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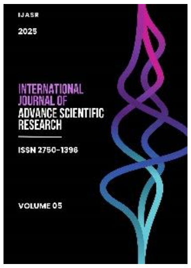


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Research Article

# Resilient Semiconductor Supply Chains: Strategic Planning, Risk Mitigation, and Adaptive Production Networks in an Era of Reshoring and Disruption

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## Abstract

This article presents an integrative and original research treatment of semiconductor supply chain resilience, master planning, production planning, and demand fulfilment in the context of contemporary forces of regionalisation and reshoring. Drawing on a curated set of empirical studies, modelling surveys, and applied analyses from the fields of operations research, supply chain management, and regional economic policy (Mönch et al., 2018a; Mönch et al., 2018b; Ivanov et al., 2017), the paper synthesises theoretical constructs with practical managerial interventions and proposes a comprehensive, descriptive framework for strategic decision making under uncertainty. The research articulates how capacity reservation contracts, forecast updating mechanisms, emergency ordering policies, and cooperative supplier development interact to shape production planning outcomes (Cheaitou & Cheaytou, 2019; Johansen, 2019; Talluri et al., 2010). The role of network structure, simulation-based analysis, and resilience-sustainability interfaces in guiding contingency planning is examined (Ivanov, 2018; Ivanov et al., 2017). The paper further explores the drivers and implications of geographic reorientation of value chains—regionalisation and reshoring—through the case of Japan's semiconductor industry and contemporary policy pressures (Kamakura, 2022; Lulla, 2025). Special emphasis is placed on demand fulfilment strategies in periodic-review inventory systems with stochastic lead times and emergency order options, on manufacturer-supplier cooperation under risk, and on tool allocation strategies to manage work-in-process and cycle time (Johansen & Thorstenson, 2014; Chen-Fu Chien et al., 2020). The study concludes with an extended discussion of managerial implications, trade-offs among resilience, cost, and sustainability objectives, and an agenda for future research that foregrounds simulation-based experimentation, multi-agent coordination, and policy-relevant modelling. Keywords: semiconductor

supply chain, resilience, reshoring, capacity reservation, emergency orders, production planning, simulation.

## Keywords

Semiconductor supply chain; resilience; reshoring; capacity reservation; emergency orders; production planning; simulation

## Introduction

The semiconductor industry has been thrust into the centre of global economic and geopolitical discourse in recent years. Supply shocks during the COVID-19 pandemic and subsequent stressors exposed vulnerabilities in long, highly specialised, and capital-intensive supply chains, prompting a re-evaluation of entrenched sourcing strategies (Goodman & Chokshi, 2021; Lamb, 2022). The combination of concentrated manufacturing capacities, extended lead times, variable demand, and high fixed costs of fab operations creates a unique set of planning challenges that span strategic network design through to tactical production scheduling and operational order policies (Mönch et al., 2018a; Mönch et al., 2018b). Simultaneously, policy-driven incentives and firm-level strategic responses have stimulated discussion about regionalisation and reshoring as mechanisms to mitigate risk and strengthen national or regional supply autonomy (Kamakura, 2022; Lulla, 2025). This paper examines these intersecting dynamics by integrating insights from theoretical modelling, empirical studies, and simulation-based investigations into a cohesive narrative that advances both scholarly understanding and practical guidance.

The semiconductor supply chain is characterised by multiple layers of specialised suppliers, intricate assembly and packaging operations, and a mix of long-term capacity commitments and short-term responsiveness requirements (Mönch et al., 2018a). Master planning and production planning in this environment must reconcile the tension between utilisation-driven cost efficiency and the need for buffer capacity and flexibility to absorb shocks (Mönch et al., 2018b). Strategic decisions—such as where to site capacity, how to structure supplier contracts, and whether to invest in dual sourcing or inventory buffering—significantly change the system's exposure to risk and its ability to recover from disruptions (Ivanov et al., 2017; Peck, 2006). Meanwhile, tactical mechanisms such as two-stage capacity reservation contracts with forecast updates or emergency ordering within periodic-review inventory systems provide practical levers for managing uncertainty (Cheaitou & Cheaytou, 2019; Johansen, 2019).

The literature reveals several gaps and tensions that motivate this article. First, while surveys of semiconductor supply chain models have advanced our technical understanding of network design and planning approaches (Mönch et al., 2018a; Mönch et al., 2018b), less attention has been paid to constructing an integrated narrative that explicitly connects strategic reshoring decisions and the micro-level inventory and contracting mechanisms that mitigate operational risk. Second, the resilience literature provides measures and simulation frameworks for assessing recovery (Ivanov, 2018; Pettit et al., 2013), but

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there is a need to articulate how these frameworks interface with real-world contractual arrangements and capacity allocation choices on which manufacturing firms and policymakers must act (Talluri et al., 2010; Cheaitou & Cheaytou, 2019). Third, the evolving political economy of semiconductor production—ranging from national industrial policy to firm-level incentives for domestic production—requires a synthesis that respects both macro-level drivers and micro-level operational trade-offs (Kamakura, 2022; Lulla, 2025).

