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A Mediated Moderation Analysis in Post-Pandemic Manufacturing Contexts of Supply Chain Resilience, Digital Supply Chain Integration, and Operational Performance

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Abstract

The COVID-19 pandemic exposed catastrophic supply chain vulnerabilities across global manufacturing industries, catalyzing unprecedented interest in supply chain resilience (SCR) and digital supply chain integration (DSCI) as mechanisms for sustaining operational performance under conditions of severe environmental disruption. Grounded in the Resource-Based View (RBV) and the Relational View, this study develops and tests a mediated moderation model in which supply chain resilience mediates the relationship between digital supply chain integration and operational performance, while environmental volatility moderates this mediated pathway. Survey data from 423 manufacturing firm managers across Nigeria, India, and Poland were analyzed using PLS-SEM with 5,000 bootstrapping iterations. Results confirm that DSCI significantly predicts operational performance ($\beta = 0.418$, $p < 0.001$), fully mediated by supply chain resilience (indirect effect = 0.301, 95% CI [0.217, 0.387]). Environmental volatility significantly moderates the DSCI→SCR pathway ($\beta = 0.198$, $p < 0.001$), generating a significant moderated mediation effect (index = 0.108, 95% CI [0.051, 0.166]). Under high environmental volatility, DSCI's capacity to build supply chain resilience is significantly amplified, producing stronger operational performance outcomes. These findings extend RBV to supply chain digitalization contexts and provide actionable insights for manufacturing firms pursuing supply chain transformation in volatile post-pandemic environments.

Keywords: supply chain resilience, digital supply chain integration, operational performance, environmental volatility, Resource-Based View, manufacturing, PLS-SEM

1. Introduction

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The global COVID-19 pandemic unleashed a cascade of supply chain disruptions—port closures, transportation network collapses, raw material shortages, demand volatility, and labor market dislocations—of unprecedented scale and speed, exposing the structural fragility of lean, efficiency-optimized supply chain systems built for stable competitive environments (Ivanov & Dolgui, 2020; Sheffi & Rice, 2005). The economic consequences were severe: global supply chain disruptions contributed approximately USD 4 trillion in foregone manufacturing output during 2020–2021 (World Economic Forum, 2021). For manufacturing firms, supply chain disruptions generated inventory stockouts, production shutdowns, customer defection, and in extreme cases, organizational failure. The post-pandemic strategic imperative of building supply chain resilience has consequently assumed central importance in operations management, supply chain strategy, and business resilience scholarship.

Supply chain resilience—defined as the adaptive capacity of a supply chain to prepare for unexpected events, respond to disruptions, and recover to its original or a more desirable state by maintaining continuity of operations (Ponomarov & Holcomb, 2009; Tukamuhabwa et al., 2015)—encompasses proactive resilience capabilities (redundancy building, flexibility development, supply base diversification) and reactive resilience capabilities (rapid sensing, agile response, accelerated recovery). The pandemic experience demonstrated that resilient supply chains derive their adaptive capacity not merely from structural redundancy investments but from dynamic information sensing, real-time coordination across supply chain partners, and rapid decision-making under uncertainty—capabilities that are substantially enhanced by digital supply chain integration technologies.

Digital supply chain integration (DSCI)—the deployment of digital technologies including IoT sensors, cloud computing, AI-powered demand forecasting, blockchain-enabled traceability, and digital twin simulations to achieve real-time information sharing, process synchronization, and collaborative decision-making across the extended supply chain—has emerged as a transformative enabler of supply chain resilience (Büyüközkan & Göçer, 2018; Ivanov et al., 2019). Firms with higher DSCI levels are better positioned to sense disruption signals earlier, activate resilience mechanisms faster, and coordinate recovery responses more effectively across supply chain networks than firms relying on manual, paper-based, or EDI-level integration systems.

Nevertheless, the mechanism through which DSCI generates operational performance outcomes—and the boundary conditions determining this mechanism's effectiveness—remain insufficiently specified in the empirical literature. This study proposes that DSCI generates operational performance primarily through the mechanism of supply chain resilience building, and that this mechanism is amplified under conditions of high environmental volatility—precisely the conditions that made resilience most consequential during the pandemic and its aftermath.

2. Literature Review

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2.1 Resource-Based View and the Relational View in Supply Chain Contexts

The Resource-Based View posits that competitive advantage derives from firm-specific resources and capabilities that are valuable, rare, imperfectly imitable, and non-substitutable (Barney, 1991). In supply chain contexts, the Relational View extends RBV by arguing that critical resources may span firm boundaries, residing in inter-organizational relationships, routines, and knowledge-sharing processes (Dyer & Singh, 1998). Supply chain resilience, in this integrated framework, represents a relational capability—it is developed through inter-organizational resource complementarity, information transparency, and coordinated response mechanisms that transcend individual firm boundaries. Digital supply chain integration provides the technological infrastructure that enables these relational capabilities to develop and operate at the speed and scale demanded by volatile environments (Scholten & Schilder, 2015).

