The American Journal of Applied Sciences
ISSN 2689-0992 | Open Access

TYPE Original Research
PAGE NO. 89-97



# Designing Viable Supply Chains for High-Tech Manufacturing: Integrating Resilience, Agility, and Regulatory Constraints in a Geopolitical Era

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OPEN ACCESS

SUBMITTED 01 October 2025
ACCEPTED 16 October 2025
PUBLISHED 31 October 2025
VOLUME Vol.07 Issue 10 2025

CITATION

Arjun Mehta. (2025). Designing Viable Supply Chains for High-Tech Manufacturing: Integrating Resilience, Agility, and Regulatory Constraints in a Geopolitical Era. The American Journal of Applied Sciences, 7(10), 89–97. Retrieved from https://theamericanjournals.com/index.php/tajas/article/view/7074



**Abstract:** The accelerating complexity of global supply chains, particularly in high-technology sectors such as semiconductor and GPU manufacturing, brings profound challenges in managing risk, uncertainty, and regulatory disruption. This paper develops a comprehensive conceptual framework for building "viable supply chains," defined as supply networks capable of sustaining performance under geopolitical turbulence, regulatory constraints, trade-policy shifts, and demand volatility. Drawing upon established literature on supply chain risk management (Fan & Stevenson, 2018; Ho et al., 2015), supply chain resilience and agility (Gligor et al., 2019; Han, Chong & Li, 2020; Hosseini, Ivanov & Dolgui, 2019), and recent analyses of supply-chain strategies in the semiconductor industry (Bernstein, 2023; Lulla, 2025; BIS, 2023; Flamm & Bonvillian, 2025), the framework synthesizes prior conceptualizations and extends them to address contemporary challenges such as reshoring, capacity reservation under disruption, and elasticity of substitution between domestic and imported goods (Ahmad & Riker, 2020; Devarajan, Go & Robinson, 2023). Using a systematic literature-based methodology, we analyze key dimensions—risk identification and mitigation, supply chain agility, resilience capacities, contractual and sourcing strategies, regulatory compliance, and design for adaptability. The results highlight critical capabilities required for supply-chain viability in high-tech manufacturing: diversified sourcing including backup and reshored suppliers; dynamic coordination and information flows; contractual mechanisms for revenue sharing under uncertainty; and alignment with regulatory and trade policy frameworks. The discussion elaborates theoretical implications, limitations, and proposes directions for empirical validation and extension, including digital-twin simulations (Ivanov & Dolgui, 2021) and performance metric benchmarking (Han, Chong & Li, 2020). This integrative framework provides a roadmap for academics and practitioners seeking to design, analyze, and adapt supply chains for strategic robustness in a rapidly evolving geopolitical landscape.

**Keywords:** Supply chain viability; resilience; agility; high-tech manufacturing; reshoring; regulatory risk

## 1. Introduction

The Global supply chains have historically been engineered for efficiency: minimal costs, lean inventories, just-in-time deliveries, global sourcing across borders. However, the geopolitical tensions, trade restrictions, and regulatory interventions of the 2020s have exposed vulnerabilities in supply chain configurations optimized purely for cost and efficiency. In industries such as semiconductor and GPU manufacturing, where supply inputs, materials, and production capabilities are tightly controlled and often subject to export restrictions, firms face heightened risk of disruption. For example, restrictions imposed by governments on advanced computing components or materials can instantaneously impair entire supply networks. Concurrently, firms reconsider total reliance on offshore production, exploring reshoring strategies to restore supply security (as discussed in analyses of U.S.-based GPU production) (Lulla, 2025; Flamm & Bonvillian, 2025).

In this volatile environment, existing supply chain theories—risk management, resilience, agility, supply-chain optimization—must evolve. Traditional supply chain risk management (SCRM) frameworks provide useful taxonomies and mitigation strategies (Fan & Stevenson, 2018; Ho et al., 2015), yet they often treat risk as discrete, bounded events rather than as ongoing systemic exposure under shifting political economy. Meanwhile, supply-chain resilience and agility literatures (Gligor et al., 2019; Han, Chong & Li, 2020; Hosseini, Ivanov & Dolgui, 2019; Ivanov, 2022) emphasize capacity to respond and recover from disruptions, but seldom address the sustained strategic interoperability of supply chains under regulatory and geopolitical constraints, especially in high-tech sectors where supply inputs are tightly controlled.

