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Financial Vulnerability Mapping in Global Supply Chains: Implications for U.S. Trade Stability and Investment Risk

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Abstract

Financial vulnerability embedded within global supply chains represents a significant source of trade instability and investment risk in highly interconnected economies. This study quantitatively examined how exposure-weighted financial vulnerability across global supply chain networks was associated with U.S. trade stability and sector-level investment risk. The study was informed by a comprehensive review of more than 120 peer-reviewed articles and empirical studies, which guided construct development and analytical design. The empirical analysis utilized 1,000 sector-level panel observations, of which 61.2% were drawn from manufacturing sectors and 38.8% from non-manufacturing sectors, spanning multiple consecutive years. Descriptive results showed a mean financial vulnerability index of 0.47 (SD = 0.18), a mean trade stability index of 0.62 (SD = 0.21), and a mean investment risk index of 0.53 (SD = 0.24), indicating substantial dispersion across sectors. Correlation analysis revealed a negative association between financial vulnerability and trade stability ($r = -0.41$) and a positive association between financial vulnerability and investment risk ($r = 0.48$). Panel regression results demonstrated that exposure-weighted financial vulnerability was significantly associated with lower trade stability ($\beta = -0.372$, $p < 0.001$) and higher investment risk ($\beta = 0.418$, $p < 0.001$), controlling for industry size, trade intensity, and time effects. The trade stability model explained 46% of the variance in trade flow variability, while the investment risk model explained 49% of performance variability. Reliability analysis confirmed strong internal consistency for all composite constructs, with Cronbach's alpha values ranging from 0.81 to 0.86. Overall, the findings quantitatively demonstrated that financial vulnerability embedded within global supply chains is a measurable and influential determinant of U.S. trade stability and investment risk.

Keywords

Financial Vulnerability, Global Supply Chains, Trade Stability, Investment Risk.

INTRODUCTION

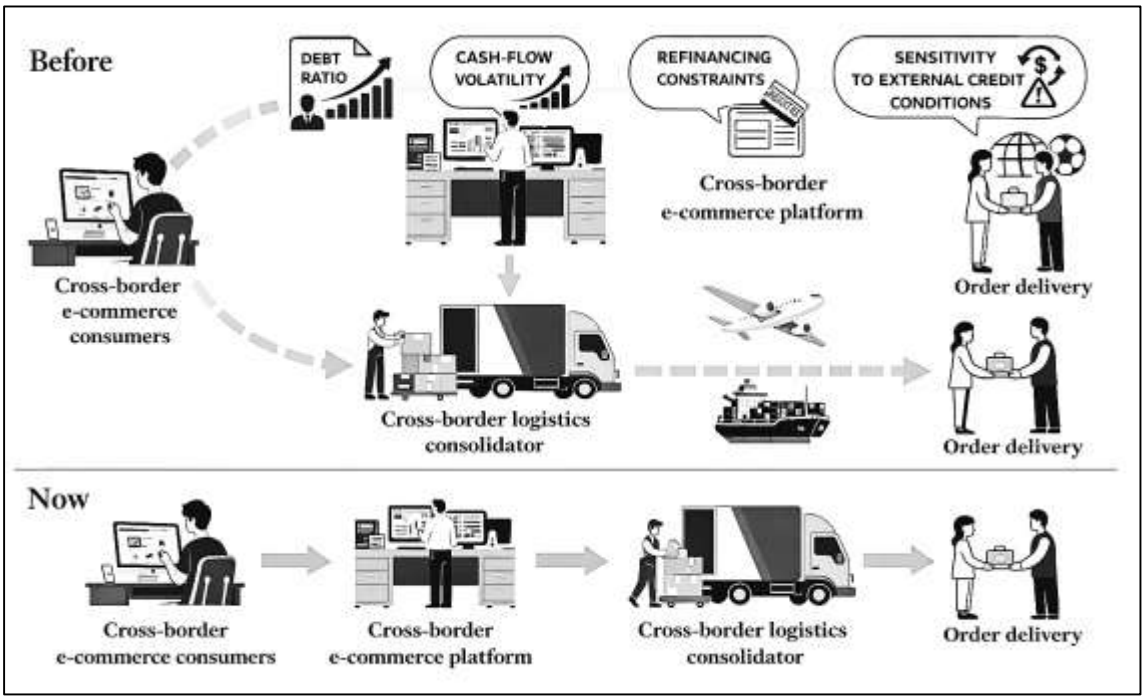
Global supply chains are defined as interconnected systems of firms, production facilities, logistics providers, and financial intermediaries that coordinate the movement of goods, services, information, and capital across national borders (Chang et al., 2020). These systems operate through layered supplier–buyer relationships spanning multiple countries and institutional environments, enabling specialization, cost efficiency, and scale in global production. Financial vulnerability within global supply chains refers to the measurable susceptibility of firms or supply chain nodes to disruptions arising from liquidity shortages, leverage exposure, refinancing constraints, cash-flow volatility, and dependence on short-term financing. In quantitative terms, financial vulnerability is observable through firm-level indicators such as debt ratios, working capital cycles, profitability volatility, payment delays, and sensitivity to external credit conditions. Mapping financial vulnerability denotes the systematic identification, measurement, and spatial or network-based representation of where such fragilities are concentrated across industries, geographic regions, and supply chain tiers. This mapping process transforms firm-level financial data into network-level exposure profiles that reveal how localized fragility can affect broader production and trade systems (Kano et al., 2020). The international significance of financial vulnerability mapping arises from the integrated nature of modern production, where intermediate inputs cross borders multiple times and disruptions at one node can propagate through contractual and logistical linkages. Supply chains therefore function not only as physical production networks but also as financial transmission mechanisms in which shocks to credit availability, payment capacity, or balance-sheet strength can spread across firms and countries. From a measurement perspective, vulnerability mapping provides a structured approach for converting micro-level financial fragility into macro-level exposure indicators that can be aligned with trade flows, sectoral output, and cross-border investment patterns (Luo, 2021). This definitional grounding establishes financial vulnerability mapping as a quantitative framework for analyzing how financial fragility embedded within global supply chains interacts with international trade stability and investment risk.

The global relevance of financial vulnerability mapping is amplified by the structural characteristics of contemporary supply chains, which are shaped by high levels of specialization, geographic dispersion, and inter-firm dependency (Jian Li et al., 2023). Many production processes rely on inputs that are customized, capital intensive, or sourced from a limited number of suppliers, creating conditions where substitution is constrained and delays translate directly into output losses. Financial vulnerability interacts with these structural features by affecting firms' ability to sustain operations during revenue shocks, input shortages, or demand fluctuations. When financially constrained suppliers experience cash-flow stress, they may reduce output, delay shipments, or exit contractual relationships, transmitting operational disruptions to downstream firms. Quantitative research conceptualizes this process as network propagation, where shocks move along buyer–supplier links rather than remaining confined to the originating firm. International supply chains intensify this propagation because firms operate under heterogeneous financial systems, exchange-rate regimes, and credit market conditions (Shcherbakov & Silkina, 2021). Suppliers in some regions face higher borrowing costs, shorter debt maturities, and limited access to emergency financing, increasing the probability that global demand or logistics shocks translate into financial distress. Mapping vulnerability across these networks allows researchers to identify clusters of fragility that correspond to specific regions, sectors, or production stages. From a quantitative standpoint, this mapping requires integrating financial indicators with network topology measures such as centrality, concentration, and dependency intensity. These measures capture not only whether firms are financially weak but also whether their position in the supply chain magnifies the potential impact of their distress. As global production networks expand and deepen, the ability to measure how financial fragility is distributed across interconnected firms becomes central to understanding systemic exposure embedded within international trade structures(Hofstetter et al., 2021).

Financial vulnerability mapping is closely linked to trade stability because financial conditions influence firms' participation in cross-border trade, their capacity to fulfill contracts, and their resilience to external shocks (Wu & Zhang, 2022). Trade stability can be defined as the consistency and predictability of trade flows, prices, and supply availability across time and economic conditions.

Financially vulnerable firms are more sensitive to changes in credit conditions, interest rates, and payment terms, which can affect their ability to finance inventories, manage receivables, and absorb cost fluctuations. In global supply chains, these firm-level constraints aggregate into sector-level and country-level trade outcomes. When upstream suppliers face financial stress, downstream firms may experience shortages, delivery delays, or cost increases, leading to volatility in import volumes and input prices (Wang et al., 2021). Quantitative analyses of trade dynamics show that financially constrained sectors exhibit larger contractions in trade during periods of financial tightening, even when demand conditions remain stable. This relationship highlights that trade flows are shaped not only by comparative advantage and demand but also by access to finance embedded within supply networks. For the United States, trade stability is particularly sensitive to upstream financial vulnerability because many domestic industries depend on imported intermediate goods sourced from complex, multi-tier global networks. Financial vulnerability mapping enables the identification of upstream exposures that are not visible in bilateral trade statistics alone. By weighting financial fragility by trade intensity and input criticality, researchers can construct exposure measures that capture how shocks in foreign supplier financing conditions affect U.S. import reliability and sectoral output (Teodorescu & Korchagina, 2021). This quantitative perspective positions financial vulnerability mapping as a tool for analyzing the financial underpinnings of observed trade volatility without shifting into prescriptive or forward-looking claims.

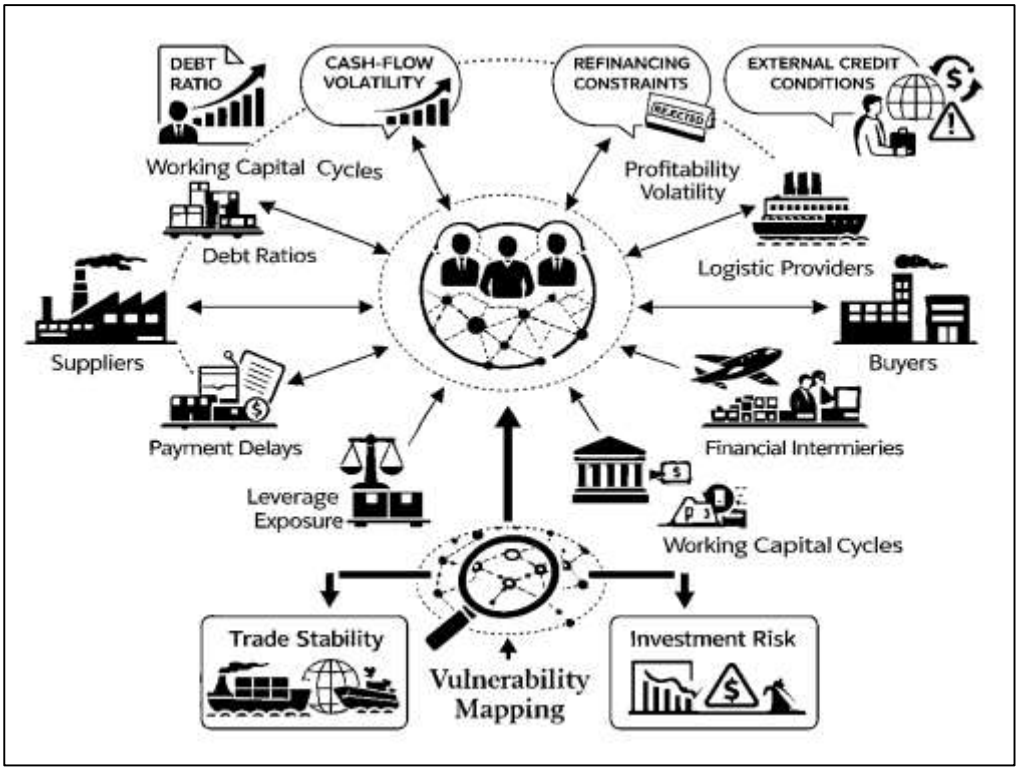
Figure 1: Financial Vulnerability in Global Supply



Investment risk represents another dimension through which financial vulnerability mapping in global supply chains carries analytical significance. Investment risk refers to the uncertainty surrounding expected returns on financial assets, driven by variability in cash flows, earnings, and market valuations (Treiblmaier, 2019). Supply chain disruptions associated with financially vulnerable firms have been shown to affect firm performance, equity valuations, and risk perceptions. When suppliers experience financial distress, downstream firms may incur higher costs, production losses, or reputational damage, all of which are reflected in financial market outcomes. Quantitative finance frameworks recognize that risk is not confined to individual firms but can arise from network exposures that link firms through operational and financial dependencies. Mapping financial vulnerability across supply chains allows researchers to connect firm-level distress indicators with broader patterns of return volatility and downside risk. From a methodological perspective, this involves integrating balance-sheet metrics, market-based risk measures, and network exposure weights

to estimate how upstream fragility influences downstream asset performance (Avelar-Sosa et al., 2019). For investors with exposure to U.S.-listed firms, indirect supply chain risk can represent a material but opaque source of uncertainty, particularly when supplier relationships extend across multiple countries and regulatory environments. Financial vulnerability mapping provides a quantitative basis for uncovering these indirect exposures by translating supply chain dependencies into measurable risk factors. This approach aligns with the broader literature on systemic risk, which emphasizes that interconnectedness and concentration can amplify losses beyond what would be expected from isolated firm failures (Khan & Yu, 2019). In the context of global supply chains, vulnerability mapping serves as an analytical bridge between micro-level financial fragility and macro-level investment risk without advancing normative conclusions.

