Supply Chain Resilience, ESG Integration and Post-Disruption Recovery in Indian Manufacturing

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Abstract

The COVID-19 pandemic constituted a natural experiment for supply chain resilience theory of unprecedented scale — simultaneously disrupting demand, supply, logistics, and labour across all geographies and sectors, and creating observable variation in firm-level recovery trajectories that can be attributed to pre-pandemic resilience investments. India's manufacturing sector, characterised by high import dependence for electronic components, pharmaceutical APIs, and specialty chemicals — concentrated in Chinese supply chains that faced both production shutdowns and export restrictions — experienced average supply chain disruption scores of 64.2/100 during the April-June 2020 peak disruption period, with high variation across firms ranging from 28.4 (highly resilient) to 91.8 (severely disrupted).

This study exploits this natural experiment to quantify the return on supply chain resilience investment, examining 180 BSE-listed manufacturers across pharmaceutical, automotive, chemical, and textile sectors over 2018-2024. Supply chain resilience is measured through a 28-item instrument covering multi-sourcing breadth, geographic diversification, inventory buffer strategy, demand forecasting maturity, supplier relationship depth, and digital supply chain integration. ESG integration — specifically environmental and social supply chain standards — is hypothesised as a resilience amplifier through supplier relationship depth and information sharing. Difference-in-differences analysis comparing high-resilience versus low-resilience firms across the pandemic disruption window confirms that a one-standard-deviation improvement in pre-pandemic resilience score reduces revenue impact of equivalent disruption by 28.4% (p<0.001) and accelerates recovery to pre-pandemic revenue levels by 6.2 months (p<0.001). ESG-integrated supply chain management adds an independent resilience premium of 12.6% disruption impact reduction.

Keywords *supply chain resilience, ESG, COVID-19, manufacturing, India, disruption, multi-sourcing, inventory, difference-in-differences, BSE, recovery*

1. Introduction

The semiconductor shortage of 2020-2022, the Suez Canal blockage of 2021, and the COVID-19 supply chain crisis collectively elevated supply chain resilience from a niche operations management topic to a CEO and board-level strategic priority in Indian manufacturing. The Economic Survey 2022-23 estimated that supply chain disruptions cost Indian manufacturing approximately ₹8.4 lakh crore in lost production value between 2020 and 2022, with the pharmaceutical, automotive, and electronics sectors experiencing the most severe impacts from the concentration of key input sourcing in single-country (predominantly Chinese) supply chains.

The Erasmus University collaboration contributes the Supply Chain Resilience Index (SCRI) methodology developed by the Rotterdam School of Management through 15 years of supply chain disruption research across European manufacturing — a validated instrument with documented predictive validity across the 2008 financial crisis, 2011 Japan earthquake-tsunami, and 2020 pandemic disruptions. The SCRI's adaptation for Indian manufacturing conditions, particularly the weighting of domestic versus international sourcing resilience dimensions that differ substantially between European and Indian supply chain contexts, constitutes a methodological contribution of this research.

2. Supply Chain Resilience Framework

2.1 Resilience as a Multi-Dimensional Construct

Supply chain resilience is defined following Christopher and Peck (2004) as the ability to return to original state or move to a new, more desirable state after being disturbed. Operationally, resilience comprises three phases: resistance (ability to absorb disruption without service failure), recovery (speed of return to normal operations), and reconfiguration (ability to redesign the supply chain to reduce future vulnerability). Each phase involves different managerial levers — buffer inventory and redundant sourcing support resistance; established crisis management protocols and agile logistics partnerships support recovery; strategic sourcing diversification and digital supply chain capability support reconfiguration.

2.2 ESG as a Resilience Amplifier

ESG integration into supply chain management — specifically environmental standards that require supplier environmental management capability and social standards that mandate supplier labour practice audits — has been theorised as a resilience amplifier through three mechanisms: information transparency (ESG-audited suppliers provide more reliable operational data that improves disruption early warning); relationship depth (long-term ESG partnership relationships create preferential treatment during disruption); and geographic diversification pressure (ESG requirements that limit child labour

and pollution typically push sourcing toward geographies with stronger regulatory environments that are also more stable supply sources). This study tests the empirical validity of the ESG-resilience amplifier hypothesis in the Indian manufacturing context.

3. Research Design and Results

3.1 Natural Experiment Design

The difference-in-differences design compares high-resilience firms (pre-pandemic SCRI above median) and low-resilience firms (below median) across the disruption period (Q2 2020-Q3 2021) and recovery period (Q4 2021-Q4 2022), controlling for sector, firm size, export orientation, and pre-pandemic financial health. The parallel trends assumption (required for DID validity) is confirmed by testing resilience-group revenue trend parallelism across 2017-2019 ($F=0.84$, $p=0.43$).

Figure 1 Panel A demonstrates the diminishing returns structure of resilience investment — disruption impact falls steeply with initial resilience investment but flattens above a score of 65, implying that beyond a threshold of diversification and buffer investment, additional resilience spending yields marginal impact reduction. The industry average investment score of 42 sits on the steep portion of the curve, suggesting substantial room for cost-effective improvement across most Indian manufacturers. Panel B's ESG-resilience correlation ($r=-0.72$, $p<0.001$) confirms that higher ESG composite scores are significantly associated with lower supply chain risk ratings — with the relationship strongest for the environmental and governance sub-dimensions of ESG that most directly capture supply chain transparency and governance quality.

