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Supply Chain Resilience, Digital Integration, and Financial Performance

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Abstract
The COVID-19 pandemic exposed critical vulnerabilities in the supply chains of Indian manufacturing small and medium enterprises (SMEs), triggering widespread demand shocks, supplier failures, and logistics disruptions that led to an estimated 18% decline in SME output in FY2021. This study examines how pre-pandemic investments in digital supply chain integration (DSCI) — encompassing ERP adoption, IoT-enabled inventory visibility, supplier portal connectivity, and digital payment infrastructure — moderated supply chain disruption severity and influenced post-disruption financial recovery trajectories. Using a longitudinal dataset of 312 manufacturing SMEs across automotive components, pharmaceuticals, and textile sectors in Gujarat, Maharashtra, and Tamil Nadu (data collected at five time points: Q1 2020 through Q4 2022), we estimate fixed-effects panel regression models with disruption severity, recovery velocity, and three-year cumulative revenue as dependent variables. Findings indicate that firms in the highest DSCI quartile experienced 34% lower supply disruption severity (measured as the ratio of fulfilled to total customer orders during April-June 2020) and achieved revenue recovery to pre-pandemic levels 4.3 months faster than lowest-quartile firms. The relationship between DSCI and disruption severity is non-linear, with a significant inflection point at approximately 65% digital adoption completeness — below which additional digitalisation yields diminishing marginal resilience benefits, suggesting threshold effects in digital supply chain investment returns. Sector analysis reveals that pharmaceutical SMEs exhibit stronger DSCI-resilience relationships than automotive or textile firms, consistent with pharmaceutical supply chains' pre-existing regulatory compliance-driven digitalisation. Implications for government MSME digitalisation policy and bank credit assessment criteria are discussed.

Keywords: *supply chain resilience, digital integration, COVID-19, Indian SMEs, panel data, disruption severity, ERP adoption, financial recovery, manufacturing, MSME policy*

1. Introduction

India's 63.4 million MSMEs, contributing approximately 30% of GDP and 40% of total exports, represent the backbone of the country's manufacturing economy yet remain disproportionately vulnerable to supply chain disruptions relative to large-firm competitors due to their limited financial buffers, concentrated supplier relationships, and historically lower technology adoption rates. The COVID-19 pandemic constituted an unprecedented stress test of this vulnerability: the nationwide lockdown from March 25, 2020 disrupted inbound logistics for 89% of manufacturing SMEs surveyed by the Confederation of Indian Industry within the first month, with 67% reporting complete production stoppage for at least six weeks.

Supply chain resilience (SCR) — defined as a firm's capacity to anticipate, resist, absorb, adapt to, and recover from supply chain disruptions while maintaining continuity of operations and financial performance (Ponomarov & Holcomb, 2009) — has received extensive conceptual treatment in the operations management literature but limited large-sample empirical examination in emerging-market SME contexts. The digital supply chain integration (DSCI) construct has been proposed as a key antecedent of SCR in developed-country large-firm contexts (Rai et al., 2006; Wieland & Marcus Wallenburg, 2013), but whether the same relationship holds for resource-constrained Indian SMEs — for whom digital adoption involves significant relative investment and change management burdens — remains an open empirical question with significant policy relevance.

This study makes three contributions: first, it provides the first large-sample longitudinal evidence of DSCI-SCR relationships in Indian manufacturing SMEs using objective financial data rather than self-reported performance; second, it identifies a non-linear threshold effect in the DSCI-resilience relationship with important investment planning implications; and third, it reveals sector-level heterogeneity that refines homogeneous policy prescriptions for MSME digitalisation.

2. Conceptual Framework

2.1 Digital Supply Chain Integration and Resilience

DSCI encompasses the degree to which a firm's internal operational systems — production planning, inventory management, financial accounting — are digitally connected with upstream suppliers and downstream customers through real-time data exchange. Higher DSCI levels theoretically enhance SCR through three mechanisms: visibility enhancement (real-time inventory and order status data enabling faster disruption detection), agility enablement (digital infrastructure supporting rapid supplier switching and demand signal processing), and coordination improvement (automated information sharing reducing the bullwhip effect and enabling collaborative response). The theoretical foundation draws on dynamic capabilities theory (Teece, Pisano & Shuen, 1997), positioning DSCI as an infrastructure capability that enhances a firm's sensing and seizing capacity in disruptive environments.

2.2 Non-Linear Adoption Effects

We hypothesise a non-linear DSCI-resilience relationship based on network externality and capability maturity arguments. Below a threshold adoption level, digital systems are fragmented — ERP is adopted but not integrated with supplier portals; IoT sensors are installed but data is not analytically processed — limiting the visibility and coordination benefits. Above the threshold, integration effects compound: end-to-end visibility enables genuinely proactive disruption response rather than reactive firefighting, and digital supplier relationships enable faster source qualification during disruptions. The inflection point is hypothesised in the 60-70% digital maturity range based on analogous findings in digital transformation literature.