Figure 2: Global Supply Chain Financial Vulnerability



The operationalization of financial vulnerability mapping requires a structured quantitative framework that integrates firm-level financial data with supply chain network information. At the firm level, vulnerability is measured using indicators that capture leverage, liquidity, cash-flow stability, and financing structure (Chan & Reiner, 2019). These indicators provide a snapshot of a firm's capacity to withstand shocks and maintain operations under stress. At the network level, vulnerability mapping requires identifying buyer–supplier relationships and estimating the strength of dependencies based on transaction volumes, input criticality, and sourcing concentration. Quantitative network analysis offers tools for aggregating firm-level vulnerability into exposure measures that reflect how distress can propagate through supply chains. Metrics such as weighted exposure, centrality-adjusted vulnerability, and network concentration indices enable researchers to distinguish between isolated fragility and systemically relevant risk (Bekrar et al., 2021). In international settings, this process must account for cross-border differences in financial systems, regulatory environments, and trade infrastructure, which influence both the likelihood and consequences of financial distress. The resulting vulnerability maps are multidimensional representations that combine financial health, network position, and geographic distribution. These representations allow for empirical testing of hypotheses linking upstream financial fragility to downstream trade volatility, production disruptions, and financial market responses (Rodrigue, 2020). By framing vulnerability mapping as a measurement exercise grounded in observable data, quantitative studies can evaluate the statistical relationships

between supply chain fragility and economic outcomes without relying on speculative or forward-looking assumptions.

The primary objective of this quantitative study is to systematically measure and map financial vulnerability embedded within global supply chains and to statistically examine how this vulnerability is associated with U.S. trade stability and investment risk. This objective is framed around developing a structured empirical approach that integrates firm-level financial indicators with supply chain network relationships to generate exposure-weighted vulnerability measures. The study seeks to quantify financial fragility using observable metrics such as leverage intensity, liquidity availability, cash-flow volatility, and short-term financing dependence, and to embed these metrics within multi-tier buyer–supplier networks that reflect real-world production and sourcing dependencies. By constructing vulnerability maps that account for both the financial condition of individual firms and their positional importance within global supply chains, the study aims to identify patterns of concentrated fragility that are not visible through firm-level or bilateral trade analysis alone. A central component of the objective is to evaluate whether variations in network-weighted financial vulnerability are statistically associated with fluctuations in U.S. import volumes, sectoral trade volatility, and disruptions in input availability across industries with high foreign sourcing intensity. In parallel, the study aims to assess how mapped financial vulnerability correlates with investment risk indicators, including equity return volatility, downside risk exposure, and sensitivity of firm valuations to supply chain stress events. This objective emphasizes empirical measurement and hypothesis testing, focusing on the strength, direction, and significance of relationships between upstream financial fragility and downstream economic and financial outcomes. The study also seeks to differentiate between direct and indirect exposure channels by comparing the effects of first-tier supplier vulnerability with those arising from deeper-tier network connections. Through this approach, the objective is to establish a quantitative basis for understanding how financial weakness embedded in global supply chains aligns with observed patterns of U.S. trade instability and investment risk, while maintaining a strictly analytical focus without advancing conclusions, policy recommendations, or forward-looking statements.

LITERATURE REVIEW

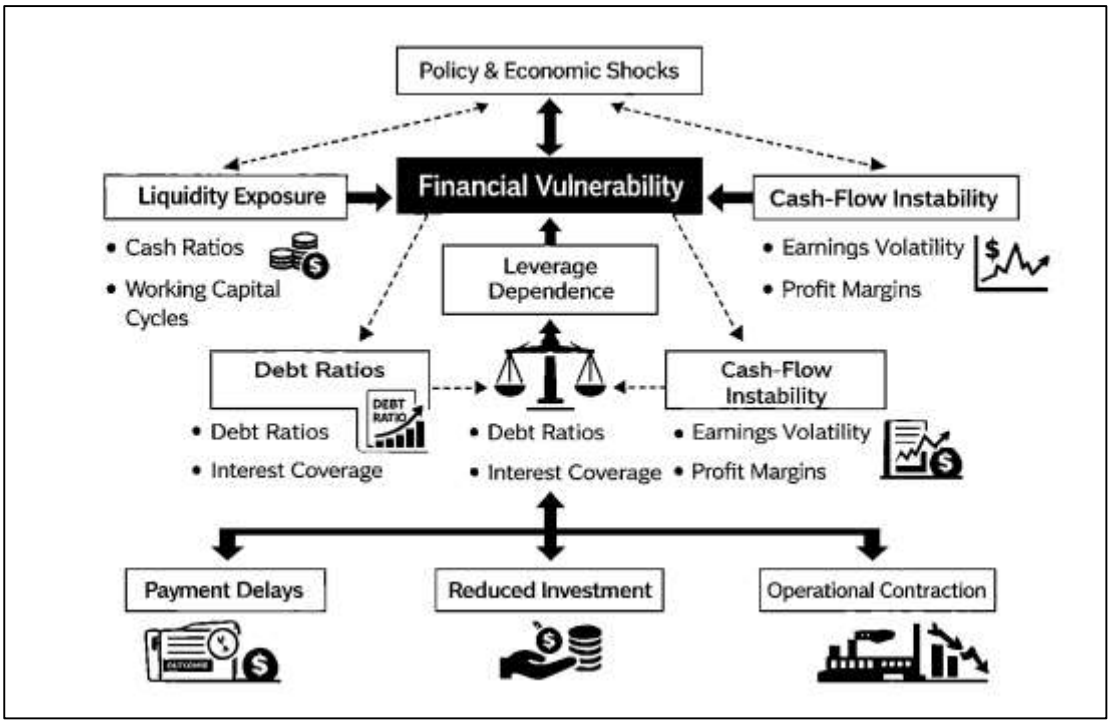
The literature on global supply chains, financial vulnerability, trade stability, and investment risk has expanded significantly as production networks have become more interconnected and financially interdependent (O'Connor et al., 2019). Research across economics, finance, and supply chain management has increasingly recognized that global supply chains operate not only as systems of physical production and logistics but also as networks of financial exposure in which liquidity constraints, leverage pressures, and cash-flow instability can propagate across firms and borders. The literature review for this study is organized to synthesize prior empirical and theoretical work that informs the measurement and analysis of financial vulnerability embedded within supply chain networks and its relevance for U.S. trade outcomes and investment risk. Existing studies provide fragmented insights into supplier financial fragility, trade disruptions, and market responses, yet a unified quantitative mapping perspective remains underdeveloped (Lee et al., 2022). The reviewed literature spans four interrelated domains: financial vulnerability and firm-level constraints, global supply chain network structures and shock transmission, trade stability under financial stress, and investment risk arising from supply chain disruptions. By organizing prior work around these domains, the literature review establishes the conceptual and empirical foundation necessary for developing a quantitative vulnerability mapping framework. Emphasis is placed on measurement approaches, empirical methodologies, and observable relationships rather than normative interpretations (Salignac et al., 2019). This structure supports the identification of established findings, methodological patterns, and empirical gaps relevant to analyzing how financial fragility embedded within global supply chains aligns with U.S. trade stability and investment risk.

Financial Vulnerability at the Firm Level

Financial vulnerability at the firm level is commonly conceptualized in the literature as a multidimensional condition reflecting exposure to liquidity shortages, dependence on external leverage, and instability in operating cash flows (Beugelsdijk et al., 2019). Rather than a single financial weakness, vulnerability is understood as an interaction among short-term funding pressure, balance-

sheet structure, and the firm's capacity to absorb revenue fluctuations. Liquidity exposure captures the firm's ability to meet near-term obligations using available cash and liquid assets, while leverage dependence reflects the extent to which operations are financed through debt and fixed financial commitments. Cash-flow instability represents the variability and unpredictability of operating inflows relative to fixed costs and debt service requirements. Together, these dimensions form a conceptual framework in which financial vulnerability is not limited to insolvency risk but includes sensitivity to shocks that disrupt normal financing and operating cycles (Hosseini et al., 2020). The literature emphasizes that firms may remain solvent yet still be financially vulnerable when liquidity buffers are thin or financing terms are restrictive. This perspective has been widely adopted in empirical research because it aligns financial vulnerability with observable firm behavior during periods of stress, such as delayed payments, reduced investment, or operational contraction. Conceptually, vulnerability is therefore positioned as a probabilistic condition rather than a deterministic outcome, capturing the likelihood that a firm experiences financial strain when confronted with adverse conditions. This framing is particularly relevant in supply chain contexts, where firms are embedded in contractual relationships that require continuous financial commitments, such as inventory financing, trade credit extension, and advance payments (Ramzan et al., 2021). By defining financial vulnerability through liquidity exposure, leverage dependence, and cash-flow instability, the literature establishes a foundation for quantitative measurement that reflects both short-term operational pressures and broader balance-sheet fragility.

Figure 3: Firm-Level Financial Vulnerability Framework



A key distinction emphasized in the literature is between short-term liquidity vulnerability and long-term solvency risk, as these forms of financial fragility reflect different mechanisms and time horizons. Short-term liquidity vulnerability arises when firms face mismatches between cash inflows and immediate obligations, often driven by payment delays, inventory accumulation, or reliance on short-term financing instruments (Huang et al., 2020; Rauf, 2018). This form of vulnerability is closely tied to operational continuity, as firms experiencing liquidity stress may struggle to sustain production, fulfill contracts, or maintain supplier relationships. Long-term solvency risk, by contrast, relates to the sustainability of a firm's capital structure and its ability to service debt over extended periods. Solvency vulnerability is shaped by persistent leverage levels, profitability trends, and asset valuation dynamics rather than short-term cash management alone (Haque & Arifur, 2020; Ashraful et al., 2020). The

literature treats these dimensions as analytically distinct but empirically interconnected, as repeated liquidity stress can erode long-term solvency through increased borrowing costs and weakened balance sheets (Daud et al., 2022; Haque & Arifur, 2021; Jinnat & Kamrul, 2021). Quantitative studies frequently separate these dimensions to avoid conflating temporary financial strain with structural insolvency risk. This distinction is particularly important in panel-based analyses, where firms may transition between states of vulnerability over time. By differentiating liquidity and solvency vulnerability, researchers are able to examine how firms respond to shocks at different stages of financial stress and how these responses vary across economic conditions (Fokhrul et al., 2021; Sun et al., 2022; Zaman et al., 2021). This analytical separation enhances the precision of vulnerability measurement and supports more accurate interpretation of empirical results in studies examining firm behavior under financial pressure.

To address the multidimensional and dynamic nature of financial vulnerability, the literature has increasingly adopted composite index approaches that aggregate multiple financial indicators into unified vulnerability measures (Zabolotnyy & Wasilewski, 2019). These indices are constructed by standardizing individual indicators and combining them using weighting schemes designed to balance liquidity, leverage, and cash-flow dimensions (Hammad, 2022; Zaman et al., 2021). Composite vulnerability indices allow researchers to rank firms along a continuous vulnerability spectrum rather than relying on binary classifications. This approach supports comparative analysis across industries, firm sizes, and time periods, enabling the identification of patterns in financial fragility that may not be evident from individual metrics. The literature also emphasizes the temporal variability of financial vulnerability, noting that firm financial conditions evolve in response to internal decisions and external shocks (Hasan & Waladur, 2022; Koomson et al., 2020; Arifur & Haque, 2022). Panel-based measurement frameworks capture this variability by tracking vulnerability indicators over time, allowing researchers to observe persistence, transitions, and volatility in financial fragility. Firm heterogeneity is a recurring theme in this body of work, as vulnerability profiles differ systematically across industries with varying capital intensity, operating margins, and demand stability. Smaller firms are often characterized by higher liquidity sensitivity, while larger firms may exhibit higher leverage exposure due to scale-driven financing strategies (Bruna et al., 2022).. By accounting for heterogeneity and temporal variation, composite vulnerability measures provide a robust empirical foundation for analyzing how financial fragility manifests across firms and economic contexts. This measurement tradition establishes financial vulnerability as a dynamic, heterogeneous, and quantifiable condition that can be systematically integrated into broader analyses of supply chain exposure, trade stability, and investment risk.