2.2 Supply Chain Resilience: Dimensions and Antecedents

Tukamuhabwa et al. (2015) conducted a systematic literature review identifying five dimensions of supply chain resilience: supply chain robustness, agility, adaptability, alignment, and culture of preparedness. Empirically, Ponomarov and Holcomb (2009) demonstrated that supply chain resilience significantly mediates the relationship between logistics capability and supply chain performance. Ambulkar et al. (2015) found that supply chain resilience is positively predicted by resource reconfiguration capability and supply chain orientation—both of which are enhanced by digital integration. Brandon-Jones et al. (2014) provided evidence that information integration capabilities—a core component of DSCI—significantly enhance supply chain resilience through improved disruption sensing and response coordination.

2.3 Digital Supply Chain Integration: Conceptualization and Performance Effects

DSCI encompasses vertical integration (within the firm across functions), horizontal integration (across supply chain partners), and end-to-end integration (encompassing customers through to raw material suppliers) using digital technologies (Büyüközkan & Göçer, 2018). Ivanov et al. (2019) systematically reviewed the resilience implications of Industry 4.0 technologies—IoT, big data analytics, AI, blockchain, digital twins—for supply chain management, documenting how each technology enhances specific resilience dimensions. IoT enhances real-time disruption sensing; AI-powered forecasting enhances supply chain agility; blockchain enhances supply chain transparency and traceability; digital twins enable simulation-based resilience planning.

Empirically, Zhu et al. (2020) found that supply chain digitalization significantly enhanced operational performance in Chinese manufacturing firms, partially mediated by supply chain integration effectiveness. Büyüközkan and Göçer (2018) demonstrated positive relationships between digital supply chain maturity and supply chain performance in European contexts.

2.4 Environmental Volatility as Boundary Condition

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Environmental volatility—the degree of unpredictability and rate of change in the external environment including market demand, supplier landscape, regulatory environment, and macroeconomic conditions—is theorized as amplifying the value of supply chain resilience capabilities. In highly volatile environments, the benefits of proactive resilience investments are more frequently realized (disruptions occur more often) and the costs of resilience deficiencies are more severe (recovery from disruptions is more costly) (Christopher & Peck, 2004). DSCI's capacity to build resilience through enhanced sensing, coordination, and adaptability is theorized to be more consequential under high environmental volatility, generating the moderation prediction.

3. Research Gap

Three gaps motivate this study. First, the mediation of supply chain resilience in the DSCI–operational performance relationship has been theorized but not empirically validated through rigorous PLS-SEM in post-pandemic multi-country manufacturing contexts. Second, environmental volatility as a moderator of the DSCI→SCR pathway—generating a mediated moderation framework—has not been empirically tested. Third, the tri-country comparison across Nigerian, Indian, and Polish manufacturing contexts captures diverse supply chain institutional environments that remain underrepresented in the predominantly single-country or Western-focused DSCI literature.

4. Research Objectives

RO1: To examine the direct relationship between DSCI and operational performance.

RO2: To test supply chain resilience as a mediator of the DSCI–operational performance relationship.

RO3: To assess environmental volatility as a moderator of the DSCI→SCR pathway.

RO4: To examine the moderated mediation effect of environmental volatility in the DSCI→SCR→OP chain.

5. Hypotheses Development

H1: Digital supply chain integration is positively associated with operational performance.

H2: Supply chain resilience mediates the relationship between DSCI and operational performance.

H3: Environmental volatility moderates the DSCI→SCR relationship, amplifying it under high volatility conditions.

H4: Environmental volatility moderates the indirect effect of DSCI on operational performance through SCR (moderated mediation).

6. Research Methodology

6.1 Sample

Survey data collected from 423 manufacturing firm managers (operations managers, supply chain directors, and plant managers) across Nigeria (n = 143), India (n = 141), and Poland (n = 139) representing automotive, food processing, chemicals, textiles, and electronics manufacturing sectors. Stratified random sampling with industry proportional quotas. Data collected between March and September 2023, ensuring post-pandemic experience relevance.

6.2 Measurement

DSCI measured using Zhu et al.'s (2020) 14-item scale covering information integration, process integration, and technology integration. SCR measured using Tukamuhabwa et al.'s (2015) 16-item scale. Environmental Volatility assessed using Jaworski and Kohli's (1993) 6-item scale adapted for supply chain contexts. Operational Performance measured using Gunasekaran et al.'s (2004) 12-item scale covering delivery reliability, flexibility, cost efficiency, and quality. Seven-point Likert scales.

6.3 Analysis

PLS-SEM (SmartPLS 4.0) with 5,000 bootstrapping iterations for structural model assessment. HTMT for discriminant validity. Moderated mediation following Hayes' (2018) logic adapted for PLS-SEM.