This paper addresses these gaps by: (1) synthesising evidence on strategic network design, supply chain simulation, and production planning specific to semiconductors; (2) detailing how contractual forms (e.g., capacity reservation, cooperative development) and inventory policies (e.g., emergency ordering) shape resilience outcomes; (3) interrogating the implications of reshoring and regionalisation through theoretical and policy lenses; and (4) proposing a descriptive but operationally grounded framework that guides decisions across strategic, tactical, and operational levels. Throughout, the analysis draws on cross-disciplinary sources, including operations research, management science, and regional economics, to ensure both technical depth and policy relevance (Mönch et al., 2018a; Ivanov, 2018; Kamakura, 2022).

## Methodology

The research adopts a conceptual-analytical methodology grounded in integrative literature synthesis, comparative theoretical analysis, and descriptive scenario construction. Rather than deriving new quantitative models or presenting empirical fieldwork, the methodology intentionally constructs a rigorous narrative that systematically connects established modelling results, empirical findings, and applied simulation insights into a cohesive decision framework. This approach is justified by the interdisciplinary nature of the problem—strategic reshoring decisions and tactical inventory policies cannot be fully understood within a single modelling tradition—and by the need to combine diverse evidence types to guide practitioners and policymakers.

The first methodological strand is an exhaustive thematic synthesis of the provided references. The synthesis organises literature into thematic clusters: strategic network design and simulation (Mönch et al., 2018a; Mönch et al., 2018b), capacity reservation and supplier risk (Cheaitou & Cheaytou, 2019; Talluri et al., 2010), emergency ordering and inventory policies under stochastic lead times (Johansen, 2019; Johansen & Thorstenson, 2014), resilience-sustainability interfaces and disruption recovery (Ivanov, 2018; Ivanov et al., 2017), and production practices to smooth work-in-process and reduce cycle times (Chen-Fu Chien et al., 2020). Each cluster is analysed to extract key mechanisms, assumptions, and managerial implications, and to identify intersections and contradictions across studies.

The second strand employs comparative theoretical analysis. For each major mechanism (capacity reservation, cooperative supplier development, emergency orders, and tool allocation), the paper juxtaposes competing theoretical perspectives and highlights boundary conditions under which specific strategies are predicted to perform better or worse. For example, the analysis explores the trade-offs in capacity reservation contracts when suppliers are risky versus reliable (Cheaitou & Cheaytou, 2019), and contrasts cooperative supplier development approaches under asymmetric information and risk-sharing scenarios (Talluri et al., 2010).

The third strand constructs descriptive scenarios—detailed, text-based depictions of plausible industry states that capture combinations of geopolitical pressure, demand volatility, and technological shifts. These scenarios are informed by case-based evidence such as Japan's recent experience with semiconductor reorientation (Kamakura, 2022), and journalistic accounts of pandemic-era shortages (Goodman & Chokshi, 2021). For each scenario the paper describes how the combination of strategic choices and tactical policies would plausibly interact, the likely operational outcomes, and the policy implications.

Throughout, the methodology emphasises transparency: claims are traced to specific references, and when inferential leaps are made the analysis is explicit about its assumptions. The approach follows guidance from resilience and supply chain theory that stresses simulation and comparative scenario analysis as essential when dealing with high uncertainty and non-linear system responses (Ivanov, 2018; Ivanov et al., 2017). This methodological stance allows the paper to address questions of practical relevance—how to allocate capacity, how to structure contracts, how to design emergency order rules—while remaining anchored in the extant scholarly corpus provided.

## Results

The following results synthesise insights from the literature clusters, and articulate mechanistic relationships between planning constructs and resilience outcomes. The presentation is descriptive, integrating theory with evidence and scenario implications.