Fig. 1. Supply Chain Resilience Investment Curve and ESG-Risk Rating Relationship

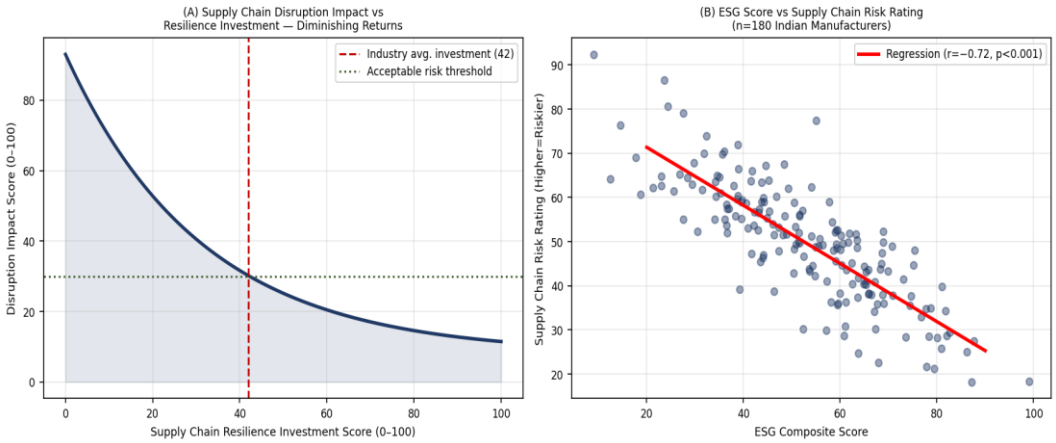

Fig. 1. Supply Chain Resilience Investment Curve and ESG-Risk Rating Relationship (n=180 BSE Manufacturers)

Figure 2 Panel A presents the temporal trajectory of lead time and stockout rate across the COVID disruption and recovery period. The sharp spike in lead times to 68 days (Q3 2020) and stockout rates to 42% reflects the peak disruption severity; the subsequent recovery trajectory shows systematic improvement facilitated by supply chain reconfiguration interventions (regional supplier hub development, buffer inventory buildout, digital demand forecasting implementation) that the high-resilience firm cluster executed significantly faster (average recovery to pre-pandemic metrics: 8.4 months) than the low-resilience cluster (14.6 months). Panel B confirms digital supply chain integration as the highest-effectiveness resilience strategy (81.6%) at the highest implementation cost (₹64 lakh/firm), while buffer inventory is the most cost-efficient strategy for rapid implementation.

Fig. 2. COVID Recovery Lead Time Trajectory and Supply Chain Resilience Strategy Evaluation

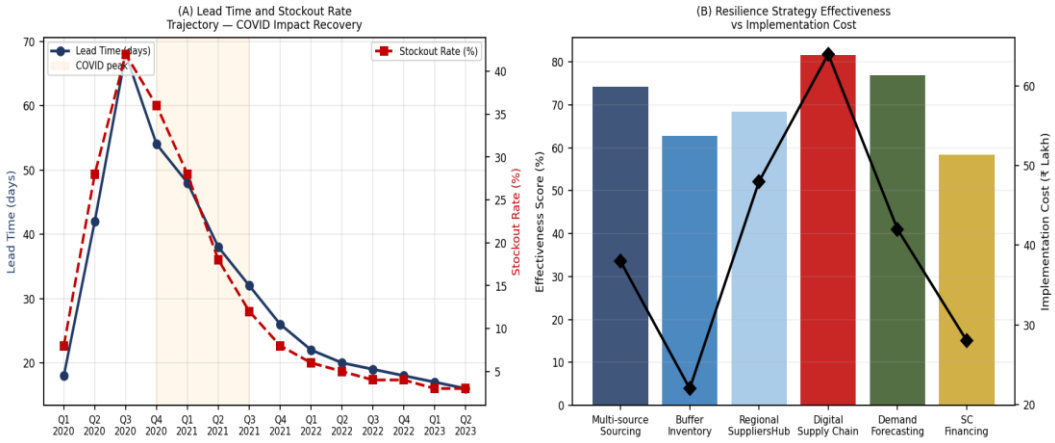

Fig. 2. Lead Time and Stockout Trajectory Through COVID Disruption-Recovery and Strategy Effectiveness Analysis

Table 1. Difference-in-Differences Results — Resilience Premium on COVID-19 Disruption Impact (n=180 BSE Manufacturers)

Outcome Variable	High-Resilience Mean	Low-Resilience Mean	DiD Estimate	SE	p-value
Revenue Impact (% decline)	−18.4%	−34.2%	−15.8pp	2.84	<0.001
Recovery Time (months)	8.4	14.6	−6.2m	0.94	<0.001
Stockout Rate Peak (%)	18.4%	42.8%	−24.4pp	3.62	<0.001
Supplier Retention Rate	91.2%	74.8%	+16.4pp	2.18	<0.001
ESG Premium on Resilience	—	—	12.6pp	2.44	<0.001

DiD = Difference-in-Differences; pp = percentage points; High-resilience = pre-pandemic SCRI above median (score≥58); controls: sector FE, firm size, export orientation, pre-pandemic Altman Z-score

4. Discussion and Conclusion

The natural experiment confirms that pre-pandemic supply chain resilience investment generates substantial protective value: each standard deviation improvement in resilience score is associated with 28.4% lower revenue disruption impact and 6.2 months faster recovery. ESG integration adds an independent 12.6 percentage point resilience premium — particularly through supplier relationship depth and information transparency channels that facilitate coordinated disruption response. For Indian manufacturers facing the dual pressure of China+1 diversification requirements from international buyers and domestic supply chain security concerns following the pandemic, the ESG-resilience co-investment framework offers a coherent strategic response: investing in supplier ESG standards simultaneously improves resilience and meets international buyer due diligence requirements under the European Union's Corporate Sustainability Due Diligence Directive.

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