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Enhancing Supply Chain Resilience and Sustainability: Integrating Big Data, AI, and Blockchain through a Relational Competence Lens

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Abstract: The complexities of modern supply chains, exacerbated by global disruptions and increasing sustainability demands, necessitate a multifaceted integration of advanced technologies with relational management practices. This article presents a conceptual and theoretical exploration of how relational competencies — trust, transparency, communication, and inter-organizational collaboration — interact with emerging technologies such as Big Data analytics, Artificial Intelligence (AI), Machine Learning (ML), and Blockchain to enhance supply chain resilience and sustainability. By synthesizing insights from seminal works on relational supply chain management (Wieland & Wallenburg, 2013), reviews on Big Data and analytics in product lifecycle and supply chain contexts (Ren et al., 2019; Wang et al., 2016; Dubey et al., 2016), studies on AI adoption in supply chains (Brintrup & Kito, 2020; Cole & Lee, 2021; Tran-Dang & Van, 2022), and foundational research on Blockchain's role in supply chains (Fang & Xiang, 2020; Sternberg & Baruffaldi, 2018; Kshetri, 2018), this study proposes an integrated framework: Relationally–Enabled Tech-Augmented Resilient Supply Chain (RE-TARSC). The framework theorizes how relational competencies moderate and mediate the effectiveness of technology deployment, impacting both resilience and sustainability outcomes. The analysis identifies mechanisms by which relational factors enable data sharing, trust in AI-driven decision-making, and adoption of transparent blockchain-based processes. The paper concludes with propositions for empirical testing, discusses limitations, and outlines future research directions.

Keywords

Supply Chain Resilience, Big Data Analytics, Artificial Intelligence, Blockchain Technology, Relational Competencies, Sustainable Supply Chain Management

INTRODUCTION:

The globalization of production and distribution networks has led to increasingly interconnected, complex, and interdependent supply chains. These networks, while offering efficiency and cost advantages, have simultaneously become vulnerable to a broad range of disruptions — from natural disasters and geopolitical upheavals to demand volatility and regulatory shifts. Against this backdrop, the dual imperatives of resilience (the ability to withstand and recover from disruptions) and sustainability (economic, environmental, and social viability over the long term) have become central in supply chain management discourse.

Traditional supply chain strategies, largely focused on cost minimization and operational efficiency, exhibit significant limitations in addressing these modern challenges. Consequently, there is a growing recognition that technological innovations — particularly Big Data analytics, AI/ML, and Blockchain — can offer powerful tools to enhance visibility, predictive capabilities, transparency, and real-time coordination across supply chains. However, technology in isolation is not a panacea. The effectiveness of these technologies critically depends on organizational and relational contexts: willingness to share data, trust in automated decision-making, commitment to transparency, and collaborative governance mechanisms.

This article proposes that the integration of relational competencies with advanced technologies constitutes a more robust pathway toward resilient and sustainable supply chains. Building on the relational view of supply chain resilience (Wieland & Wallenburg, 2013), and drawing from comprehensive reviews of technological advancements (Ren et al., 2019; Wang et al., 2016; Dubey et al., 2016; Brintrup & Kito, 2020; Tran-Dang & Van, 2022; Fang & Xiang, 2020), we develop a conceptual framework — the Relationally-Enabled Tech-Augmented Resilient Supply Chain (RE-TARSC) — that delineates how relational and technological dimensions interact to influence resilience and sustainability outcomes.

The key research question guiding this study is: How do relational competencies moderate and mediate the impact of Big Data analytics, AI/ML, and Blockchain on supply chain resilience and sustainability? By addressing this question, we aim to fill a significant gap in the literature: while existing studies examine technology adoption or relational competencies separately, few have theoretically explored their intersection. This gap inhibits comprehensive understanding and hinders practical implementation of technology-enabled supply chain strategies.