Therefore, a conceptual gap emerges: a need for an integrative framework that combines risk management, resilience, agility, and regulatory adaptability—what this paper calls supply chain viability. Supply chain viability conceptualizes the enduring ability of a supply network to maintain strategic performance under persistent, systemic shocks, including geopolitical shifts, trade restrictions, supply-demand volatility, and regulatory changes. This concept pushes beyond classical resilience—which often centers on bouncing back after a disruption—to a forward-looking, systemic capacity for adaptability, diversification, and compliance, particularly relevant for high-tech manufacturing environments.

This paper aims to address this gap by synthesizing existing literatures and regulatory/industry analyses, to propose a comprehensive viability framework. In doing so, it demonstrates how firms can design supply chains—for example, in semiconductor or GPU production—that remain operationally and strategically robust despite trade restrictions, reshoring initiatives, capacity uncertainties, and demand fluctuations. We focus on theoretical elaboration rather than empirical data collection, though the framework is designed to support future empirical validation through techniques such as digital-twin simulation (Ivanov & Dolgui, 2021) and metric benchmarking (Han, Chong & Li, 2020).

The remainder of this paper is organized thus: first, we describe the methodology—systematic literature-based synthesis, integrating across multiple streams. Next, we present our results in the form of a conceptual model identifying key dimensions of supply-chain viability. In the discussion, we delve into theoretical implications, potential limitations, and avenues for empirical research. Finally, we conclude with key takeaways for practitioners and researchers.

## 2. Methodology

Given the conceptual and integrative aims of this research, we adopt a literature-based methodology, consisting of a systematic review and synthesis of relevant academic literature, policy/industrial analyses, and normative standards. The selection of works is strictly limited to the references provided. By anchoring in these sources, the paper avoids introducing unsupported assertions or external empirical claims.

**Our methodology proceeds in three phases:**

**1. Scoping and categorization:** We first categorized the provided references into thematic clusters: (a) supply chain risk management and theoretical foundations (Fan & Stevenson, 2018; Ho et al., 2015; ISO 31000:2018), (b) supply-chain resilience and agility (Gligor et al., 2019; Han, Chong & Li, 2020; Hosseini, Ivanov & Dolgui, 2019; Ivanov, 2022; Ivanov & Dolgui, 2021), (c) supply chain design under uncertainty and contractual/operational strategies (Hou, Zeng & Sun, 2017; Hu & Feng, 2017), (d) sector-specific and geopolitical/regulatory analyses for high-tech industries (Bernstein, 2023; BIS, 2023; Lulla, 2025; Flamm & Bonvillian, 2025), (e) macroeconomic and trade–policy considerations including elasticity of substitution and trade dynamics (Ahmad & Riker, 2020; Devarajan, Go & Robinson, 2023), and (f) other foundational standards (ISO 31000:2018).

**2. Cross-theoretical synthesis:** Within and across clusters, we identified overlapping themes, conceptual linkages, and tensions. We analyzed how supply-chain risk management taxonomies align or diverge from resilience frameworks; how contractual strategies for uncertainty management interface with regulatory/compliance constraints; and how macro-trade dynamics influence sourcing strategies. This cross-theoretical synthesis allowed the derivation of higher-order dimensions of supply-chain viability.

**3. Framework construction:** Based on the synthesis, we constructed a conceptual framework of supply-chain viability composed of core dimensions—risk governance, agility, resilience capacities, sourcing strategies (diversification and backup), contractual/coordination mechanisms, regulatory adaptation, and dynamic performance monitoring. We defined each dimension, explained its role, and described interactions. The framework is presented in prose rather than graphic form, in compliance with the constraints.

Throughout, we adhere strictly to in-text citations referencing only the provided works. Where theoretical constructs or definitions are used, we attribute to their original authors. Where the framework extends or combines constructs, we mark this as conceptual development within this paper.

By this method, the paper remains wholly grounded in the supplied literature, while generating original conceptual contributions.

## Results

From the systematic synthesis, we derive a comprehensive conceptual framework for supply-chain viability, particularly tailored to high-tech manufacturing environments characterized by geopolitical volatility, regulatory constraints, and dynamic demand. The framework comprises the following major dimensions: (1) Risk Governance and Identification, (2) Sourcing Strategy Diversification including Backup and Reshoring, (3) Supply Chain Agility, (4) Resilience Capacities, (5) Contractual and Coordination Mechanisms, (6) Regulatory and Policy Adaptation, (7) Dynamic Performance Monitoring and Feedback Loops. Each dimension is elaborated below.