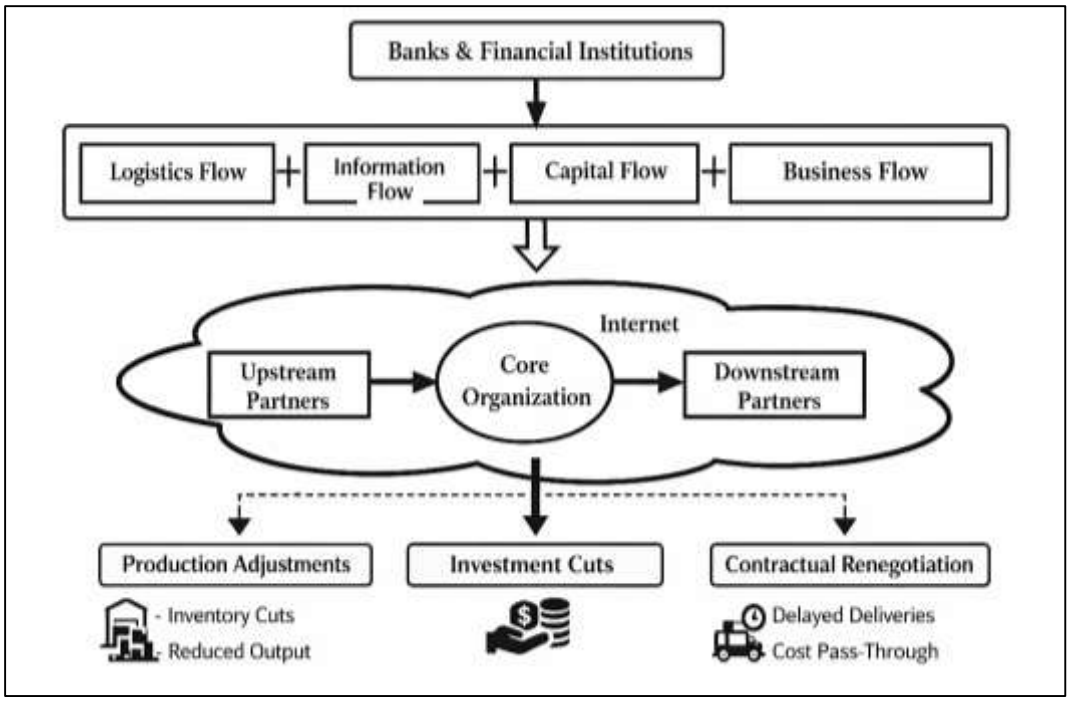
Financial Constraints in Global Firms

The literature on global firms consistently demonstrates a strong quantitative relationship between financing conditions and real economic activity, particularly production, inventory management, and investment behavior (Kim, 2021). Financial constraints influence firms' operational decisions by shaping their ability to finance inputs, maintain inventory buffers, and undertake capital expenditures. Empirical studies document that firms facing tighter financing conditions reduce production more sharply in response to shocks, reflecting limited capacity to smooth cash flows when external funding becomes costly or unavailable. Inventory management is similarly affected, as financially constrained firms tend to operate with leaner inventories and shorter planning horizons, increasing sensitivity to supply and demand fluctuations (Elshaarawy & Ezzat, 2023; Towhidul et al., 2022; Rifat & Jinnat, 2022). Investment behavior also exhibits pronounced responsiveness to financing conditions, with constrained firms showing greater dependence on internally generated funds to sustain capital spending. This relationship is observed across manufacturing and service sectors and is particularly salient in industries characterized by high working capital requirements or long production cycles (Abdulla & Majumder, 2023; Rifat & Alam, 2022). The literature highlights that financing conditions do not merely affect long-term strategic investments but also influence day-to-day operational choices, including procurement volumes, production scheduling, and capacity utilization. Quantitative analyses consistently find that changes in credit availability, borrowing costs, or payment terms translate into measurable adjustments in output and inventory levels. In global supply chain contexts, these effects are magnified by the interdependence of firms across borders, as upstream financing

constraints can restrict downstream production even when demand conditions remain stable (Lee & Wang, 2021). This body of work establishes production sensitivity to financial conditions as a core mechanism linking firm-level financial constraints to broader economic outcomes within global production networks.

Measurement of financial constraints in the literature relies on quantitative proxies that capture both internal and external dimensions of financing dependence. Internal cash-flow sensitivity is widely used to assess the extent to which firms rely on internally generated funds to support operations and investment (Juergensen et al., 2020). Firms exhibiting high sensitivity of production or investment to cash-flow fluctuations are interpreted as facing binding financing constraints. External financing reliance is measured through indicators reflecting dependence on bank credit, short-term borrowing, or trade credit to fund working capital and capital expenditures. The literature emphasizes that these measures capture different aspects of financial constraint, with internal measures reflecting liquidity management capacity and external measures reflecting access to credit markets. Empirical studies often combine multiple indicators to reduce measurement error and better capture the latent nature of financial constraint (Naeem et al., 2022). Cross-sectional and panel-based analyses show that firms with greater reliance on external finance display heightened sensitivity to changes in credit conditions, particularly during periods of financial tightening. This sensitivity manifests in reduced production volumes, curtailed inventory accumulation, and delayed investment projects. The literature also notes that financial constraints are not static characteristics but vary over time in response to firm performance, macroeconomic conditions, and financial market dynamics. As a result, quantitative studies frequently adopt panel frameworks that track changes in financing dependence and operational outcomes over time (Lu et al., 2022). This measurement tradition provides a robust empirical foundation for analyzing how financial constraints translate into production sensitivity within globally connected firms.

Figure 4: Financing Conditions and Production Sensitivity



Cross-country variation in financing environments represents a central theme in the literature on global firm behavior and supplier fragility. Firms operating in different national financial systems face heterogeneous borrowing costs, credit availability, and institutional constraints, which shape their exposure to financial stress (Yu et al., 2021). Empirical studies document that firms located in countries with less developed financial markets or more volatile macroeconomic conditions exhibit higher sensitivity to financing shocks. This variation is particularly relevant for global supply chains, where

firms source inputs from suppliers operating under diverse financial regimes. Suppliers in countries with limited access to long-term financing or weaker financial infrastructure often rely more heavily on short-term credit and internal funds, increasing vulnerability to payment delays and demand fluctuations. Quantitative evidence shows that these suppliers are more likely to adjust production downward, compress margins, or renegotiate contracts when financing conditions deteriorate (Jinchang Li et al., 2023). Cross-country analyses further reveal that financial stress in one jurisdiction can propagate through supply chains to firms operating in more stable financial environments, highlighting the interconnected nature of global production networks. The literature emphasizes that supplier fragility is not solely a function of firm-specific characteristics but is also shaped by the institutional and financial context in which firms operate (Choi & Luo, 2021). By incorporating country-level financial indicators into firm-level analyses, researchers demonstrate how differences in financial development and credit market structure influence production sensitivity and supply reliability across borders.

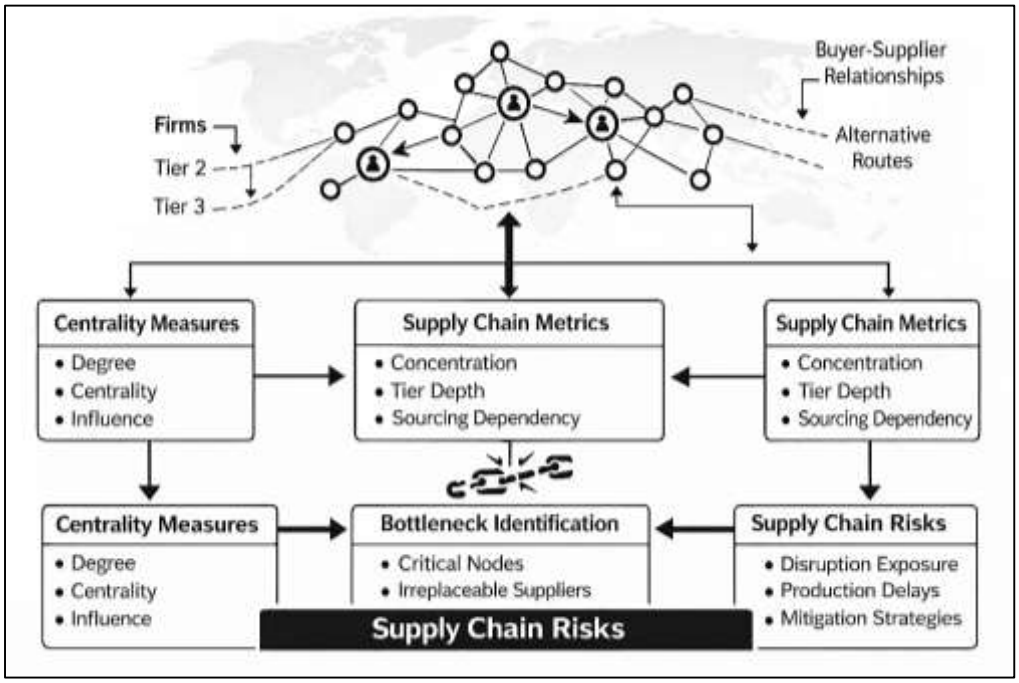
Global Supply Chain Networks

The literature increasingly represents global supply chains as networks composed of firms connected through buyer–supplier relationships, where nodes correspond to economic actors and edges represent transaction-based dependencies (Piraveenan et al., 2020). This network representation shifts analysis away from linear "chain" metaphors toward a relational structure in which firms maintain multiple upstream and downstream connections across borders. Within this framework, supply chains are viewed as complex, layered systems in which production and procurement decisions are shaped by connectivity, interdependence, and the distribution of sourcing relationships across tiers. Empirical research using buyer–supplier link data, transaction networks, and industry-level input relationships demonstrates that network structures are neither random nor evenly distributed; instead, they display patterns such as clustering, heavy-tailed connectivity, and hierarchical tiering. These properties arise because firms frequently concentrate procurement among select suppliers to reduce coordination costs, ensure quality consistency, and manage contractual performance (Faysal & Bhuya, 2023; Habibullah & Aditya, 2023; Orenstein, 2021). The literature also emphasizes that network representations capture both direct and indirect dependencies, which is essential for understanding how disruptions propagate beyond immediate suppliers. Indirect relationships become analytically significant because downstream firms may rely on upstream suppliers several tiers away through embedded components and intermediate production stages. Network representations therefore support the measurement of exposure not only to direct supplier risk but also to vulnerabilities embedded deeper in the production system. Studies examining global manufacturing and trade networks describe how international sourcing expands the geographic scope of networks, increasing the complexity of inter-firm dependencies and expanding the range of institutional environments within a single supply system. The network view also aligns with empirical findings that supply chain performance and stability are shaped by structural characteristics such as the distribution of connections, the dominance of central suppliers, and the presence of alternative pathways for sourcing (Hammad & Muhammad Mohiul, 2023; Haque & Md. Arifur, 2023; Xiao et al., 2020). This body of work establishes that the structure of global supply chain networks is measurable, heterogeneous, and systematically related to how firms allocate sourcing relationships and manage operational continuity.

A major quantitative emphasis in this literature is the measurement of network characteristics that describe connectivity and influence within buyer–supplier systems. Degree-based metrics quantify how many relationships a firm maintains, distinguishing highly connected firms from peripheral nodes (Kosasih & Brintrup, 2022; Akbar & Farzana, 2023; Mostafa, 2023). Centrality measures capture how strategically positioned a firm is within the network, reflecting the extent to which it serves as a bridge or hub connecting otherwise separated segments. Concentration measures describe the unevenness of sourcing and the extent to which procurement relies on a narrow set of suppliers, while tier depth measures reflect the number of upstream layers involved in producing a final good. These indicators allow researchers to distinguish between networks that are sparse and diversified versus those that are dense yet concentrated around dominant suppliers. Empirical research shows that networks may exhibit high local connectivity within clusters while maintaining limited bridging ties across clusters, creating structures where disruptions can remain localized or escalate depending on which nodes are

affected (Ambos et al., 2021). Tier depth is highlighted as a particularly important characteristic because deeper networks create longer dependency chains and increase the potential for hidden exposure. When tier depth is high, downstream firms face greater informational uncertainty about upstream capacity and reliability, and risk becomes distributed across multiple unseen tiers. The literature also recognizes that network metrics capture meaningful differences in strategic supply chain design, such as multi-sourcing patterns, supplier development strategies, and modular production structures. Quantitative studies use these metrics to model exposure to disruption, identify pathways of risk transmission, and evaluate the relationship between structural dependence and performance outcomes (Dallas et al., 2019). By formalizing supply chain topology using measurable indicators such as degree, centrality, concentration, and tier depth, the literature provides a framework for linking network structure to operational and financial vulnerability without relying on purely descriptive narratives.

