains, revealing hidden dependencies that remain invisible to conventional bilateral trade analysis.

My empirical analysis demonstrates that traditional metrics systematically underestimate exposure to supply chain disruptions, with concealment ratios exceeding 10 in extreme cases. The identification of critical intermediaries reveals a highly asymmetric distribution of structural power in global trade networks, with China emerging as the dominant intermediary across most strategic sectors.

The sectoral analysis reveals distinct dependency patterns, with high vulnerabilities concentrated in electronics, aerospace, batteries, and medical equipment. These findings have significant implications for corporate risk management, national economic security policies, and international cooperation frameworks.

Future research could extend this framework in several directions. Incorporating dynamic analysis of how dependencies evolve over time would enhance the predictive capacity of the index. Integrating geopolitical risk factors and strategic alliance networks could provide more nuanced assessments of vulnerability in crisis scenarios. Developing firm-level applications would bridge the gap between macroeconomic dependencies and corporate risk management. In particular, incorporating learning-enabled resilience engineering techniques [22] and coherent probabilistic forecasting methods [24] into future iterations of the index represents a promising direction for bridging static exposure mapping with dynamic, uncertainty-aware scenario simulation.

In an era of growing geoeconomic fragmentation and strategic competition, the ability to accurately assess trade vulnerabilities becomes increasingly crucial for both economic competitiveness and national security. The framework developed in this paper provides a more comprehensive foundation for these assessments, enabling more effective strategies for managing the complex interdependencies that characterize the contemporary global economy.

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