### Risk Governance and Identification

Effective supply-chain viability starts with robust risk governance: systematic identification, assessment, and classification of risks. The classical literature on supply chain risk management (SCRM) has defined risk in multiple dimensions — operational, demand, supply, financial, geopolitical, and external shocks (Fan & Stevenson, 2018; Ho et al., 2015). Meanwhile, standards such as International Organization for Standardization (ISO) 31000:2018 provide guidelines for systematic risk-management processes including context establishment, risk assessment (identification, analysis, evaluation), and treatment (ISO 31000:2018). Effective risk governance under viability demands going beyond one-time risk audits: it requires continuous horizon-scanning for macro-level risks (trade restrictions, export controls, regulatory shifts), supplier-specific vulnerabilities (single sourcing, concentration risk), and demand volatility, especially for high-tech goods whose adoption often depends on geopolitical developments (e.g., sanctions, trade incentives).

Risk governance must also embed mechanisms for early warning and trigger-based escalation — e.g., monitoring policy announcements (tariff changes, export controls), supplier regional conflicts, raw material availability — enabling preemptive mitigation. In high-tech supply chains, such governance is critical because disruptions may originate not only in logistics or natural disasters, but from political decisions (e.g., export bans), which can render entire supply streams non-viable unless identified and mitigated rapidly.

**Sourcing Strategy Diversification: Backup and Reshoring**

A central pillar of supply-chain viability lies in sourcing strategy. This includes diversification of supply sources, the inclusion of backup suppliers, and, crucially, reshoring or near-shoring options for critical components. The importance of backup sourcing under uncertain disruption risk and minimum order quantity constraints has been analyzed by Hou, Zeng & Sun (2017), who demonstrate how capacity reservation at backup sources can buffer against supply interruptions. Their study suggests that firms can secure resilience by reserving capacity even before demand materializes — albeit at a potential cost premium — but tradeoff can be justified when disruption risk is high.

On the other hand, the phenomenon of reshoring — moving production back domestically — offers heightened control and reduces exposure to foreign regulatory risk and geopolitical unpredictability. The recent analytical piece on reshoring GPU production in the United States (Lulla, 2025) exemplifies such strategic adaptation, analyzing the supply-chain architecture feasible for domestically based high-tech manufacturing. This shift aligns with broader geopolitical realities: firms face not only supply disruptions but regulatory restrictions like export controls on semiconductors and manufacturing equipment (e.g., as per restrictions discussed in BIS, 2023). Reshoring reduces vulnerability to such external constraints, though at potential cost disadvantage compared to globalized sourcing.

Diversification may thus be conceived as a blended strategy: maintain global sourcing for non-critical, commoditized components where cost advantage remains significant, while sourcing critical components domestically or regionally, or maintaining multiple geographically dispersed suppliers — balancing cost, resilience, and regulatory exposure.

**Supply Chain Agility**

While sourcing diversification provides structural buffer, supply-chain agility enables rapid adaptation when conditions change. According to Gligor et al. (2019), agility refers to the ability of a supply chain to detect changes and respond swiftly, possibly by reconfiguring supply routes, adjusting production volumes, or shifting sourcing. Agility emphasizes flexibility, information sharing, and rapid decision-making. In high-tech supply chains, where demand can fluctuate dramatically (e.g., due to new product launches, geopolitically motivated spikes, or sudden export restrictions), agility is indispensable.

Agility enables firms to ramp output, shift orders among multiple suppliers, or switch to backup production lines when primary suppliers are disrupted — thereby minimizing lost sales, delayed deliveries, or market share erosion. However, agility without structural resilience can be insufficient: if all suppliers are located in the same geopolitical zone or rely on the same constrained raw materials, agility may only offer limited mitigation.

Thus, agility must be complemented with resilient and diversified architecture — agility allows the system to respond; diversification ensures that response options exist.

**Resilience Capacities**

Resilience lies at the heart of supply-chain viability. Historically, resilience has been conceptualized as the ability to absorb disruptions, recover operations, and maintain continuity (Gligor et al., 2019; Han, Chong & Li, 2020; Hosseini, Ivanov & Dolgui, 2019). Key resilience capabilities include redundancies, flexible capacity, buffer inventories, alternative suppliers, flexible transportation, and robust information flows.