3. Data and Methodology

3.1 Sample Construction

The sample of 312 SMEs was constructed through stratified sampling from the MSME Ministry's Udyam Registration database, stratified by sector (automotive components: n=104; pharmaceuticals: n=98; textiles: n=110) and DSCI quartile measured at Q4 2019 (pre-pandemic baseline). SMEs were defined by the revised MSME classification (investment ≤ ₹50 crore, turnover ≤ ₹250 crore). Financial performance data were sourced from MCA21 audited financial statements; DSCI scores were constructed from a structured interview instrument administered by trained research associates across five waves.

3.2 Econometric Specification

The primary estimator is a fixed-effects panel regression model with firm-level fixed effects absorbing all time-invariant confounders, including sector, location, and unobserved managerial capability. Disruption severity is operationalised as 1 minus the order fulfilment ratio during the peak disruption quarter (Q1 FY2021). Recovery velocity is the number of months from disruption peak to return to 95% of pre-pandemic quarterly revenue. The non-linear DSCI effect is tested by including DSCI and $DSCI^2$ as regressors; the threshold is estimated by segmented regression.

4. Results

4.1 Main Effects

Figure 1 presents the three-panel results overview. Panel A shows the DSCI quartile distribution versus disruption severity, confirming a monotonic negative relationship: Q1 firms (lowest DSCI) experienced mean disruption severity of 0.61 (order fulfilment ratio 0.39); Q4 firms experienced 0.27 severity (fulfilment ratio 0.73). Panel B presents recovery velocity by DSCI quartile and sector, revealing that pharmaceutical SMEs in Q4 recovered to baseline revenue within 5.2 months versus 11.8 months for textile SMEs in Q1. Panel C plots the non-linear DSCI-resilience relationship, with the fitted quadratic confirming the threshold effect.

Fig. 1. (A) Disruption Severity by DSCI Quartile; (B) Revenue Recovery Velocity by Sector and DSCI Quartile; (C) Non-Linear DSCI-Resilience Relationship with Inflection Point

Table 1 presents the fixed-effects panel regression results across three model specifications. Model 1 includes only DSCI as a linear predictor; Model 2 adds the quadratic term; Model 3 adds sector-DSCI interaction terms. The quadratic term in Model 2 is significant ($\beta = -0.18$, $p < 0.01$), confirming non-linearity. The inflection point estimated from segmented regression falls at DSCI = 0.638 (95% CI [0.591, 0.684]), consistent with the hypothesised 60-70% range.

Table 1. Fixed-Effects Panel Regression: DSCI, Disruption Severity, and Recovery Velocity

Variable	Model 1 (β)	Model 2 (β)	Model 3 (β)	SE (M3)
DSCI Score	−0.42***	−0.51***	−0.48***	0.08
DSCI² (quadratic)	—	−0.18**	−0.16**	0.06
Pharma × DSCI	—	—	−0.21**	0.09
Textile × DSCI	—	—	0.08 (ns)	0.11
Firm Size (log assets)	−0.09*	−0.08*	−0.07*	0.04
R^2 Within	0.31	0.38	0.43	—

**** p < 0.001; ** p < 0.01; * p < 0.05; ns = not significant; Dependent variable: Disruption Severity (order fulfilment deficit ratio); n = 312 firms, 5 time periods; Firm fixed effects included in all models*

5. Discussion

The threshold effect at 65% DSCI maturity carries important practical implications for SME investment planning and government subsidy programme design. Below this threshold, incremental digitalisation — adding one more software module or digitising one more supplier relationship — yields diminishing marginal resilience returns because the system lacks the integration completeness to generate genuine end-to-end visibility. This implies that partial digitalisation support programmes, which provide SMEs with subsidies to adopt individual digital tools without addressing the integration layer, may generate poor value for money. The stronger DSCI-resilience relationship in pharmaceuticals likely reflects the sector's pre-existing compliance-driven digitalisation investment — regulatory requirements for batch traceability and cold chain monitoring had forced pharmaceutical SMEs to develop integration capabilities before the pandemic that subsequently served resilience purposes for which they were not originally designed.

6. Conclusion

This study provides the first large-sample longitudinal evidence that pre-pandemic digital supply chain integration significantly moderated disruption severity and accelerated financial recovery for Indian manufacturing SMEs during COVID-19, with a non-linear relationship featuring a threshold at approximately 65% digital maturity. Sector heterogeneity, most pronounced in pharmaceuticals, suggests that regulatory-driven digitalisation generates positive resilience externalities. Government MSME digitalisation policy should be redesigned to support integration completeness rather than adoption breadth, and bank SME credit assessment models should incorporate DSCI score as a risk-adjustment variable alongside traditional financial ratios.

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