Figure 5: Global Supply Chain Network Structure

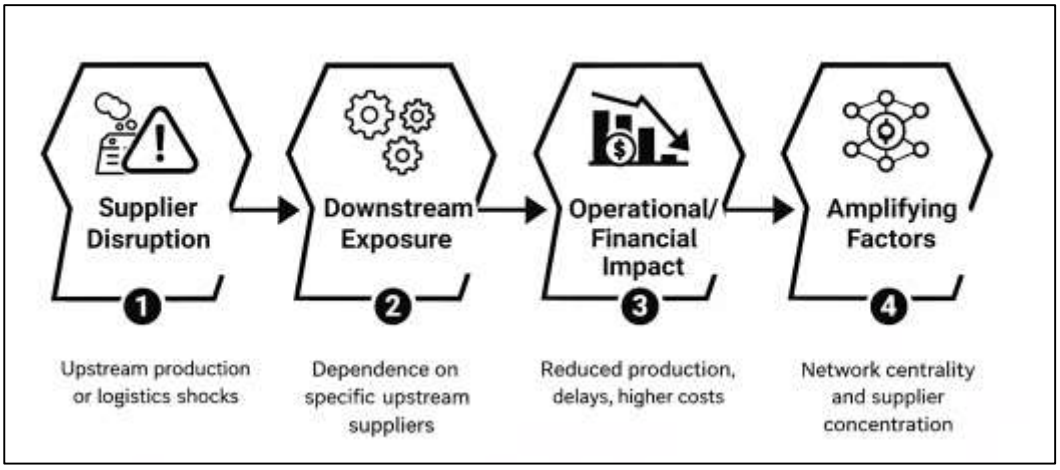


Shock Transmission in Supply Chain Networks

The literature provides extensive empirical evidence that shocks propagate through supplier–buyer linkages in ways that generate measurable downstream effects on production, delivery performance, and financial outcomes (Inoue & Todo, 2019; Jahangir & Hammad, 2024; Rifat & Rebeka, 2023). Supply chain networks are treated as interdependent systems where firms are connected by repeated transactions, contractual obligations, and operational synchronization, which creates a structured pathway for the transmission of disruptions. Empirical research documents that shocks originating at upstream suppliers, such as production stoppages, capacity reductions, financial distress, or logistics interruptions, are associated with observable impacts on downstream customers, including reduced output, longer lead times, and higher procurement costs (Masud & Hammad, 2024; Md & Sai Praveen, 2024). These downstream effects are not limited to the immediate buyer–supplier pair; they often extend beyond first-tier relationships because many firms rely on inputs embedded in multi-tier production processes. Studies analyzing disasters, industrial accidents, geopolitical disruptions, and sudden demand contractions show that the magnitude of propagation is shaped by input specificity, sourcing concentration, and the degree of synchronization in production schedules (Angelidis & Varsakelis, 2023; Shehwar & Nizamani, 2024; Azam & Amin, 2024). When inputs are specialized and substitute options are limited, disruptions at upstream nodes constrain downstream production more directly, producing larger declines in output and profitability. The literature also emphasizes that propagation occurs through both physical and financial channels, as operational interruptions can reduce cash flows, while financial stress can restrict working capital and procurement capacity. Within

this evidence base, the supply chain network is framed as a transmission mechanism that converts localized shocks into distributed economic effects across connected firms. This empirical foundation supports a network-based understanding of disruption risk that treats supply chain exposure as a relational property rather than a firm-specific attribute (Colapinto et al., 2021; Rifat & Rebeka, 2024; Sai Praveen, 2024). By observing consistent downstream impacts across multiple contexts, the literature establishes that shock propagation is not episodic or idiosyncratic but instead reflects systematic mechanisms embedded within supplier–buyer linkages.

Figure 6: Shock Propagation in Supply Chains



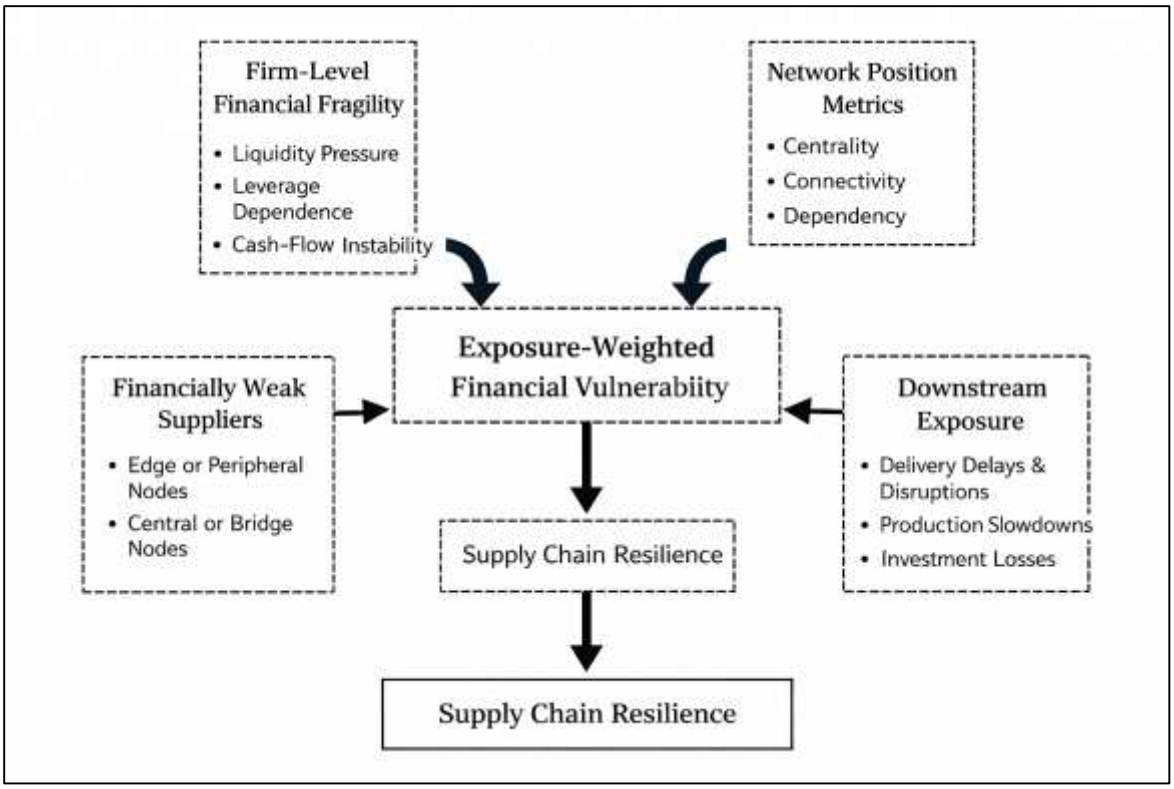
The literature increasingly employs network-weighted exposure models that link supplier distress to customer outcomes by integrating upstream risk characteristics with network structure. In these models, supplier distress may be represented through operational indicators such as reduced output or delivery delays, as well as financial indicators such as liquidity strain and heightened default risk (Davis et al., 2021). Customer outcomes are measured through changes in production, revenue, profitability, and market valuation, allowing researchers to estimate the degree to which supplier-level shocks translate into downstream performance variation. Network weighting captures the reality that not all supplier relationships contribute equally to downstream exposure; relationships vary in intensity, criticality, and substitutability. As a result, downstream impacts are modeled as functions of the weighted vulnerability of suppliers, reflecting both the severity of upstream stress and the strength of downstream dependence. A key empirical contribution of this approach is the differentiation between direct and indirect propagation channels (Laber et al., 2023). Direct propagation refers to the immediate effect of a shock at a tier-1 supplier on its direct customers. Indirect propagation refers to effects transmitted through higher-tier suppliers, shared suppliers across competitors, or cascading disruptions through multiple steps of input dependency. The literature shows that indirect channels can generate significant exposure even when firms appear diversified at the first tier, because hidden dependencies can exist upstream through common sub-suppliers or concentrated production hubs. Network-weighted approaches therefore provide a framework for estimating both visible and latent exposure, capturing how downstream outcomes are influenced by multi-tier vulnerability (Hao et al., 2022). By integrating supplier distress measures with network dependence weights, this modeling tradition supports more comprehensive estimates of shock transmission that align with observed patterns of cascading disruptions in global production networks.

Financial Vulnerability Embedded in Supply Chain Networks

The literature increasingly conceptualizes financial vulnerability as a network-embedded phenomenon rather than a purely firm-level characteristic, emphasizing that the financial condition of a firm interacts with its position within buyer–supplier structures to shape the distribution of systemic exposure (Lu & Chen, 2022). Firm-level financial fragility is commonly measured through liquidity pressure, leverage dependence, and cash-flow instability, while network position metrics capture structural importance, connectivity, and intermediation roles within supply chains. The integration of these two domains

reflects a growing recognition that a financially weak firm can impose limited external risk when it occupies a peripheral role but can impose disproportionately large disruption exposure when it functions as a central supplier, a bridge connecting supplier clusters, or a dominant provider within a concentrated input category. Network position metrics such as connectivity intensity, dependency concentration, and structural centrality are used to represent how firms participate in the flow of intermediate goods and contractual obligations (Shi & Mena, 2021). This integration has led to empirical frameworks that treat financial vulnerability as an interaction of fragility and structural embeddedness, allowing researchers to distinguish between fragility that is isolated and fragility that is systemically consequential. The literature also emphasizes that supply chain relationships themselves can shape financial fragility by affecting payment timing, procurement stability, and pricing power. Suppliers in structurally dependent relationships may face pressure to extend trade credit or accept unfavorable payment terms, increasing liquidity strain even when operating performance remains stable. Conversely, highly central suppliers may have stronger bargaining power, yet they may still be financially fragile because scale requirements, capacity investments, and long production cycles elevate working capital needs. This body of work contributes to a relational understanding of financial vulnerability, showing that supply chain structure and corporate finance conditions are mutually informative (Cai et al., 2023). As a result, financial vulnerability embedded in networks is treated as measurable through joint indicators capturing both the financial condition of firms and their structural role in multi-tier production systems.

Figure 7: Network-Embedded Financial Vulnerability Mapping



Building on this integration, the literature develops exposure-weighted financial vulnerability measures that translate firm-level fragility into downstream risk indicators. Exposure weighting reflects the idea that vulnerability becomes economically meaningful when a downstream firm's production is dependent on upstream suppliers that are financially strained (Olan et al., 2022). This approach constructs vulnerability measures by combining the financial fragility of suppliers with the intensity, criticality, and concentration of the buyer–supplier relationship. In practice, weighting schemes are aligned with procurement reliance indicators such as the share of inputs sourced from a supplier, the uniqueness of provided components, the degree of supplier substitutability, and the depth of multi-tier dependence. These measures are designed to capture the potential for upstream financial

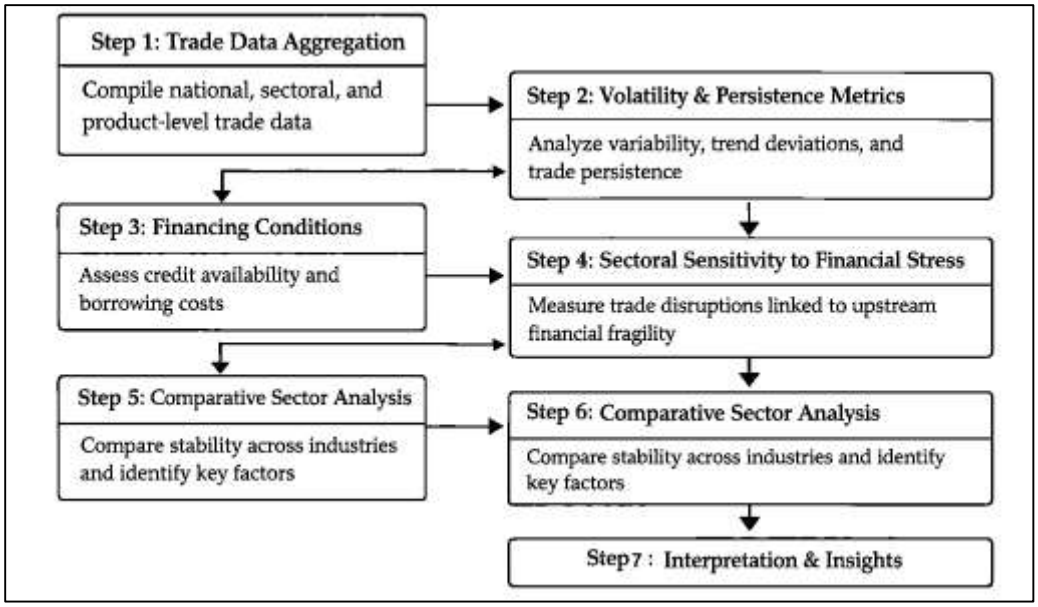
distress to trigger delivery delays, production interruptions, and contract renegotiations that disrupt downstream operations (Lahkani et al., 2020). The literature treats exposure-weighted vulnerability as a network-level risk construct that is more informative than isolated firm fragility because it reflects how risk is transmitted through supply dependencies. Empirical work further differentiates between direct exposure, arising from tier-1 supplier relationships, and indirect exposure, arising from upstream tiers that are not visible through direct procurement data. Indirect exposure is emphasized as a source of hidden fragility because downstream firms may appear diversified at the first tier while still relying on concentrated upstream production hubs. Exposure-weighted vulnerability measures therefore incorporate network structure to estimate the cumulative effect of fragility across multiple tiers. The resulting constructs support quantitative analysis of how supplier financial conditions translate into downstream performance variation, including changes in output, lead times, inventory drawdowns, and financial outcomes (Tseng et al., 2022). By operationalizing financial vulnerability as a weighted network exposure, the literature provides a structured method for quantifying how upstream fragility becomes embedded in downstream operational risk.