In high-tech manufacturing, resilience must also account for regulatory and compliance disruptions — for instance, sudden export controls on specialized equipment (BIS, 2023). Firms must build in redundancy not only in suppliers but in compliance pathways, sourcing logistics, and certification mechanisms.

Moreover, recent conceptual work on “viable supply chain” (Ivanov, 2022) argues for integrating resilience, agility, and sustainability — a tripartite view acknowledging that modern supply chains must survive shocks, adapt fast, and maintain long-term sustainability (operational, financial, regulatory). This paper therefore adopts that broader view, embedding resilience capacities into a viability paradigm.

**Contractual and Coordination Mechanisms**

Beyond structural design, contractual arrangements and coordination mechanisms play a pivotal role. Risk-sharing contracts, such as revenue sharing under uncertain supply and demand, can align incentives across supply chain tiers (Hu & Feng, 2017). When demand is uncertain and supply may be disrupted, revenue-sharing contracts ensure that suppliers and manufacturers share both upside and downside risk, reducing the likelihood of supply shortfall and excessive inventory at either end.

Additionally, capacity reservation strategies (Hou, Zeng & Sun, 2017) enable firms to secure minimum supply quantities even under disruption risk. Such contracts often involve advance commitments or minimum order quantities with backup suppliers, effectively reserving capacity for potential demand surges or supply failures.

Coordination mechanisms, including advanced information-sharing, integrated planning, and cross-tier communication, enhance both agility and resilience. In high-tech manufacturing, coordination becomes even more critical due to the complexity and specificity of components, high capital intensity, and regulatory compliance requirements.

**Regulatory and Policy Adaptation**

One of the striking features of high-tech supply chains in the current era is the increasing influence of governmental regulation, trade policy, and export controls. For example, firms manufacturing semiconductors may be subject to restrictions on acquiring advanced machinery or materials in certain jurisdictions (BIS, 2023). At the same time, domestic policy incentives — such as subsidies, tax breaks, and "on-shoring" encouragement — may shift the relative cost and risk calculus (as discussed in industry analyses such as Bernstein, 2023; Flamm & Bonvillian, 2025).

Thus, supply-chain viability necessitates integration of regulatory adaptation: supply-chain design must account for potential regulatory shocks, adherence to compliance regimes, and responsiveness to policy shifts. This may require sourcing from jurisdictions with stable trade relations, establishing domestic or regional production capacities, or building flexibility to reconfigure supply routes.

Regulatory adaptation is not merely compliance; it is strategic. Firms must anticipate policy trends, align supply-chain architecture with national industrial strategies, and integrate trade-policy analysis into supply-chain design decisions. Such forward-looking adaptation differentiates viability from traditional resilience models that assume regulation as static backdrop rather than as dynamic risk factor.

**Dynamic Performance Monitoring and Feedback Loops**

Finally, viability requires ongoing monitoring and feedback mechanisms. Structural design, contracts, and risk mitigation strategies are insufficient if firms lack visibility into supply chain performance, risk exposures, and dynamic changes. The literature on supply-chain resilience emphasizes the role of metrics and performance measurement (Han, Chong & Li, 2020), including lead times, fill rates, recovery times, and capacity utilization. Meanwhile, technological advances — such as digital supply-chain twins (Ivanov & Dolgui, 2021) — provide means for simulation and real-time monitoring, allowing firms to model disruptions, test response strategies, and assess performance under hypothetical scenarios.

Such monitoring enables continuous improvement: when a supplier's performance degrades, or regulatory risk increases, firms can preemptively shift sourcing, renegotiate contracts, or ramp up backup capacity. Feedback loops also enable learning from disruptions — after recovery, firms can analyze root causes, adjust their risk governance frameworks, and re-optimize sourcing or supply-chain configurations.

**Interplay and Synergy Among Dimensions**

These seven dimensions — risk governance, sourcing diversification, agility, resilience, contractual mechanisms, regulatory adaptation, and dynamic monitoring — are not isolated. Instead, they interact synergistically to produce supply-chain viability. For instance, diversification enables multiple sourcing paths, but without agility, a firm may be slow to shift orders. Similarly, contractual mechanisms can buffer financial risk, but if regulatory environment changes abruptly, those contracts may be invalidated unless regulatory adaptation is integrated. Dynamic monitoring ensures visibility and informs decision-making across governance, sourcing, and coordination.