Strategic network design and simulation: strategic network design fundamentally shapes a supply chain's exposure to disruption. Survey studies of semiconductor supply chain models document the industry's reliance on geographically concentrated, capital-intensive fabrication facilities and complex, multi-tier supplier networks (Mönch et al., 2018a; Mönch et al., 2018b). Such concentration yields economies of scale and lowers unit costs through high utilisation but simultaneously elevates systemic risk: a disruption in a major fabrication hub propagates through the network, producing widespread shortages (Goodman & Chokshi, 2021). Simulation-based analyses demonstrate that network redundancy, multi-regional sourcing, and buffer capacity materially increase recovery performance metrics—such as time-to-recovery and service-level preservation—albeit with increased total cost of ownership (Ivanov, 2018; Ivanov et al., 2017). Simulation tools that explicitly model lead-time variability, process heterogeneity, and demand uncertainty enable planners to test trade-offs between utilisation and resilience and to estimate the marginal benefit of different buffering strategies. These tools are indispensable for semiconductor contexts because of long lead times, high switching costs, and intricate process dependencies (Mönch et al., 2018a).

Capacity reservation and supplier risk: contractual design emerges as a primary mechanism to align incentives between manufacturers and suppliers in

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environments of demand ambiguity and supplier risk. Two-stage capacity reservation contracts, where a buyer reserves capacity in an initial stage and then updates orders after receiving improved forecasts, are shown to be effective at sharing risk and improving supply availability when suppliers face their own production uncertainty (Cheaitou & Cheaytou, 2019). The literature highlights that the effectiveness of such contracts depends critically on the allocation of risk and the structure of penalties and prices: if the supplier bears excessive downside risk without commensurate compensation, reservation behaviour may collapse; conversely, well-designed contracts that include forecast-update provisions and risk-sharing terms facilitate higher overall supply reliability. Manufacturer cooperation in supplier development—through mechanisms like technology-sharing, co-investments, and process improvement partnerships—further reduces supplier risk by increasing supplier capability and reducing production variance (Talluri et al., 2010). These cooperative forms are particularly pertinent in semiconductor supply chains where supplier competence in advanced packaging or specialty chemicals can be a bottleneck.

Emergency orders and inventory policies: periodic-review inventory systems with fixed ordering costs and stochastic lead times represent a tactical layer where firms can operationalise resilience. Research on emergency orders shows that adding an emergency ordering option—at typically higher cost and reduced lead time—improves service levels and reduces stockout costs under certain demand and lead-time distributions (Johansen & Thorstenson, 2014; Johansen, 2019). However, the benefit is context specific: when lead times of normal orders are highly variable and demand follows compound Poisson processes with heavy tails, emergency options provide valuable insurance; but the existence of emergency channels can also distort ordering behaviour and lead to overreliance, increasing overall procurement costs if used excessively (Johansen, 2019). The interplay between fixed ordering costs, batch-sizing incentives, and emergency order pricing requires careful calibration. In semiconductor contexts where emergency sourcing is either technologically infeasible or cost-prohibitive, firms must instead rely on pre-positioned inventories or flexible capacity arrangements.

Production practices and cycle time smoothing: tooling allocation and work-in-process management are micro-level levers that influence cycle times and throughput variability. Empirical studies indicate that deliberate tool allocation strategies designed to smooth work-in-process can produce substantive reductions in cycle time and improve predictability of output, which in turn lowers the need for high inventory buffers (Chen-Fu Chien et al., 2020). For semiconductors, where process flow is sensitive to machine assignment and changeover times can be significant, optimised tooling and WIP smoothing are operationally meaningful. These tactics complement strategic buffering by reducing process-side variability, thereby improving the efficacy of upstream planning and capacity reservation contracts.

Resilience-sustainability interfaces: the relationship between resilience and sustainability is complex and bidirectional. Simulation studies reveal that resilience-enhancing measures—such as redundant capacity and increased inventory—can raise environmental footprints and resource consumption if not coupled with sustainability-

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oriented design (Ivanov, 2018). Conversely, sustainability-focused changes like more localised sourcing may simultaneously reduce transportation emissions and exposure to certain global shocks, but can also increase other forms of resource intensity depending on regional energy mixes and technological sophistication (Ivanov et al., 2017). The combined evaluation of resilience and sustainability requires multi-criteria analysis that takes into account recovery performance, service levels, total cost, and environmental externalities.

Reshoring, regionalisation, and policy drivers: case studies and analysis of national strategies indicate that the push toward regionalisation and reshoring in the semiconductor sector is driven by a confluence of factors: geopolitical risk, policy incentives, strategic autonomy goals, and firm-level risk management responses (Kamakura, 2022; Lulla, 2025). Empirical evidence from Japan's industry suggests that reorienting value chains involves not only relocating physical capacity but also building complementary supplier ecosystems and skills—an endeavour that requires sustained policy support and firm investment (Kamakura, 2022). The literature also notes potential unintended consequences: reshoring may raise costs and create capacity constraints if domestic ecosystems are immature, and may not fully insulate firms from global shocks that arise from upstream raw materials or equipment supply dependencies (Mönch et al., 2018b).