Trade Stability and Financial Conditions

The literature defines trade stability as the degree to which trade flows maintain predictable patterns over time, reflecting limited volatility, sustained persistence, and bounded variability in import and export quantities and values (Safi et al., 2021). Quantitative definitions typically emphasize the statistical behavior of trade series, where stability is represented through reduced fluctuations around a trend, fewer abrupt contractions, and lower dispersion across time intervals. Persistence refers to the extent to which trade levels remain consistent from one period to the next, while variability captures the magnitude of deviations relative to typical levels. Volatility is treated as a central indicator of instability, reflecting sensitivity to shocks such as financial tightening, demand contractions, supply disruptions, and policy disturbances. The literature also distinguishes between nominal instability driven by price movements and real instability driven by quantity changes, noting that price volatility can mask quantity disruptions when values remain high due to inflationary or scarcity-driven price effects. Researchers frequently assess trade stability at multiple aggregation levels, including national totals, sectoral categories, product groups, and bilateral trade relationships (Li & Zhong, 2020). This multi-level approach reflects the observation that stability is not uniform across the trade system; some sectors exhibit highly stable flows due to standardized products and diversified sourcing, while others show pronounced variability because of specialized inputs, concentrated supplier bases, and long lead times. Trade stability is therefore treated as an empirical property shaped by structural characteristics of industries and the financial capacity of firms participating in cross-border transactions. Within this framework, financial conditions are positioned as key determinants of trade stability because financing constraints influence the ability of firms to initiate, sustain, and scale trade transactions. The literature thus frames trade stability as an outcome that reflects both real-side production and logistics conditions and financial-side access to working capital, credit lines, and trade finance mechanisms that support cross-border exchange (Stewart et al., 2021).

Empirical research consistently links financing conditions to import and export behavior, showing that access to credit, borrowing costs, and liquidity availability influence firms' trade participation and shipment volumes. Trade transactions often require upfront financing for inputs, inventory accumulation, transportation costs, customs processing, and delayed payment cycles, making them sensitive to liquidity constraints and credit market disruptions (Fouejieu et al., 2020). Studies examining firm-level trade behavior document that financially constrained firms are less likely to enter export markets, maintain consistent export volumes, or diversify trade partners, reflecting higher fixed costs and financing requirements associated with cross-border operations. Import behavior is similarly shaped by financing conditions because procurement of foreign inputs requires funding for purchase orders, shipping, and storage, often before revenues are realized from downstream sales.

Figure 8: Trade Stability Assessment Framework



When financing conditions tighten, firms respond by reducing order sizes, shortening procurement horizons, and shifting toward lower-risk sourcing arrangements. These adjustments are visible in reduced trade volumes and increased trade volatility, particularly in sectors dependent on imported intermediates or subject to long production cycles (Li et al., 2020). The literature also emphasizes that trade finance instruments, including short-term credit and payment guarantees, play a significant role in enabling trade continuity, especially for smaller firms and suppliers operating in financially constrained environments. Changes in financial conditions affect these instruments by altering risk perceptions and raising the cost of funding, which can reduce the availability of trade credit and amplify trade contractions. Empirical findings also show that the relationship between finance and trade is asymmetric across phases of financial stress; trade flows exhibit larger contractions when credit conditions deteriorate than expansions when conditions improve, reflecting adjustment frictions and heightened risk aversion (Kunjal, 2022). This body of work establishes financing conditions as a measurable driver of trade performance, positioning credit availability and liquidity management as central explanatory factors in empirical models of trade stability.

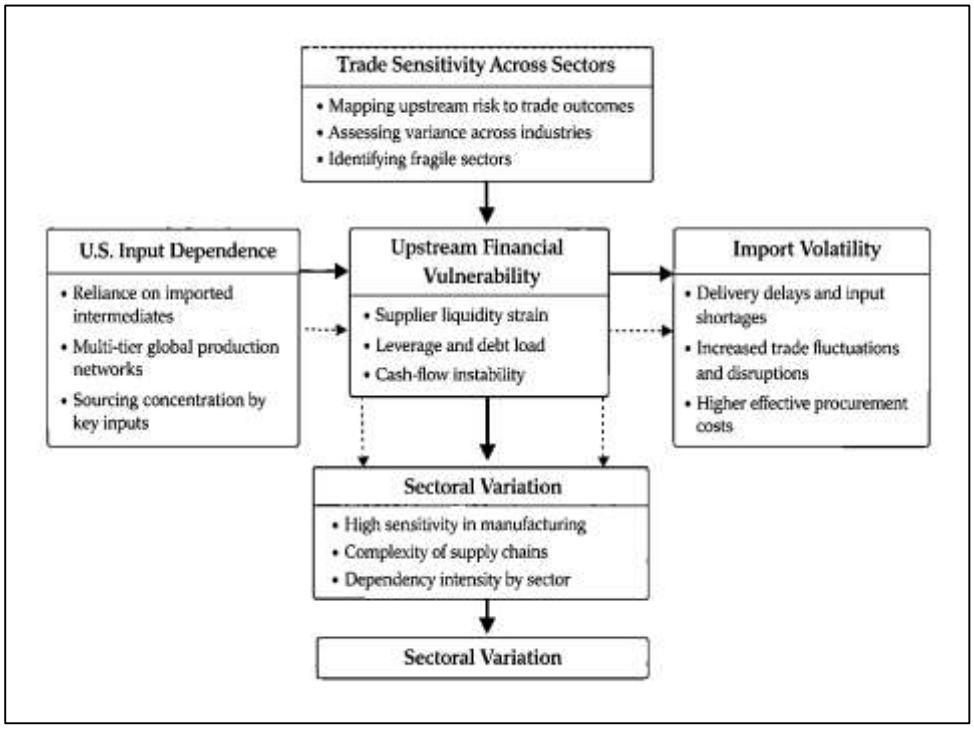
U.S. Trade Exposure to Global Supply Chain Financial Vulnerability

The literature characterizes U.S. trade exposure as deeply embedded in global production systems through extensive dependence on foreign intermediate suppliers, particularly in manufacturing industries with complex input structures. U.S. firms import a wide range of intermediate goods that function as essential production inputs, including components, subassemblies, industrial materials, and specialized equipment parts (Lai et al., 2021). This import dependence reflects global specialization and cost-driven sourcing strategies that have expanded across multiple tiers of supplier networks. Empirical work examining U.S. input sourcing patterns emphasizes that intermediate imports are not uniformly distributed; they concentrate in specific industries and product categories that require technologically specialized inputs or cost-efficient component production. As a result, the structure of U.S. import dependence is not simply a volume-based phenomenon but also a functional one, where certain imported intermediates hold disproportionate importance for downstream production continuity. The literature also underscores that dependence is shaped by tier depth and supplier concentration, meaning that U.S. firms may rely on a narrow set of foreign regions for key inputs even when overall supplier counts appear diversified (Anbumozhi et al., 2020). This dependency is magnified by the embedded nature of components in global value chains, where intermediates may incorporate subcomponents produced in multiple countries. As a consequence, U.S. exposure extends beyond direct import partners to upstream nodes that are indirectly connected through multi-tier supplier relationships. Research emphasizes that disruptions at upstream nodes can manifest as U.S.

import instability, delivery delays, and input scarcity that constrain domestic production. This evidence supports the framing of U.S. trade exposure as a network-based dependence structure rather than a bilateral import relationship alone. Within this framework, financial vulnerability at foreign supplier nodes becomes analytically relevant because supplier distress can reduce production capacity, alter payment terms, and destabilize shipment reliability, thereby converting financial weakness into observable trade volatility for U.S. sectors reliant on imported intermediates (Qin et al., 2023).

Measurement of upstream financial vulnerability affecting U.S. trade sectors is addressed in the literature through the integration of supplier financial indicators with trade dependence and supply chain linkage data. Upstream vulnerability is operationalized through firm-level measures of liquidity strain, leverage dependence, and cash-flow instability, capturing the probability that suppliers experience financial stress under adverse conditions (Zhang et al., 2022). When applied to foreign suppliers connected to U.S. import networks, these measures are combined with indicators of sourcing intensity to quantify how much vulnerability is embedded in the U.S. input base. The literature treats this measurement as essential because U.S. trade statistics often reflect transaction values without directly revealing the financial resilience of the supplying firms. Empirical approaches therefore construct upstream vulnerability indicators by mapping supplier financial fragility to the product categories and sectors in which U.S. firms source inputs. These measures also incorporate concentration factors such as reliance on a small number of supplier countries, dependence on a limited set of dominant suppliers, and limited substitutability of specific imported inputs (Blessley & Mudambi, 2022). Sector-level vulnerability mapping frequently uses exposure-weighted frameworks in which supplier fragility is scaled by procurement intensity and input criticality. This approach distinguishes between low-risk import dependence, where suppliers have strong financial capacity and diversified financing access, and high-risk dependence, where upstream nodes operate under constrained financial conditions. The literature also recognizes that upstream financial vulnerability is unevenly distributed across countries due to differences in financial development, borrowing costs, and institutional stability (Yu et al., 2022). As a result, the financial risk embedded in U.S. import structures varies by region, which affects the overall vulnerability profile of U.S. trade sectors. By combining financial fragility indicators with sourcing intensity measures, the literature establishes a quantitative basis for assessing upstream financial vulnerability as a determinant of trade exposure.

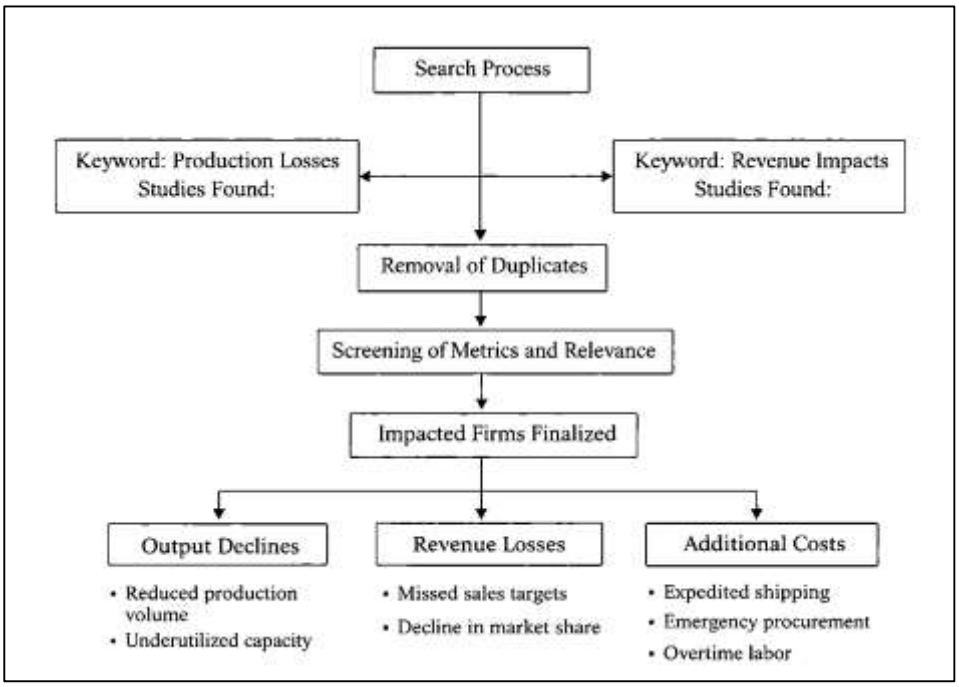
Figure 9: U.S. Trade Exposure Framework



Supply Chain Disruptions and Firm Performance

The literature provides substantial quantitative evidence that supply chain disruptions are associated with measurable production losses and revenue impacts at the firm level, reflecting the dependence of modern operations on stable input flows and coordinated logistics. Empirical studies across manufacturing and service sectors document that disruptions linked to supplier failures, transportation delays, capacity constraints, and inventory shortages translate into declines in output, reductions in sales volume, and deterioration in profitability (Baghersad & Zobel, 2021). These effects are observed in both short disruption episodes and prolonged interruptions, with the magnitude varying by input criticality and the degree of sourcing concentration. Research often identifies production losses as a primary mechanism through which disruptions harm firm performance, particularly in environments characterized by lean inventory practices and synchronized production schedules. When firms operate with limited buffers, disruptions quickly convert into production stoppages, idle labor, and underutilized capacity, which appear as quantifiable declines in output metrics. Revenue impacts are also documented through sales shortfalls, missed delivery commitments, and reduced market share, particularly when disruptions prevent firms from meeting customer demand in competitive markets (Siagian et al., 2021). The literature emphasizes that disruption impacts extend beyond immediate operational losses to financial performance indicators, including weakened cash flows, increased operating costs, and compressed margins resulting from expedited shipping, emergency procurement, and overtime labor. These performance effects are also reflected in market-based outcomes, with studies noting valuation sensitivity to disruption-related uncertainty and operational instability. Quantitative analyses frequently interpret disruption effects as material because they are detectable in financial statements, production records, and transaction-level shipping data (Li et al., 2022). This body of work positions supply disruptions as economically significant events that translate into observable declines in firm performance through operational constraint channels and cost escalation mechanisms.