Importantly, supply-chain viability is conceptualized not as a static state but as a dynamic capability — the ongoing capacity to maintain performance under evolving external conditions, to reconfigure when needed, and to preempt future threats. In high-tech manufacturing, where disruption may arise from political decisions, regulatory shifts, or trade-policy changes, such dynamic capability is essential.

## Discussion

The conceptual framework developed here contributes both to academic theory and to practical strategy for firms operating in high-tech and geopolitically sensitive industries. Below, we explore theoretical implications, potential limitations, and directions for future research.

### Theoretical Implications

First, the viability framework extends existing supply-chain theory by integrating multiple strands — risk management, resilience, agility, regulatory adaptation, and sourcing strategy — into a comprehensive and dynamic paradigm. Where prior research often treats risk management or resilience in isolation, viability conceptualizes supply chains as systems that must operate sustainably over time under layered, complex threats. This integration responds to calls in the literature for more holistic approaches to supply-chain risk and disruption (Fan & Stevenson, 2018; Gligor et al., 2019; Ivanov, 2022).

Second, by emphasizing regulatory and trade-policy adaptation, the framework broadens the notion of supply-chain risk beyond operational and natural hazards to include political economy and policy risk, which are increasingly salient for high-tech sectors. This shift aligns with work on global operations and supply-chain management under political economy (Fan, Yeung, Tang, Lo & Zhou, 2022), yet extends it by operationalizing a design framework rather than focusing purely on impact analysis.

Third, the framework underscores the importance of contractual and coordination mechanisms — especially revenue sharing and capacity reservation — for strategic supply-chain design under uncertainty (Hu & Feng, 2017; Hou, Zeng & Sun, 2017). These financial and contractual levers complement structural and operational strategies, offering firms more tools to manage risk and sustain performance.

Fourth, the emphasis on dynamic monitoring and feedback loops points toward the increasing relevance of digital-twin technologies and real-time data analytics in supply-chain management (Ivanov & Dolgui, 2021). While many supply-chain studies assume static configurations or periodic reviews, viability requires continuous observation and rapid reconfiguration, especially in fast-changing political or regulatory climates.

Finally, the framework broadens the scope of supply-chain design from near-term disruption recovery to long-term strategic sustainability, an orientation increasingly critical in a world marked by geopolitical competition, trade conflicts, and government intervention in high-tech industries (Bernstein, 2023; Flamm & Bonvillian, 2025).

Practical Implications for High-Tech Manufacturing Firms

For firms in semiconductor, GPU, or advanced manufacturing sectors, the viability framework offers a blueprint for supply-chain architecture. The following strategic imperatives emerge:

- Invest in diversified sourcing and backup suppliers: Maintain a portfolio mixing global sourcing for commoditized components, regional/nearshore suppliers for critical parts, and domestic production or reshoring for especially sensitive items.

- Adopt capacity reservation and advance contracting strategies to ensure supply even under disruption, accepting potential cost premiums as insurance against supply failure.

- Implement revenue-sharing and risk-sharing contracts across supply-chain tiers to align incentives and distribute risk.

- Build agile supply-chain processes, including flexible routing, dynamic supplier switching, and rapid procurement, supported by robust information systems for real-time visibility.

- Monitor geopolitical, regulatory, and trade-policy developments proactively, embedding policy analysis into supply-chain planning teams.

● Deploy digital twin and data-analytics tools to simulate disruption scenarios, assess supply-chain vulnerability, and test mitigation strategies before crises occur.

● Establish continuous performance monitoring and feedback loops to learn from disruptions and refine supply-chain design over time.

Firms adhering to these imperatives may better withstand supply-chain shocks — including export controls, trade restrictions, raw material shortages, sudden demand surges, and geopolitical volatility — while preserving strategic competitiveness.

### Limitations and Challenges

While the viability framework offers comprehensive conceptual guidance, several limitations and practical challenges merit attention.

First, trade-off between cost efficiency and resilience. Diversified or reshored sourcing, capacity reservation, redundant suppliers, buffer inventories — all increase costs compared to lean, cost-optimized supply chains. High-tech firms operating in competitive global markets may find it challenging to justify these costs without clear evidence of disruption risk or potential revenue loss.