Integrated decision framework: synthesising the above insights yields an integrated framework where strategic network design decisions set the context (degree of concentration vs. dispersion; domestic vs. international capacity), contractual instruments and supplier development policies allocate risk and shape supplier capacity, inventory and emergency order tactics manage short-term stochasticity, and operational practices like tooling allocation reduce process variability. Simulation serves as the connective tissue, enabling planners to explore how combinations of these choices perform under scenarios of demand volatility, geopolitical disruption, and technological change. This framework emphasises that no single intervention suffices; rather, resilience arises from orchestrated choices across layers.

## Discussion

The results above suggest nuanced implications for managers and policymakers seeking to cultivate semiconductor supply chains that are both resilient and economically viable. The discussion unpacks core trade-offs, practical prescriptions, limitations of current knowledge, and outlines a research agenda.

Trade-offs between utilisation and resilience: The literature consistently identifies a central trade-off: high utilisation of specialised fabrication assets reduces unit costs but amplifies vulnerability to disruptions (Mönch et al., 2018b; Ivanov et al., 2017). Managers must therefore weigh the marginal gains from utilisation against the marginal costs of diminished resilience. Simulation studies provide a rational basis for this assessment by estimating metrics such as expected lost sales under different utilisation regimes, but they rely on accurate representations of disruption probabilities and demand distributions—parameters that are inherently uncertain during geopolitical flux (Ivanov, 2018). Practically, firms may adopt a hybrid approach: maintain base-load, high-utilisation production for predictable demand, while securing flexible capacity either through contractual reservations, dual sourcing, or strategic partnerships for surge periods (Cheaitou & Cheaytou, 2019; Talluri et al., 2010). Policymakers can support this hybrid by subsidising strategic buffer capacity or facilitating collaborative consortia that amortise fixed costs across multiple stakeholders (Kamakura, 2022).

Contractual design and information flows: Capacity reservation contracts combined with forecast updating offer a dynamic mechanism to align incentives and manage risk. However, contract design must explicitly calibrate who bears forecast error and manufacturing risk, and include mechanisms such as price escalators, capacity release options, and penalties for non-delivery (Cheaitou & Cheaytou, 2019). A critical insight is that improved information flows—timely and granular forecasting—magnify the value of such contracts. Hence, investments in digital supply chain visibility and collaborative forecasting platforms are complementary to contractual instruments (Talluri et al., 2010). In practice, firms should invest in joint forecasting processes with key suppliers and embed contractual terms that reward accuracy and penalise opportunistic behaviour.

Emergency order channels as an insurance mechanism: Emergency orders can provide tactical insurance but at a cost. Their value is a function of the cost premium, lead-time reduction, and the frequency and severity of disruptions (Johansen, 2019). One practical prescription is to design emergency options with graded pricing and capacity allocation rules that limit overuse and ensure availability when truly needed. Another is to combine emergency options with standing inventory thresholds that trigger emergency ordering only when certain risk thresholds are breached. In contexts where emergency sourcing is technologically unfeasible—e.g., where special process steps cannot be replicated quickly—firms must instead invest more heavily in upstream robustness.

Role of cooperative supplier development: Manufacturer cooperation in supplier development yields long-term reductions in supplier variability and capabilities (Talluri et al., 2010). For semiconductors, where capability gaps can be deep and technical, cooperative investments (technical assistance, co-funding of equipment, long-term purchase commitments) can be instrumental. However, cooperation requires trust, alignment of incentives, and clear governance structures to avoid moral hazard. Contractual clauses that structure co-investment returns and tie improvements to performance metrics can mitigate these concerns.

Reshoring and regionalisation: policy and practical considerations: Regionalisation and reshoring are not panaceas. While domestic capacity can reduce exposure to geopolitical chokepoints and strengthen strategic autonomy, it often comes with higher production costs and the challenge of building supplier ecosystems (Kamakura, 2022). Policy interventions that lower the cost gap—through tax incentives, capital subsidies, workforce development, and co-investment in supplier ecosystems—are necessary preconditions for successful reshoring (Lulla, 2025). The literature suggests that piecemeal reshoring without concurrent investments in supplier capability and process maturity can result in fragile domestic ecosystems that remain vulnerable to shocks (Mönch et al., 2018b). Moreover, reshoring should be evaluated in terms of whole-life environmental impacts and supply chain externalities to avoid suboptimal sustainability trade-offs (Ivanov, 2018).