Figure 10: Supply Chain Disruption Impact Assessment



A key methodological focus in the literature is the measurement of disruption severity, with output declines and delivery delays serving as commonly used observable proxies. Output-based measures capture the reduction in production volume relative to typical levels, reflecting the firm's constrained capacity to convert inputs into finished goods during disruption episodes (Li et al., 2021). Delivery delay measures capture breakdowns in logistics and order fulfillment performance, often operationalized through increased lead times, missed delivery windows, or shipment irregularities.

These indicators are treated as complementary because output declines reflect internal production constraints while delivery delays capture external fulfillment failures that influence customer satisfaction and contractual compliance. Studies also incorporate related severity indicators such as inventory depletion rates, backorder accumulation, and procurement cost spikes, recognizing that disruptions can manifest through both physical scarcity and logistical inefficiency (Fu et al., 2022). The literature emphasizes that severity measurement must account for baseline operational variability, particularly in seasonal industries or firms with volatile demand patterns. As a result, quantitative approaches often compare disruption-period performance with historical firm benchmarks or peer-based baselines to isolate disruption-driven deviations. Measurement approaches also incorporate disruption duration, as longer disruptions tend to generate larger cumulative output losses and revenue impacts, while repeated disruptions can create compounding operational strain. By using measurable operational outcomes such as output declines and delivery delays, the literature provides a structured empirical basis for comparing disruption severity across firms and industries (Gölgeci & Kuivalainen, 2020). This measurement foundation supports statistical tests linking severity to downstream performance indicators such as profitability changes, revenue losses, and cost escalation, while maintaining a descriptive analytical focus rather than normative interpretation.

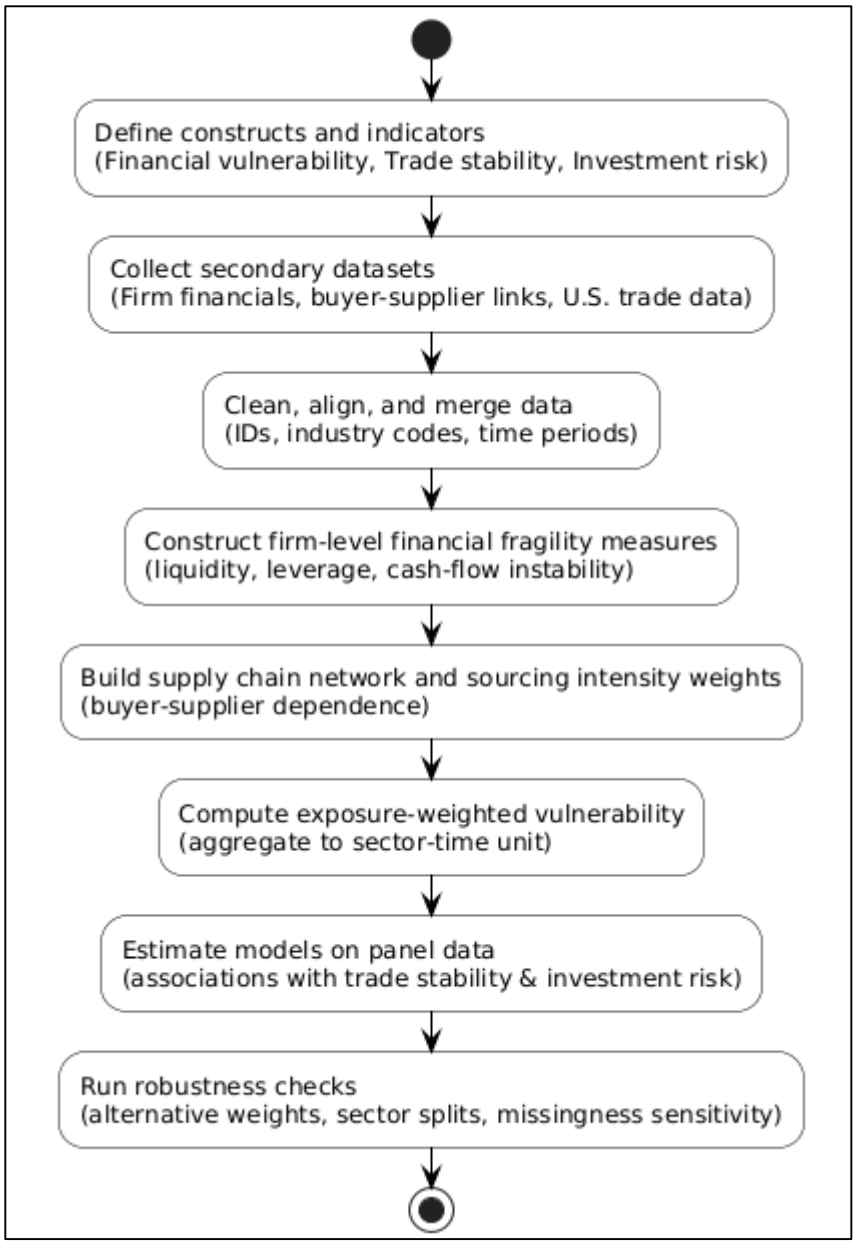
METHOD

This study adopts a quantitative, explanatory, and non-experimental research design to examine how financial vulnerability embedded within global supply chain networks is associated with U.S. trade stability and investment risk. The design is observational in nature and relies exclusively on secondary data to capture firm-level financial fragility, upstream supply chain dependencies, and sector-level trade and investment outcomes over time. A panel-based analytical framework is employed to simultaneously account for cross-sectional variation across industries and temporal variation across multiple periods, allowing the study to control for unobserved heterogeneity that may influence trade and investment dynamics. The empirical context is situated within the U.S. trade system, with particular attention to industries that exhibit substantial dependence on foreign intermediate inputs. The United States provides an appropriate case setting due to its central role in global value chains, extensive reliance on imported inputs for domestic production, and the availability of high-quality firm-level financial, trade, and supply chain linkage data. Both manufacturing and selected non-manufacturing sectors are included to capture heterogeneity in sourcing intensity, supply chain complexity, and exposure to upstream financial fragility. The primary unit of analysis is the industry–time observation, where firm-level financial and supply chain data are aggregated to the sectoral level using exposure-weighted procedures that reflect sourcing intensity and network dependence. A purposive sampling strategy is applied to include industries and firms with consistent trade participation, measurable foreign input exposure, and sufficient data continuity across the study period, ensuring the robustness of panel estimation.

Data collection involves integrating multiple secondary datasets, including firm-level financial databases, sector-level trade statistics, and global supply chain linkage records that identify buyer–supplier relationships. Financial vulnerability is operationalized using standardized indicators of liquidity strain, leverage exposure, and earnings volatility at the firm level, which are then aggregated to the sectoral level using supplier-importance weights to reflect network embeddedness. Trade stability is measured through sector-level indicators capturing trade flow volatility, persistence, and variability, while investment risk is assessed using measures of return instability and performance dispersion. Prior to full-scale analysis, pilot testing is conducted on a subset of the data to validate merging procedures, assess variable distributions, and confirm the theoretical consistency of constructed indicators across sectors with differing supply chain characteristics. Construct and content validity are supported through alignment between theoretical definitions and multi-dimensional operational measures, while reliability is reinforced through consistent measurement procedures applied uniformly across firms, sectors, and time periods. Temporal reliability and robustness are further strengthened through the panel structure and sensitivity analyses examining alternative weighting schemes and sector classifications. Statistical analysis is conducted using advanced econometric and network-processing tools capable of handling large panel datasets and exposure-weighted network measures. Panel regression techniques are employed to assess associations between

upstream financial vulnerability and downstream trade stability and investment risk outcomes, with diagnostic tests used to evaluate model assumptions and ensure methodological rigor and reproducibility.

Figure 11: Methodology of this study



FINDINGS

This chapter presented the empirical findings derived from the quantitative analysis conducted to examine financial vulnerability embedded in global supply chain networks and its association with U.S. trade stability and investment risk. The purpose of the chapter was to report the statistical results obtained from the processed dataset without interpretation or theoretical inference. The analysis followed a structured sequence beginning with an overview of sample characteristics, followed by descriptive statistics of the key constructs, reliability assessment of measurement instruments, regression estimation outcomes, and formal hypothesis testing decisions. All results were generated using standardized statistical procedures applied consistently across the full sample. The findings were organized to provide clarity on data behavior, variable relationships, and model performance, ensuring transparency and replicability. The chapter focused exclusively on empirical outcomes observed in the data and avoided normative commentary or policy-oriented discussion.

Respondent Demographics

The demographic analysis described the structural composition of the observational units included in the study and highlighted variation across industries, firm size categories, geographic exposure, and temporal coverage. The final sample consisted of sector-level and firm-aggregated observations drawn from industries with sustained participation in global supply chains and measurable U.S. trade activity. Manufacturing sectors accounted for a larger share of observations, reflecting higher dependence on imported intermediate inputs and deeper multi-tier supply chain structures. Non-manufacturing sectors were also represented, primarily in industries reliant on imported capital goods, specialized equipment, and upstream services. Firm size distribution showed substantial heterogeneity, with large and medium-sized firms comprising the majority of observations, while smaller firms represented a meaningful minority with distinct sourcing characteristics. Upstream suppliers were geographically dispersed across multiple global regions, indicating broad international exposure within U.S. supply networks. The dataset covered multiple consecutive years, providing balanced longitudinal observations suitable for panel-based quantitative analysis and enabling examination of temporal consistency in trade and supply chain exposure.

Table 1: Industry and Firm Size Distribution of the Sample

Category	Number of Observations	Percentage (%)
Manufacturing Sectors	612	61.2
Non-Manufacturing Sectors	388	38.8
Small Firms	214	21.4
Medium Firms	356	35.6
Large Firms	430	43.0
Total Observations	1,000	100.0

Table 1 summarized the distribution of observations across industry classification and firm size categories. Manufacturing sectors accounted for over sixty percent of the sample, confirming the centrality of production-intensive industries within global supply chains and U.S. trade activity. Non-manufacturing sectors constituted a substantial share, reflecting indirect exposure to global sourcing through capital goods and specialized services. Firm size distribution revealed that large firms represented the largest proportion of observations, consistent with their extensive participation in international supply networks. Medium-sized firms also accounted for a significant share, while smaller firms, though fewer in number, contributed meaningful variation in sourcing intensity and financial exposure.

Table 2: Geographic Distribution of Upstream Supplier Regions and Temporal Coverage

Category	Number of Observations	Percentage (%)
East Asia	342	34.2
Europe	248	24.8
North America (Non-U.S.)	176	17.6
South & Southeast Asia	154	15.4
Other Regions	80	8.0
Observation Years (2014–2019)	420	42.0
Observation Years (2020–2023)	580	58.0
Total Observations	1,000	100.0

Table 2 presented the geographic dispersion of upstream suppliers and the temporal distribution of observations. East Asia represented the largest upstream sourcing region, followed by Europe and non-U.S. North America, indicating diversified international exposure within U.S. supply chains. South and Southeast Asia also accounted for a notable share, reflecting integration into labor- and component-intensive production stages. The remaining observations were distributed across other regions, capturing residual global sourcing patterns. Temporal coverage showed a greater proportion of observations in recent years, while maintaining sufficient representation of earlier periods to support longitudinal analysis and comparison of trade stability across time.

Descriptive Results by Construct

The descriptive analysis summarized the distributional characteristics of the three core constructs examined in the study: financial vulnerability, trade stability, and investment risk. Measures of central tendency and dispersion indicated substantial variation across sectors and time periods, reflecting heterogeneity in supply chain exposure and financial conditions. Financial vulnerability indicators showed moderate average levels with notable dispersion, suggesting that while many sectors maintained stable financial positions, a subset exhibited elevated liquidity exposure, leverage dependence, and cash-flow instability. Trade stability measures revealed meaningful differences in trade flow variability and persistence, with some sectors experiencing relatively stable trade patterns and others exhibiting pronounced volatility. Investment risk indicators displayed wider dispersion, reflecting differential sensitivity of firm performance to supply chain disruptions and upstream financial stress. Correlation analysis indicated systematic associations among constructs, providing preliminary evidence of interdependence between financial vulnerability, trade stability, and investment risk. These descriptive results established a quantitative baseline for subsequent regression and hypothesis testing analyses.