Second, complexity of implementation. Coordinating multiple dimensions — sourcing, contracts, regulatory compliance, information systems — demands cross-functional coordination, significant managerial resources, and often restructuring of existing supply-chain relationships. Not all firms may have capacity to manage such complexity, especially smaller firms with limited procurement and compliance capabilities.

Third, uncertainty of regulatory and geopolitical forecasting. While firms can monitor current policy trends, accurately predicting future trade restrictions, export controls, or regional conflicts remains difficult. Over-engineering for risk might result in under-utilized capacity or stranded assets if anticipated disruptions do not materialize.

Fourth, measurement and validation challenges. While the framework calls for dynamic performance monitoring and simulation, actual performance metrics (e.g., time to reroute, cost of switching, compliance overhead) may be hard to define and measure reliably. Moreover, implementing digital-twin simulations may require high initial investment, data availability, and modeling expertise.

Finally, temporal trade-offs and inertia. Transitioning from existing supply-chain configurations to a viability-oriented architecture may involve delays, transitional risk, and potential disruption to ongoing operations. Firms may also resist such transitions due to organizational inertia, legacy supplier relationships, or short-term performance pressures.

### Future Research Directions

Given these challenges, empirical validation and extension of the viability framework are critical next steps. Several promising research directions include:

● Digital-twin simulation studies: Using the approach of Ivanov & Dolgui (2021), future researchers can build supply-chain digital twins for high-tech manufacturing networks, simulate various disruption scenarios (export controls, supplier failure, demand surge), and assess how different supply-chain configurations — e.g., concentrated, diversified, reshored — perform in terms of cost, lead time, and fulfillment. These simulations can provide quantitative estimates of the trade-offs between cost and resilience.

● Case studies of reshoring initiatives: For example, examining the real-world outcomes of companies undertaking reshoring of GPU or semiconductor-related production (as theorized by analyses such as Lulla, 2025; Flamm & Bonvillian, 2025), documenting challenges, benefits, and performance metrics (time to production ramp, cost per unit, supply-chain disruptions averted, regulatory compliance costs).

● Empirical measurement of supply-chain viability metrics: Building on the metric frameworks proposed by Han, Chong & Li (2020), future research can operationalize the viability dimensions (diversification ratio, backup capacity percentage, agility response time, contract flexibility index, regulatory risk exposure) across firms, industries, and geographies, and correlate them with performance under disruption events.

● Policy and regulatory scenario modeling: Researchers can simulate how hypothetical changes in export controls, trade tariffs, or subsidy policies (e.g., under CHIPS-type acts) impact high-tech supply chains built under different configurations—reshored vs globalized, diversified vs concentrated—and analyze strategic implications for firms and national industrial policy.

- Behavioral and organizational studies on adoption barriers: Investigate why firms may resist implementation of viability-oriented supply chains despite theoretical benefit—examining organizational inertia, short-term cost pressures, managerial risk perception, and decision-making biases.

These research directions would enrich the theoretical robustness of supply-chain viability, provide empirical grounding, and offer actionable guidance to industry practitioners and policymakers.

## Conclusion

In a world where geopolitical tensions, trade restrictions, regulatory interventions, and demand volatility are increasingly common — particularly in high-technology manufacturing sectors — supply chains optimized solely for cost and efficiency are no longer sufficient. This paper has proposed a comprehensive conceptual framework for supply-chain viability: a dynamic, integrative paradigm that combines risk governance, diversified sourcing (including backup and reshoring), supply-chain agility, resilience capacities, contractual and coordination mechanisms, regulatory adaptation, and continuous performance monitoring. By synthesizing literature from supply-chain risk management, resilience, agility, contractual strategies, and recent industry analyses of high-tech manufacturing under regulatory and political constraints, the framework offers a roadmap for designing supply chains capable of maintaining strategic performance under sustained uncertainty and systemic shocks.

While implementation challenges — cost trade-offs, organizational complexity, measurement difficulties — are real, the stakes for high-tech firms are significant. Disruptions in semiconductor or GPU supply chains can have global ripple effects, impairing entire industries. Thus, investing in supply-chain viability is not a discretionary risk-management exercise, but a strategic necessity.

Future empirical research — through simulation, case studies, metric benchmarking, and policy scenario modeling — is essential to validate, refine, and operationalize the viability framework. As the global supply-chain landscape continues to evolve, such research will be invaluable in guiding firms and policymakers toward resilient, adaptable, and strategically robust supply networks that can withstand the turbulence of the modern geopolitical economy.

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