The contributions of this article are threefold. First, it synthesizes disparate strands of literature into an integrated theoretical model. Second, it explicates the mechanisms by which relational competencies influence technology effectiveness in supply chains. Third, it provides a roadmap for empirical validation and practical application, offering testable propositions and highlighting contingencies and boundary conditions.

METHODOLOGY

Given the conceptual nature of the research objective — to integrate existing literature into a unified theoretical framework — a qualitative, theory-building methodology was adopted. This methodology comprises four key phases:

1.Extensive Literature Review: An exhaustive review of foundational and contemporary studies focusing on relational competencies and supply chain resilience (notably Wieland & Wallenburg, 2013), Big Data and analytics in supply chain and lifecycle contexts (Ren et al., 2019; Wang et al., 2016; Dubey et al., 2016; Vanpoucke et al., 2017), AI and ML applications in supply chains (Brintrup & Kito, 2020; Cole & Lee, 2021; Tran-Dang & Van, 2022; Chowdhury, 2025), and Blockchain-based supply chain applications (Fang & Xiang, 2020; Sternberg & Baruffaldi, 2018; Kshetri, 2018).

2.Conceptual Mapping and Coding: Key concepts, mechanisms, relational competencies, technological affordances, and outcomes (resilience, sustainability) were extracted and coded. Similar themes across different studies were grouped to identify overlapping dimensions and contrasting positions.

3.Synthesis and Model Construction: Using the coded themes, a conceptual model was constructed that captures how relational competencies enable or constrain technology adoption and effectiveness, and how combined they lead to resilience and sustainability outcomes.

4.Derivation of Propositions: Based on the model, a set of testable propositions was developed. These propositions define hypothesized relationships among relational competencies, technology adoption, and supply chain performance outcomes.

Throughout this process, methodological rigor was maintained by ensuring that every conceptual linkage is grounded in at least one cited study, and by explicitly acknowledging where the integration involves inference beyond the original studies.

RESULTS The synthesis of the literature leads to the construction of the proposed RE-TARSC framework, which conceptualizes supply chain resilience and sustainability as outcomes of interplay between relational competencies and advanced technologies. The key components and relationships derived from the literature synthesis are as follows:

●Relational Competencies: Derived from Wieland & Wallenburg (2013), relational competencies include trust, collaboration intensity, communication quality, shared vision/values, and commitment to mutual benefits. These competencies influence supply chain resilience by enabling coordinated responses to disruptions, resource sharing, and joint risk management.

●Technological Enablers:

1.Big Data Analytics: Provides enhanced visibility, demand forecasting, anomaly detection, and lifecycle analysis. As reviewed by Ren et al. (2019), Wang et al. (2016), Dubey et al. (2016), and Vanpoucke et al. (2017), big data supports informed decision-making over the product lifecycle, logistics, and operations.

2.Artificial Intelligence / Machine Learning (AI/ML): Enables predictive analytics, dynamic routing, demand-supply matching, and real-time decision support. The discussions by Brintrup & Kito (2020), Cole & Lee (2021), Tran-Dang & Van (2022), and Chowdhury (2025) illustrate both potential performance benefits and risks associated with AI adoption.

3.Blockchain Technology: Offers decentralized, immutable, and transparent record-keeping, which can enhance traceability, trust, and verification across supply chain partners (Fang & Xiang, 2020; Sternberg & Baruffaldi, 2018; Kshetri, 2018).

●Dynamic Interplay and Mechanisms:

1.Relational Competencies → Technology Adoption & Trust: High levels of trust and collaborative culture make inter-organizational data sharing more feasible and acceptable, mitigating concerns over confidentiality and competitive disadvantage. This facilitates adoption of Big Data analytics and AI. Without trust, partners may withhold data, undermining data-driven processes.

2.Relational Competencies → Governance of Technology Use: Shared values and commitment foster collective governance, joint rules for data use, standardization, and joint oversight for blockchain deployment. This collective governance ensures accountability, fair cost-benefit sharing, and management of risks such as data misuse or privacy breaches.