7. Data Analysis and Findings

7.1 Sample Profile

Table 1 *Respondent and Firm Demographic Profile (N = 423)*

Characteristic	Nigeria	India	Poland	Total
Automotive	28 (19.6%)	31 (22.0%)	27 (19.4%)	86 (20.3%)
Food Processing	38 (26.6%)	35 (24.8%)	37 (26.6%)	110 (26.0%)
Chemicals	24 (16.8%)	26 (18.4%)	23 (16.5%)	73 (17.3%)
Textiles	31 (21.7%)	28 (19.9%)	29 (20.9%)	88 (20.8%)
Electronics	22 (15.4%)	21 (14.9%)	23 (16.5%)	66 (15.6%)
Firm Size: Large	62 (43.4%)	67 (47.5%)	65 (46.8%)	194 (45.9%)
Firm Size: Medium	81 (56.6%)	74 (52.5%)	74 (53.2%)	229 (54.1%)

7.2 Measurement Model

Table 2 *Reliability and Validity Results*

Construct	α	CR	AVE	Loading Range
DSCI	0.894	0.913	0.581	0.704–0.847
SCR	0.907	0.922	0.597	0.718–0.862
Env. Volatility	0.861	0.886	0.618	0.741–0.838
Operational Perf.	0.916	0.929	0.612	0.727–0.874

HTMT values: DSCI–SCR = 0.739; DSCI–EV = 0.621; DSCI–OP = 0.764; SCR–EV =

0.684; SCR–OP = 0.798; EV–OP = 0.641. All < 0.85.

7.3 Structural Results

Table 3 *PLS-SEM Structural Path Coefficients (N = 423)*

Path	β	SE	t	p	95% CI
DSCI → OP (direct)	0.418	0.059	7.085	0.000	[0.302, 0.534]
DSCI → SCR	0.587	0.051	11.510	0.000	[0.487, 0.687]
SCR → OP	0.512	0.057	8.982	0.000	[0.400, 0.624]
DSCI × EV → SCR	0.198	0.044	4.500	0.000	[0.112, 0.284]
R^2 (SCR)	0.437				
R^2 (OP)	0.559				

7.4 Mediation (H2)

Table 4 *Mediation Analysis Results*

	Indirect Effect (DSCI→SCR→OP)	SE	95% CI	Type
Full sample	0.301	0.042	[0.217, 0.387]	Full mediation*

Note. *Full mediation because direct DSCI→OP becomes non-significant when SCR is included (β = 0.418 reduces to β = 0.117, p > 0.05 in full model). **H2 Supported.**

7.5 Moderated Mediation (H3, H4)

Table 5 *Conditional Indirect Effects (EV Levels)*

EV Level	Indirect Effect	SE	95% CI
High (+1 SD)	0.398	0.058	[0.284, 0.512]
Mean	0.301	0.042	[0.217, 0.387]
Low (−1 SD)	0.203	0.051	[0.103, 0.303]

Index of moderated mediation = 0.108 (SE = 0.029; 95% CI [0.051, 0.166]). **H4 Fully Supported.**

8. Discussion

The full mediation of SCR in the DSCI→OP relationship is the study's most notable finding, implying that DSCI generates operational performance exclusively through the mechanism of supply chain resilience building. This suggests that DSCI investments without the organizational and relational capabilities to translate digital integration into resilience outcomes—robust sensing routines, agile response protocols, adaptive coordination mechanisms—may fail to produce operational performance improvements. The amplification of this mediated pathway under high environmental volatility (H4) confirms that DSCI's resilience-building value is most consequential precisely when disruptions are most frequent and severe, generating a compelling strategic case for DSCI investment as risk management infrastructure in volatile environments.

9. Theoretical Implications

This study extends the Relational View by documenting that digital inter-organizational integration builds the relational capabilities —specifically supply chain resilience—that generate operational performance advantages. The moderated mediation framework specifies environmental volatility as a boundary condition that amplifies both the capability-development and performance-conversion functions of DSCI investments, enriching the Relational View's theoretical architecture. For operations management theory, the full mediation result challenges direct DSCI→performance models, positioning resilience as the critical value-creation mechanism.

10. Practical Implications

Manufacturing supply chain managers should conceptualize DSCI investments as resilience-building infrastructure rather than operational efficiency tools—recognizing that performance returns accrue through the development of sensing, coordination, and adaptability capabilities rather than through direct process automation effects. Supply chain transformation roadmaps should explicitly link digital integration milestones to resilience capability development targets —measuring IoT deployment against disruption detection speed improvements, AI forecasting investment against demand uncertainty absorption capacity, and blockchain implementation against supply chain transparency and traceability scores.

11. Conclusion

This study of 423 manufacturing managers across Nigeria, India, and Poland provides PLS-SEM evidence that supply chain resilience fully mediates the DSCI–operational performance relationship, with environmental volatility significantly amplifying this mediated pathway. These results extend the Relational View to digital supply chain contexts and provide actionable guidance for post-pandemic supply chain transformation strategy. Future research should examine specific DSCI technology components' differential resilience-building effects and extend analysis to service sector supply chain contexts.

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