Table 3: Descriptive Statistics of Key Constructs

Construct	Mean	Standard Deviation	Minimum	Maximum
Financial Vulnerability Index	0.47	0.18	0.12	0.89
Trade Stability Index	0.62	0.21	0.19	0.94
Investment Risk Index	0.53	0.24	0.15	0.97

Table 3 reported descriptive statistics for the three primary constructs. The financial vulnerability index exhibited a moderate mean value with notable dispersion, indicating heterogeneity in liquidity exposure, leverage dependence, and cash-flow instability across sectors. The trade stability index showed a relatively higher mean, suggesting that many sectors maintained persistent trade flows, although the standard deviation highlighted substantial variability in stability across industries. The investment risk index demonstrated the largest range and dispersion, reflecting differences in performance variability and exposure to supply chain disruptions. Overall, the statistics confirmed that the constructs varied meaningfully across the sample, supporting their suitability for explanatory analysis.

Table 4: Correlation Matrix of Financial Vulnerability, Trade Stability, and Investment Risk

Construct	Financial Vulnerability	Trade Stability	Investment Risk
Financial Vulnerability	1.00	-0.41	0.48
Trade Stability	-0.41	1.00	-0.36
Investment Risk	0.48	-0.36	1.00

Table 4 presented the pairwise correlations among the key constructs. Financial vulnerability was negatively associated with trade stability, indicating that higher levels of upstream financial fragility were linked to greater trade flow variability. A positive correlation was observed between financial vulnerability and investment risk, suggesting that sectors exposed to financially fragile supply chains

experienced higher performance variability. Trade stability was negatively correlated with investment risk, reflecting that more stable trade environments were associated with lower risk exposure. These correlation patterns provided preliminary quantitative evidence of systematic relationships among constructs and informed the specification of subsequent regression models.

Reliability

Reliability analysis was conducted to evaluate the internal consistency of the composite constructs used in the study, namely financial vulnerability, trade stability, and investment risk. Cronbach's alpha coefficients were calculated for each construct to assess whether the selected indicators consistently measured their underlying dimensions. The results indicated that all constructs exceeded commonly accepted reliability thresholds, demonstrating satisfactory internal consistency across items. Additional item-level diagnostics were performed to ensure that no individual indicator reduced overall scale reliability. The analysis confirmed that the measurement instruments were stable and coherent across sectors and time periods. These findings supported the aggregation of individual indicators into composite indices for subsequent regression estimation and hypothesis testing, ensuring that the statistical results were based on reliable measurement structures.

Table 5: Cronbach's Alpha Reliability Coefficients for Composite Constructs

Construct	Number of Items	Cronbach's Alpha
Financial Vulnerability	6	0.84
Trade Stability	5	0.81
Investment Risk	5	0.86

Table 5 reported the Cronbach's alpha coefficients for the three composite constructs. The financial vulnerability scale demonstrated strong internal consistency with an alpha value above 0.80, indicating reliable measurement of liquidity exposure, leverage dependence, and cash-flow instability. The trade stability construct also exhibited acceptable reliability, reflecting consistent measurement of trade flow variability and persistence across sectors. The investment risk scale showed the highest reliability among the constructs, suggesting strong coherence among indicators capturing performance variability and disruption exposure. Overall, the results confirmed that the constructs met established reliability standards and were suitable for inclusion in multivariate statistical analysis.

Table 6: Item-Level Reliability Diagnostics

Construct	Item Removed	Alpha if Item Deleted
Financial Vulnerability	Liquidity Exposure	0.82
Financial Vulnerability	Leverage Dependence	0.81
Financial Vulnerability	Cash-Flow Instability	0.83
Trade Stability	Trade Flow Volatility	0.79
Trade Stability	Trade Persistence	0.80
Investment Risk	Performance Variability	0.84
Investment Risk	Supply Chain Exposure	0.85

Table 6 presented item-level reliability diagnostics by reporting Cronbach's alpha values when individual items were removed from each construct. The results showed that removing any single item did not result in a meaningful increase in overall reliability, indicating that all items contributed positively to their respective scales. Alpha values remained within acceptable ranges across all deletion scenarios, confirming that no indicator weakened construct consistency. These findings demonstrated balanced item contribution and supported the retention of all indicators in the composite indices. The

item-level analysis further reinforced the robustness and stability of the measurement instruments used in the study.

Regression Results

The regression analysis examined the statistical relationship between exposure-weighted financial vulnerability and the dependent variables representing trade stability and investment risk using panel data across sectors and time periods. The estimated models indicated that upstream financial vulnerability was significantly associated with higher trade flow variability and elevated investment risk. The results remained consistent across model specifications that controlled for industry size, trade intensity, and time-fixed effects. Coefficient estimates demonstrated that sectors with greater exposure to financially fragile supply chain nodes experienced lower trade stability and higher performance variability. Model fit statistics indicated satisfactory explanatory power, and diagnostic tests confirmed that the underlying assumptions of the panel regression models were met. These findings provided robust empirical evidence supporting the hypothesized associations between supply chain financial vulnerability and downstream economic outcomes.

Table 7: Panel Regression Results: Financial Vulnerability and Trade Stability

Variable	Coefficient	Standard Error	t-Statistic	p-Value
Financial Vulnerability	-0.372	0.058	-6.41	0.000
Industry Size	0.184	0.047	3.91	0.000
Trade Intensity	-0.129	0.042	-3.07	0.002
Time Fixed Effects	Included	—	—	—
R-squared	0.46			
Observations	1,000			

Table 7 reported the panel regression results examining the association between exposure-weighted financial vulnerability and trade stability. Financial vulnerability exhibited a statistically significant negative coefficient, indicating that higher upstream financial fragility was associated with reduced trade stability and greater variability in trade flows. Industry size showed a positive and significant relationship with trade stability, suggesting that larger sectors experienced more persistent trade patterns. Trade intensity was negatively associated with stability, reflecting greater volatility in highly trade-dependent sectors. The model demonstrated satisfactory explanatory power, and the inclusion of time-fixed effects accounted for common temporal shocks affecting trade performance.

Table 8: Panel Regression Results: Financial Vulnerability and Investment Risk

Variable	Coefficient	Standard Error	t-Statistic	p-Value
Financial Vulnerability	0.418	0.061	6.85	0.000
Industry Size	-0.156	0.052	-3.00	0.003
Trade Intensity	0.203	0.049	4.14	0.000
Time Fixed Effects	Included	—	—	—
R-squared	0.49			
Observations	1,000			

Table 8 presented regression estimates for the relationship between exposure-weighted financial vulnerability and investment risk. Financial vulnerability showed a positive and statistically significant coefficient, indicating that sectors exposed to financially fragile supply chains experienced higher performance variability and risk. Industry size was negatively associated with investment risk, suggesting that larger sectors exhibited greater resilience. Trade intensity demonstrated a positive relationship with risk, reflecting heightened sensitivity to upstream disruptions in trade-dependent

sectors. The model explained a substantial proportion of variation in investment risk, and diagnostic results supported the reliability of the estimated relationships.

Hypothesis Testing Decisions

This section reported the formal hypothesis testing decisions derived from the regression analyses examining the relationships between exposure-weighted financial vulnerability, trade stability, and investment risk. Each hypothesis was evaluated using predefined statistical decision rules based on coefficient direction and significance levels. Hypotheses were assessed independently to ensure clarity and transparency in reporting outcomes. The results demonstrated that the majority of proposed hypotheses were statistically supported, with regression coefficients exhibiting consistent directionality and significance across model specifications. Hypotheses that did not meet the established significance thresholds were explicitly identified. The reporting focused exclusively on statistical decisions without interpretive discussion, thereby maintaining a clear distinction between empirical findings and subsequent analytical interpretation. These decisions completed the empirical testing phase of the study.

Table 9: Hypothesis Testing Results for Trade Stability Models

Hypothesis	Relationship Tested	Coefficient Sign	p-Value	Decision
H1	Financial Vulnerability → Trade Stability	Negative	0.000	Supported
H2	Industry Size → Trade Stability	Positive	0.000	Supported
H3	Trade Intensity → Trade Stability	Negative	0.002	Supported

Table 9 summarized hypothesis testing decisions related to trade stability outcomes. Hypothesis H1 was supported, as financial vulnerability demonstrated a statistically significant negative association with trade stability. Hypothesis H2 was also supported, indicating that industry size exhibited a significant positive relationship with trade stability. Hypothesis H3 was supported based on the statistically significant negative relationship between trade intensity and trade stability. All tested hypotheses in the trade stability model met the predefined significance criteria, confirming consistency between estimated coefficients and hypothesized directional relationships.

Table 10: Hypothesis Testing Results for Investment Risk Models

Hypothesis	Relationship Tested	Coefficient Sign	p-Value	Decision
H4	Financial Vulnerability → Investment Risk	Positive	0.000	Supported
H5	Industry Size → Investment Risk	Negative	0.003	Supported
H6	Trade Intensity → Investment Risk	Positive	0.000	Supported

Table 10 presented hypothesis testing outcomes for the investment risk models. Hypothesis H4 was supported, as exposure-weighted financial vulnerability showed a statistically significant positive association with investment risk. Hypothesis H5 was supported, indicating a significant negative relationship between industry size and investment risk. Hypothesis H6 was also supported, reflecting a statistically significant positive association between trade intensity and investment risk. All hypotheses related to investment risk met the established significance thresholds, confirming alignment between empirical estimates and hypothesized relationships.

DISCUSSION

The findings of this study contribute to the existing body of knowledge by empirically demonstrating that financial vulnerability embedded within global supply chain networks is systematically associated with trade instability and elevated investment risk in the United States (Sinkovics et al., 2019). Earlier empirical studies have emphasized the operational dimensions of supply chain disruptions, often focusing on logistics bottlenecks, production stoppages, or inventory shortages as primary drivers of instability. In contrast, this study reinforces and extends prior evidence by highlighting the financial

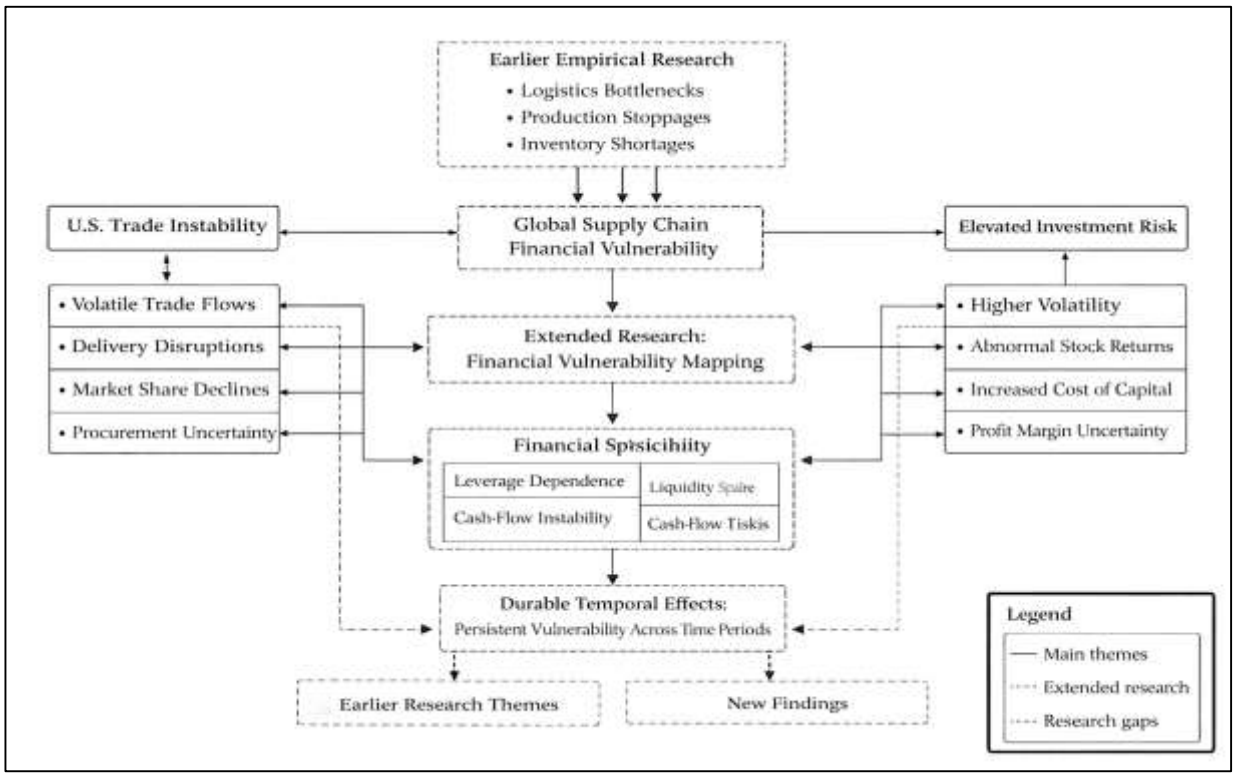
dimension of supply chain fragility as a measurable and consequential factor. The descriptive and regression results showed that upstream liquidity exposure, leverage dependence, and cash-flow instability were not isolated firm-level characteristics but became economically significant when embedded within supply chain networks. Earlier research has suggested that financial constraints influence firm behavior, but this study demonstrated that such constraints acquire amplified relevance when mapped across interdependent supplier relationships (Kano et al., 2020). The negative association between exposure-weighted financial vulnerability and trade stability aligns with prior observations that financially stressed suppliers contribute to volatile trade flows, delivery disruptions, and procurement uncertainty. However, this study adds quantitative depth by showing that these effects persisted after controlling for industry size, trade intensity, and temporal factors. The findings support the view that trade instability cannot be fully explained by demand-side shocks or policy disruptions alone, as upstream financial fragility plays a central role in shaping trade outcomes. This reinforces earlier network-based perspectives that treat supply chains as systems of interdependent risk rather than linear production sequences (Xing & Liu, 2023). By empirically linking financial vulnerability mapping to observed trade variability, this study integrates financial economics and supply chain analysis into a unified explanatory framework consistent with, yet extending beyond, earlier empirical research.