3.Technology → Enhanced Visibility and Decision Quality: Big Data and AI provide predictive and prescriptive insights; blockchain ensures data integrity and transparency. Combined, these technologies reduce information asymmetry, enhance certainty, and improve responsiveness.

4.Relational Competencies × Technology → Resilience and Sustainability Outcomes: The joint presence of relational competencies and technological enablers leads to greater resilience — quicker adaptation to disruptions, more robust supply continuity — and improved sustainability, via optimized resource use, reduced waste, better lifecycle management, and transparent ethical compliance.

From this conceptual synthesis, the following propositions emerge:

●Proposition 1: Supply chains characterized by strong relational competencies are more likely to successfully adopt and integrate Big Data analytics, AI/ML, and Blockchain technologies.

●Proposition 2: The positive effect of technology on supply chain resilience is stronger when relational competencies are high.

●Proposition 3: The combined presence of relational competencies and technology adoption leads to superior sustainability outcomes compared to technology adoption alone.

●Proposition 4: Governance mechanisms rooted in relational competencies mitigate the risks associated with technology deployment — such as data privacy breaches, algorithmic bias, and partner conflict.

These results represent a theoretically grounded, integrative framework that accounts for both human-relational dynamics and technological affordances, providing a holistic understanding of supply chain resilience and sustainability in the digital age.

DISCUSSION

The RE-TARSC framework advances supply chain theory in several ways. First, it bridges two predominant but often siloed research streams: relational supply chain management (trust, collaboration, communication) and technology-driven supply chain innovation (analytics, AI, blockchain). By explicitly modeling their interaction, the framework fosters a more holistic understanding of how supply chains can evolve to meet contemporary challenges.

Theoretical Implications

One of the core contributions is the reconceptualization of relational competencies not merely as influencing traditional coordination and risk sharing, but as foundational enablers of technology adoption and governance. In conventional supply chain literature, relational competencies are often associated with flexibility, coordination, and risk mitigation (Wieland & Wallenburg, 2013). However, in technologically sophisticated supply chains, these competencies take on additional significance: they create the social infrastructure necessary for data sharing, trust in algorithmic decisions, and collective governance of shared digital assets (blockchain). This theoretical extension elevates relational competencies to a strategic role in digital supply chain transformation.

Moreover, the framework proposes a contingent model of technology effectiveness: advanced technologies do not uniformly yield resilience or sustainability benefits; rather, their impact is conditional on relational context. This challenges deterministic narratives that treat technologies as inherently beneficial. Instead, RE-TARSC suggests that without relational readiness — trust, collaboration, shared governance — technology-driven strategies may yield suboptimal or even counterproductive results. For example, a supply chain may deploy blockchain for traceability, but without shared commitment and collaborative governance, the ledger may remain underutilized, data may be incomplete, or partners may resist participating, undermining benefits.

Practical Implications

For practitioners, the framework suggests that investing in technology alone is insufficient. Organizations need to cultivate relational competencies across their supply chain networks. This involves building trust, aligning visions and values, establishing shared governance structures, and promoting transparency and collaboration. For example, when introducing blockchain-based traceability, firms should engage partners in co-designing governance rules, standards, and data-sharing protocols, rather than imposing top-down systems. Similarly, adoption of AI-driven demand forecasting should be accompanied by training, transparency about algorithms, and collaborative decision-making to build confidence and shared ownership.

The framework also emphasizes the importance of phased integration. Rather than saturating the supply chain with multiple technologies at once, firms may benefit from incremental adoption — first establishing relational foundations, then gradually integrating Big Data, AI/ML, and blockchain — ensuring each step is supported by collaborative governance and trust-building. This phased approach reduces resistance, enhances adoption success, and gradually builds a resilient, technology-enabled ecosystem.

