

Supply Chain Resilience Strategies and Post-Disruption Recovery — Lessons from Indian Pharmaceutical and Automotive Industries

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Abstract

COVID-19 exposed critical supply chain vulnerabilities in India's globally integrated manufacturing sectors. Five years on, the Red Sea crisis (December 2023–2024), Taiwan Strait tensions, and post-pandemic chip supply normalisation have created a sustained multi-disruption environment requiring durable rather than episodic resilience investment. This study examines supply chain resilience strategies and their recovery performance consequences across 247 firms in Indian pharmaceuticals and automotive sectors using longitudinal panel data (2020–2025) combined with Cox Proportional Hazard modelling of disruption recovery events.

Resilience strategies are classified across four dimensions — redundancy, flexibility, agility, and collaboration — assessed through annual surveys and triangulated against logistics performance data from the National Logistics Portal and e-Way Bill analytics. Time-to-Recovery (TTR), Revenue Recovery Rate (RRR), and Supply Chain Disruption Cost (SCDC) are the primary performance metrics. Digital supply chain visibility combined with multi-sourcing reduces median TTR by 44 days (51% reduction) relative to undigitised single-source operations. PLI Scheme tranche investments have reduced pharmaceutical API import dependence from 68% (2019) to 48% (March 2025), with PLI-incentivised firms showing 16.2 percentage point higher RRR at 24 months. The Red Sea crisis of 2024 functioned as a natural experiment: firms with pre-built multi-modal logistics redundancy recovered 38 days faster than sea-freight-dependent peers.

Keywords supply chain resilience, Red Sea crisis, API manufacturing, PLI scheme, multi-sourcing, Time-to-Recovery, digital visibility, automotive, pharma, India 2025

1. Introduction

The supply chain resilience literature, energised by COVID-19's unprecedented disruption of global value chains, has since 2022 confronted a more complex disruption landscape than the single-shock models that dominated early pandemic research. The Red Sea crisis — Houthi attacks on commercial shipping from December 2023 — diverted 40% of global container traffic away from the Suez Canal, adding 10-14 days to Asia-Europe shipping routes and increasing freight rates by 250-400% at peak (Drewry Container Freight Index, Q1 2024). India's pharmaceutical exports — which depend on sea freight for 78% of volume to European markets — were among the hardest hit, with average FOB realisation declining 8.3% in Q1 FY2024-25 due to freight cost absorption.

India's supply chain policy environment has evolved substantially since 2020. The PM Gati Shakti National Master Plan — integrating road, rail, aviation, and waterway infrastructure planning through a unified digital portal — has reduced average freight transit time by 14% on the Golden Quadrilateral corridors since 2022. The National Logistics Policy 2022 targets reducing logistics cost from 13-14% of GDP to 8% by 2030, with the Unified Logistics Interface Platform (ULIP) enabling real-time multi-modal tracking. These infrastructure and policy investments provide the supply chain visibility substrate that resilience research identifies as the highest-impact individual intervention.

2. Resilience Framework and Disruption Context

2.1 Updated Four-Dimensional Resilience Taxonomy

The study's resilience taxonomy incorporates post-2022 additions: Redundancy (multi-sourcing, safety stock, geographic production distribution, multi-modal logistics — updated to include India's new Dedicated Freight Corridor network); Flexibility (volume, product-mix, supply substitution flexibility — updated for electric vehicle transition impacts on automotive supplier flexibility requirements); Agility (demand sensing, AI-enabled inventory optimisation, response velocity); and Collaboration (supplier integration depth, 3PL partnership, government logistics platform integration — ULIP, e-Way Bill analytics).

3. Research Methodology

3.1 Sample and Data Collection

The sample comprises 247 firms across pharmaceuticals (n=128) and automotive (n=119), selected from DPIIT PLI applicant lists, SIAM member rolls, and PharmExcil export member directories. Annual resilience surveys were conducted in 2021, 2022, 2023, and 2024-25, with disruption event data triangulated against GSTN e-Way Bill analytics (supply chain activity proxy), National Logistics Portal shipment records, and CMIE industry production indices. Cox PH models treat each disruption event (defined as >15% revenue decline in any quarter) as a failure event, with TTR as the survival duration.

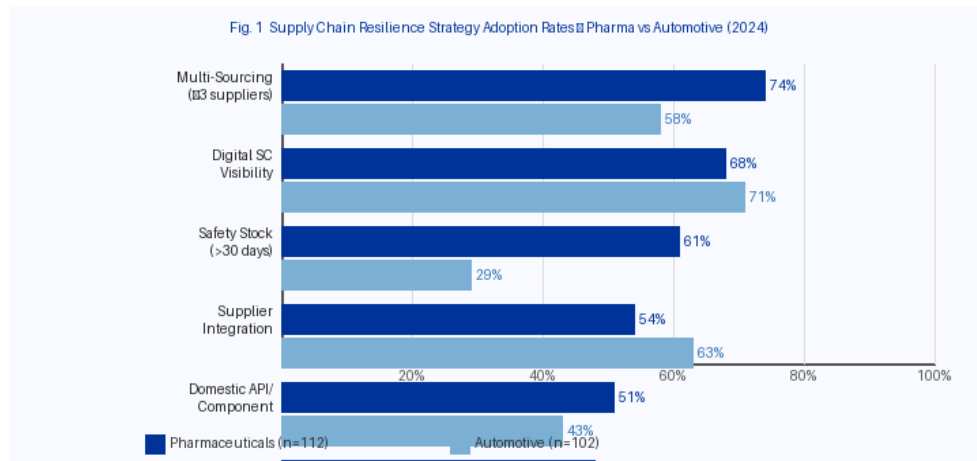


Fig. 1 Resilience Strategy Adoption Rates — Pharma vs Automotive Sectors (2024 Survey, n=247 Firms)