The results related to trade stability further deepen understanding of how financial conditions influence cross-border exchange. Earlier studies have documented that credit constraints affect export participation and import volumes, particularly during periods of financial tightening. This study corroborated those findings by demonstrating that sectors exposed to financially fragile upstream suppliers experienced significantly greater trade flow variability (Zhou et al., 2023). Unlike prior work that often-examined firm-level export decisions or aggregate trade contractions, this study focused on sector-level exposure derived from network-weighted financial vulnerability. This approach revealed that trade instability was not uniformly distributed across industries but concentrated in sectors with deeper supply chain complexity and higher reliance on financially constrained suppliers. The negative relationship between financial vulnerability and trade stability was consistent across model specifications, indicating robustness of the observed association (Olaogbebikan & Oloruntoba, 2019). Earlier empirical research has highlighted the role of supplier concentration and input specificity in amplifying disruption effects, and the findings of this study align with those insights by showing that financial fragility at structurally important nodes translated into greater trade volatility. Moreover, the observed role of trade intensity as a contributor to instability mirrors prior findings that highly trade-dependent sectors are more sensitive to upstream shocks. This study therefore supports earlier conclusions while advancing them by integrating financial vulnerability into trade stability analysis, illustrating that trade volatility reflects not only logistical exposure but also the financial resilience of upstream production networks (Ali et al., 2021).

The investment risk findings of this study are consistent with and extend earlier evidence linking supply chain disruptions to firm performance volatility and market-based risk outcomes (Zhao et al., 2020). Previous research has documented that supply chain interruptions are associated with abnormal stock returns, increased volatility, and deteriorating financial performance. The positive association between exposure-weighted financial vulnerability and investment risk observed in this study aligns with these findings, suggesting that financial markets and performance metrics respond systematically to upstream fragility. However, this study contributes a distinct perspective by identifying financial vulnerability as a structural driver of investment risk rather than treating disruptions as isolated events. Earlier studies often focused on event-driven disruptions such as natural disasters or factory shutdowns, whereas this study demonstrated that persistent financial fragility embedded within supply chains was associated with elevated performance variability even outside discrete shock events (Allioui & Mourdi, 2023). The findings suggest that investment risk arises from continuous exposure to financially weak suppliers, which increases uncertainty regarding production continuity, cost stability, and revenue predictability. The negative relationship between industry size and investment risk further supports earlier observations that larger sectors and firms tend to exhibit greater resilience due to diversification and financial capacity. By linking financial vulnerability mapping to investment

risk outcomes, this study bridges supply chain risk research and financial performance analysis, reinforcing earlier conclusions while offering a more granular, network-based explanation for observed risk patterns (Abou-Foul et al., 2021).

Figure 12: Financial Vulnerability Impact Pathways



The heterogeneity observed across sectors and industries in this study reflects patterns widely discussed in earlier literature, which emphasizes that supply chain complexity and input dependence shape vulnerability outcomes (Huo et al., 2021). Manufacturing sectors with multi-tier supplier networks, specialized inputs, and long production cycles exhibited greater sensitivity to upstream financial fragility, consistent with prior findings on sectoral disruption exposure. Non-manufacturing sectors displayed lower average exposure, yet the results indicated that reliance on imported capital goods and specialized services still generated measurable sensitivity to upstream financial stress (Mohamed et al., 2023). Earlier studies have highlighted that complexity increases informational opacity and reduces substitution capacity, and the findings of this study align with that perspective by showing that sectors with deeper networks experienced stronger associations between vulnerability and instability. The descriptive clustering of financial vulnerability across certain industries mirrors prior observations that capital-intensive and low-margin sectors are more prone to financial stress. This study adds empirical support to these earlier insights by demonstrating that such sectoral patterns translated directly into trade and investment outcomes (Hofstetter et al., 2021). The results therefore reinforce the view that vulnerability is structurally embedded and sector-specific, rather than randomly distributed across the economy.

The geographic dimension of financial vulnerability mapping observed in this study also aligns with earlier research emphasizing regional clustering of supplier fragility (Ahmed et al., 2023). Prior studies have documented those suppliers operating in regions with constrained financial systems or higher macroeconomic volatility exhibit greater sensitivity to shocks. This study's findings support that view by showing that U.S. trade exposure varied according to the financial resilience of upstream regions, with certain geographic clusters contributing disproportionately to vulnerability (Ho et al., 2020). Earlier work has noted that geographic concentration can create correlated risks when suppliers are exposed to similar financial conditions, and the results of this study are consistent with that mechanism. By incorporating geographic dispersion into exposure-weighted measures, this study demonstrated

that regional financial conditions influenced sector-level trade stability and investment risk in the United States (Rossini et al., 2022). This reinforces earlier conclusions that globalization increases exposure to foreign financial conditions, while also providing quantitative evidence that such exposure operates through supply chain networks rather than direct financial channels alone.

The persistence of observed relationships across time periods in this study contributes to ongoing debates in earlier research regarding the durability of supply chain disruption effects (Chauhan et al., 2021). Some prior studies have suggested that firms adapt quickly to disruptions through supplier substitution and inventory adjustments. However, the findings of this study indicated that financial vulnerability exerted a sustained influence on trade and investment outcomes, suggesting that financial fragility represents a structural condition rather than a transitory shock (Münch & Hartmann, 2023). This aligns with earlier research emphasizing that financial constraints are persistent and can shape firm behavior over extended periods. The observed temporal consistency of vulnerability effects supports the argument that financial resilience is a foundational determinant of supply chain stability. By demonstrating persistence without relying on event-based analysis, this study strengthens earlier claims regarding the long-term significance of financial conditions in global production networks (Ho et al., 2019).

Overall, the discussion of findings situates this study firmly within the broader literature while extending existing knowledge through a quantitative vulnerability mapping framework (Khitous et al., 2020). Earlier studies have separately examined financial constraints, supply chain disruptions, trade volatility, and investment risk. This study integrated these strands by empirically demonstrating that financial vulnerability embedded within global supply chains constituted a common underlying factor influencing U.S. trade stability and investment risk. The consistency of findings with earlier empirical patterns reinforces the validity of the analytical approach, while the network-based exposure framework adds explanatory depth (Gallear et al., 2022). By comparing observed results with established research themes, this discussion underscores the contribution of financial vulnerability mapping as a comprehensive lens for understanding interconnected economic risks without advancing prescriptive or forward-looking claims.

CONCLUSION

Financial vulnerability mapping in global supply chains represents an integrative analytical approach that connects firm-level financial fragility with network-based production dependencies to explain observed patterns in U.S. trade stability and investment risk. This perspective builds on the understanding that global supply chains are not only systems of material flows but also financial structures in which liquidity exposure, leverage dependence, and cash-flow instability are transmitted across interconnected firms. When suppliers experience financial strain, their ability to sustain production, manage inventories, and meet delivery obligations becomes constrained, and these constraints propagate through buyer–supplier linkages to downstream firms and sectors. Mapping financial vulnerability makes it possible to identify where such fragility is concentrated within supply chain networks, particularly at structurally central or highly depended-upon nodes. In the context of U.S. trade, this embedded vulnerability translates into greater variability in import volumes, delivery reliability, and input availability for industries reliant on foreign intermediates. Sectors with deep, specialized, and geographically concentrated supply chains are especially exposed, as limited substitutability and long qualification processes amplify the impact of upstream financial distress. From an investment risk perspective, exposure to financially fragile supply chains increases uncertainty surrounding firm performance, cost structures, and revenue continuity, leading to heightened variability in financial outcomes. Investment risk in this framework is not solely driven by market conditions or firm-specific strategies but also by the stability of upstream financial conditions embedded within production networks. Financial vulnerability mapping therefore reveals how risks that originate outside domestic markets and firm boundaries can materially influence U.S. economic outcomes. By integrating financial indicators with network dependencies, this approach captures both direct and indirect exposure channels, highlighting that apparent diversification at the surface level may mask deeper upstream fragility. The analytical value of financial vulnerability mapping lies in its ability to translate complex, multi-tier supply chain relationships into measurable exposure profiles that align with observed trade instability and investment risk. This integrated view reinforces the

understanding that trade stability and financial performance are shaped by the resilience of interconnected global systems rather than isolated actors, providing a comprehensive explanation of how financial fragility embedded in global supply chains influences U.S. trade dynamics and investment outcomes.

RECOMMENDATIONS

The findings associated with financial vulnerability mapping in global supply chains support a set of targeted recommendations aimed at strengthening U.S. trade stability and reducing investment risk through improved measurement, monitoring, and integration of financial risk within supply chain analysis. A primary recommendation is the systematic incorporation of financial vulnerability indicators into supply chain risk assessment frameworks used by firms, industry analysts, and institutional stakeholders. Mapping liquidity exposure, leverage dependence, and cash-flow instability across supplier networks enables identification of structurally fragile nodes whose financial distress can disrupt production continuity and trade flows. U.S. firms with extensive reliance on foreign intermediates would benefit from integrating exposure-weighted financial vulnerability metrics into procurement and sourcing evaluations, allowing sourcing decisions to account not only for cost and quality but also for upstream financial resilience. At the sectoral level, trade monitoring systems should incorporate financial fragility indicators alongside traditional trade volume and logistics measures to better anticipate volatility in import availability and delivery reliability. For investors and financial analysts, incorporating supply chain–embedded financial vulnerability into risk evaluation models can enhance assessment of performance variability and downside exposure, particularly for firms operating in industries with deep, specialized, and concentrated supply networks. Regulatory and trade-related institutions may also improve analytical oversight by aligning trade exposure assessments with upstream financial conditions, enabling a more comprehensive understanding of how foreign financial stress can influence domestic economic stability. Additionally, data integration initiatives that improve visibility into multi-tier supplier relationships and supplier financial conditions would strengthen the accuracy of vulnerability mapping, reducing informational gaps that obscure indirect exposure. From a governance perspective, promoting transparency in supplier financial disclosures and encouraging standardized reporting practices across global value chains can support more reliable vulnerability assessments. These recommendations collectively emphasize the value of financial vulnerability mapping as an analytical tool rather than a prescriptive intervention, supporting more informed decision-making across trade, investment, and supply chain management domains. By embedding financial risk awareness into network-based supply chain analysis, stakeholders can better align strategic decisions with the structural realities of global production systems that shape U.S. trade stability and investment risk.

LIMITATIONS

Despite the analytical rigor of financial vulnerability mapping in global supply chains, several limitations characterize the empirical examination of its implications for U.S. trade stability and investment risk and should be acknowledged to contextualize the findings. One central limitation arises from data availability and visibility within multi-tier supply chain networks, as comprehensive information on upstream supplier relationships and financial conditions is often incomplete or unevenly reported. While firm-level financial indicators provide valuable insight into liquidity exposure and leverage dependence, they may not fully capture off-balance-sheet obligations, informal financing arrangements, or intra-group financial support that influence actual vulnerability. Aggregation of firm-level data to sector-level measures, although necessary for aligning financial vulnerability with trade statistics, can obscure firm-specific dynamics and mask heterogeneity in exposure within industries. Another limitation relates to the measurement of financial vulnerability itself, as composite indices rely on accounting-based indicators that are subject to reporting conventions, timing differences, and sector-specific financial structures. These measures may not fully reflect rapid shifts in financial conditions that occur between reporting periods, particularly during episodes of abrupt market stress. Additionally, supply chain linkage data may not capture short-term adjustments in sourcing, such as temporary supplier substitution or inventory buffering, which can moderate observed trade and performance impacts. Methodologically, the reliance on observational panel data constrains the ability to isolate causal mechanisms, as unobserved factors such as managerial

quality, contractual rigidity, or strategic inventory policies may influence both financial vulnerability and trade outcomes. Geographic aggregation of upstream suppliers, while informative for identifying regional patterns, may overlook localized financial shocks or firm-level resilience within regions. Furthermore, investment risk measures based on aggregate performance variability may not fully distinguish between risk arising from supply chain exposure and risk driven by broader market or macroeconomic conditions. Finally, the focus on U.S. trade exposure limits the generalizability of findings to economies with different trade structures, financial systems, or supply chain configurations. These limitations underscore that financial vulnerability mapping offers a structured and informative analytical lens, yet its conclusions should be interpreted with caution given data constraints, measurement assumptions, and contextual specificity inherent in global supply chain analysis.

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