Limitations

Despite its contributions, the study has several limitations. First, as a purely conceptual and theoretical piece, it does not provide empirical validation. The propositions offered remain hypothetical and require rigorous empirical testing across diverse supply chain contexts, industries, and geographies. Differences across sectors — e.g., perishable goods vs. heavy industry — may influence how relational competencies and technological affordances interact; the framework may need adaptation accordingly.

Second, the framework assumes a baseline willingness among supply chain partners to collaborate and share data. In many real-world cases, competitive pressures, power asymmetries, and legal/regulatory constraints (e.g., data privacy laws) may severely limit data sharing and collective governance. In such contexts, relational competencies may be difficult to establish or may require substantial investments over time. The framework does not yet account for adversarial relationships or high-power asymmetry, which may fundamentally alter or inhibit the mechanisms proposed.

Third, while the framework acknowledges risks associated with technology deployment — such as data misuse, algorithmic bias, privacy issues — it does not systematically address how to mitigate these beyond governance rooted in trust and collaboration. In practice, more formal mechanisms (e.g., regulatory compliance, technical safeguards, audits) may be required. The reliance on relational governance may not be sufficient, especially in large, heterogeneous supply networks with multiple stakeholders.

Finally, the rapidly evolving nature of technologies poses a moving target for theory. AI algorithms, blockchain platforms, data governance standards, and regulatory environments are continuously changing. The framework's applicability may shift over time, requiring periodic revision and adaptation to new technological and institutional developments.

Future Research Directions

Building on the RE-TARSC framework and considering its limitations, future research could proceed in the following directions:

●Empirical Validation: Conduct multi-industry, cross-national empirical studies to test the propositions. Use mixed methods — surveys to assess relational competencies, case studies to examine technology adoption processes, and performance metrics (resilience, sustainability outcomes) over time.

●Boundary Conditions and Moderators: Investigate how contextual factors — industry characteristics, power asymmetry, regulatory environment, cultural differences — moderate the relationships in the framework. For instance, does relational competency matter more in high-uncertainty industries (e.g., perishables) than in stable industries?

●Governance Mechanisms and Institutionalization: Explore how relational governance can be institutionalized, especially in fragmented supply chains with multiple tiers. Research could examine hybrid governance models combining relational governance with formal contracts, third-party audits, and regulatory compliance.

●Technology Evolution and Adaptive Frameworks: As technologies evolve (e.g., more advanced AI, next-generation blockchain, IoT integration), the framework should be revisited and adapted. Longitudinal studies could examine how supply chains evolve over time, how relational competencies and technology adoption co-evolve, and what factors sustain or erode resilience.

●Ethics, Privacy, and Trust Erosion: Investigate how data privacy concerns, ethical AI issues, and data breaches affect trust and relational competencies over time. Research could examine cycles of trust-building and erosion, and propose mechanisms to sustain relational health in digital supply chains.

CONCLUSION

In an era marked by volatility, complexity, and rising demand for sustainability, supply chains must evolve beyond traditional efficiency-driven paradigms. The integration of advanced technologies such as Big Data analytics, AI/ML, and Blockchain holds great promise. However, this study argues — via the proposed RE-TARSC framework — that relational competencies remain the fundamental enablers of successful technology adoption and effective deployment. By conceptualizing supply chain resilience and sustainability as outcomes of the dynamic interplay between social-relational and technological dimensions, this framework offers a holistic and nuanced theoretical lens.

The synergy of trust, collaboration, shared governance, and technological capabilities can empower supply chains to be more transparent, adaptive, and sustainable. For practitioners, this underscores the importance of investing in human and organizational relationships, not merely technology infrastructure. For scholars, it opens up a rich research agenda aimed at empirically testing and refining the proposed propositions, exploring boundary conditions, and adapting the framework to evolving technologies and institutional contexts.

Ultimately, this research reaffirms that technology does not operate in a vacuum — its promise can be realized only when embedded within relationships characterized by trust, collaboration, and shared purpose. The RE-TARSC framework thus charts a path toward resilient, sustainable, and technologically empowered supply chains for the future.

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