Resilience for Whom? A Tier Exposure Constraint for Supply Chain Network Design under Cascading Disruption

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Abstract

Supply chain resilience is normally measured on a throughput variable of the focal firm or the aggregate network. We show that such measures are systematically biased in networks with steep inter-tier power asymmetry, because the cheapest available adjustment channel is the one they cannot observe. We formalise a downstream cost cascade in which unabsorbed disruption cost is transferred along supplier tiers, give its closed form through a Neumann series on a transfer matrix, and define a tier exposure ratio R as the ratio of unabsorbed cost per unit of revenue at the lower tier to the same quantity at the focal tier. We prove that focal-tier time to recovery is non-increasing in the transfer share while R is strictly increasing in it, so measured resilience improves exactly as lower-tier fragility worsens. We then embed R in a two-stage stochastic network design model as a design-stage constraint, with the conventional cost-minimising design nested as a special case. Evidence from India across four cascading disruptions between 2018 and 2024 shows large and stable tier divergence: four to six months to recovery at the focal tier against ten to fourteen below it, and formal trade finance access of approximately 89 against 41 per cent. A computational study prices the constraint: R falls from 4.43 to 1.00 for 0.09 per cent of expected total network cost, and closing the workforce adjustment channel moves the cost-minimising transfer share from 0.605 to 0.040.

Keywords

Supply chain resilience, network design, stochastic programming, cascading disruption, multi-tier supply networks, tier exposure, emerging markets.