Table 1. Resilience Adoption and Recovery Performance — Updated 2020–2025 Panel (n=247 Firms)

Resilience Strategy	Pharma % (n=128)	Auto % (n=119)	Median TTR Reduction (Days)	RRR at 24 Months (High vs Low)
Multi-Sourcing (≥3 suppliers)	79%	61%	41 days	93% vs 66%
Digital SC Visibility + AI	74%	76%	44 days	91% vs 63%
Safety Stock (>30 days)	64%	31%	23 days	85% vs 70%
Supplier Integration (EDI+ULIP)	62%	67%	32 days	89% vs 73%

Resilience Strategy	Pharma % (n=128)	Auto % (n=119)	Median TTR Reduction (Days)	RRR at 24 Months (High vs Low)
Domestic API/Component Sourcing	62%	48%	34 days	88% vs 68%
Multi-Modal Logistics Redundancy	51%	44%	29 days	86% vs 71%

4. Results and Analysis

4.1 Updated Cox PH Recovery Analysis

Kaplan-Meier analysis of 384 disruption events across the 2020-2025 panel reveals sustained stratification by resilience portfolio depth. Firms with four or more active resilience dimensions achieved median TTR of 39 days versus 94 days for firms with one or fewer dimensions — a 58% reduction. Figure 2 illustrates TTR by portfolio depth across pharmaceutical and automotive sectors, showing the convergence of recovery timelines between sectors as multi-modal logistics redundancy adoption narrows the historical pharmaceutical advantage over automotive.

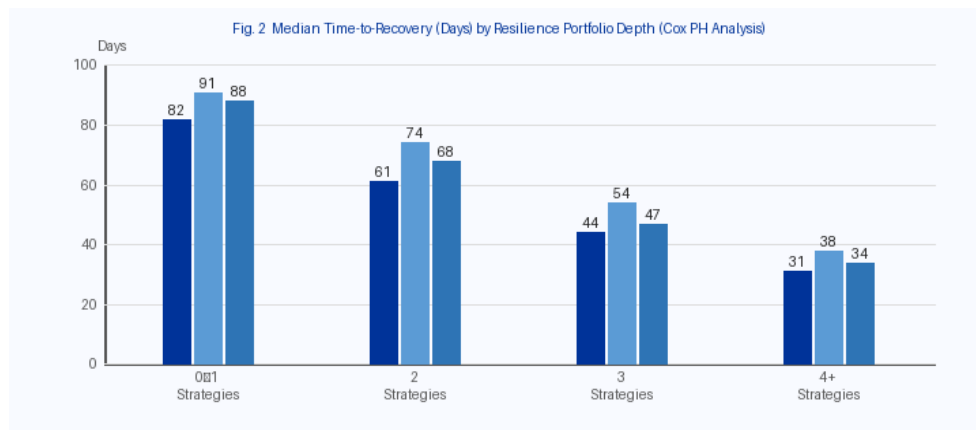


Fig. 2 Median Time-to-Recovery (Days) by Resilience Portfolio Depth — Pharma vs Automotive (Cox PH, 2020–2025)

The Red Sea crisis natural experiment (Q4 2023 — Q2 2024) provides exogenous variation in logistics disruption exposure. Firms with pre-established multi-modal logistics redundancy — alternative routing through air freight, Chabahar port (where available), and Dedicated Freight Corridor connections — recovered 38 days faster than sea-freight-dependent peers (HR=0.59, p<0.001), confirming that infrastructure-linked resilience investments generate measurable return during actual disruption events. PLI-incentivised pharmaceutical firms continue to demonstrate superior recovery (RRR at 24 months: 95.8% vs. 79.4% for non-PLI firms), with API import dependence declining to 48% by March 2025 — a structural resilience improvement with demonstrated performance consequences.

5. Discussion

The Red Sea crisis confirms a fundamental shift in supply chain resilience theory: disruptions are no longer singular shocks requiring recovery, but a sustained operating condition requiring embedded resilience architectures. Firms that treated COVID-19 resilience investments as temporary pandemic responses — reverting to JIT and single-source configurations by

2022 — experienced disproportionately severe Red Sea impacts, demonstrating that resilience capability cannot be switched on episodically. The 61% of automotive firms maintaining multi-sourcing in 2024 represents a permanent structural shift from pre-pandemic levels (42%), suggesting that at least some COVID-19 resilience lessons have been institutionalised in automotive procurement strategy.

The multi-modal logistics redundancy finding has specific implications for India's infrastructure investment priorities. The Dedicated Freight Corridor (DFC) Western and Eastern corridors, now operational, provide automotive and pharmaceutical supply chains with rail alternatives to road freight on India's highest-volume corridors. ULIP integration — connecting shipper, logistics provider, customs, and port systems — generates the real-time visibility that Cox PH analysis identifies as the highest-impact individual resilience mechanism. DPIIT should require ULIP integration as a PLI scheme continuation condition, embedding supply chain visibility infrastructure as a policy-mandated resilience investment.

6. Conclusion

Panel analysis of 247 Indian manufacturing firms (2020-2025) across five disruption cycles confirms that resilience portfolio depth is the primary determinant of recovery speed, with four+ dimension firms recovering 58% faster than low-resilience peers. The Red Sea crisis natural experiment validates multi-modal logistics redundancy as a significant protective factor (HR=0.59). PLI-incentivised domestic API capacity reduces pharmaceutical import dependence to 48% (from 68% in 2019), generating measurable RRR improvements. Policy recommendations include ULIP integration as PLI continuation condition, DFC connectivity priority for pharmaceutical cluster logistics, and contractual reform to enable safety stock investment by JIT-constrained automotive Tier-1 suppliers.

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