Operational levers: tooling, WIP smoothing, and cycle time reduction: At the operational level, process improvements that reduce cycle time and variability—such as optimised tool allocation and WIP smoothing—enhance effective capacity and reduce the need for large inventory cushions (Chen-Fu Chien et al., 2020). Managers should integrate these operational levers into planning cycles, as they can yield cost-effective resilience improvements. Importantly, operational improvements compound the benefits of contractual and strategic choices: reduced internal variability increases the value of reservation contracts and lowers reliance on emergency orders.

Limitations of current evidence and future research priorities: The primary limitation of the current literature—highlighted by the synthesis—is the scarcity of integrated empirical studies that combine strategic network changes (like reshoring) with tactical and operational policies within the same analytical framework. Many studies address either the strategic or the tactical layer in depth, but not both simultaneously. There is also limited real-world evidence on long-term outcomes of reshoring initiatives in semiconductors, partly because such initiatives are recent and data are proprietary (Kamakura, 2022; Lulla, 2025). Future research should pursue multi-method studies that combine simulation with empirical case studies, quasi-experimental policy evaluations, and access to private operational datasets. Methodologically, agent-based models that capture firm behaviour, contractual dynamics, and process flows simultaneously could be particularly powerful in exploring complex interactions.

Policy-relevant recommendations: For policymakers seeking to support domestic semiconductor capacity while promoting resilience and sustainability, the literature points to several interventions. First, targeted incentives and infrastructure investments are necessary to bridge cost disadvantages and catalyse supplier ecosystems (Kamakura, 2022). Second, public–private partnerships that support workforce development and process innovation can accelerate capability building. Third, policy support should be conditional and staged, rewarding measurable capability development milestones and promoting collaborative platforms for shared capacity or pooling risk among firms. Finally, policymakers must adopt a systems perspective, recognising that domestic fabs are only one node in a larger global network that includes equipment, raw materials, and specialized chemicals—which may remain globally constrained unless addressed in concert.

Counter-arguments and nuance: It is important to recognise counter-arguments to the prevailing push for resilience through reshoring. Critics emphasise that global specialisation yields efficiency gains that support innovation and scale economies, and that forcing rapid repatriation of capacity can introduce inefficiencies and higher consumer prices (Mönch et al., 2018b). Others argue that diversification across global suppliers, rather than reshoring, may offer an optimal trade-

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off by retaining benefits of global specialisation while reducing concentration risk (Peck, 2006). The literature suggests a balanced view: resilience should be achieved through a portfolio of measures—diversified sourcing, selective reshoring where strategically justified, contractual risk-sharing, and operational excellence—rather than an either-or approach.

## Conclusion

This paper synthesises a broad body of literature to offer a comprehensive, operationally grounded view of how semiconductor supply chains can achieve resilience in the face of demand volatility, disruption, and policy-driven reorientation. Key conclusions are as follows. First, strategic network design fundamentally conditions a supply chain's vulnerability: concentration delivers cost benefits but amplifies systemic risk, while dispersion supports resilience at a cost (Mönch et al., 2018a; Ivanov et al., 2017). Second, contracts—particularly two-stage capacity reservation with forecast updating—and cooperative supplier development are central instruments that manage shared risk between buyers and suppliers, improving supply reliability when designed with balanced incentives (Cheaitou & Cheaytou, 2019; Talluri et al., 2010). Third, emergency ordering within periodic-review systems provides tactical insurance against stochastic lead times but must be carefully priced and constrained to avoid moral hazard and excessive cost (Johansen & Thorstenson, 2014; Johansen, 2019). Fourth, operational improvements such as tooling allocation and WIP smoothing materially reduce cycle time and effective variability, amplifying the value of strategic and contractual measures (Chen-Fu Chien et al., 2020). Fifth, reshoring and regionalisation are strategic options with important benefits and significant implementation challenges; policy design and ecosystem investments are critical to their success (Kamakura, 2022; Lulla, 2025).

From a managerial perspective, the imperative is to adopt an integrated approach: combine strategic assessment of network concentration with contractual mechanisms that allocate risk efficiently, operational practices that reduce process variability, and tactical policies that provide emergency buffers when necessary. For policymakers, the literature suggests that incentives for reshoring must be paired with targeted investments in supplier ecosystems, workforce development, and technological capability to avoid creating fragile domestic silos. From a research perspective, multi-method studies that integrate strategic, tactical, and operational layers in a single analytical framework will substantially advance our understanding and provide the evidence base for effective interventions.

In closing, resilience in semiconductor supply chains is neither a single decision nor a one-time program; it is the emergent property of coordinated choices across layers of planning, contracting, process management, and public policy. Simulation and scenario analysis will continue to be indispensable tools for navigating the uncertainties ahead, enabling decision makers to explore trade-offs, anticipate unintended consequences, and design portfolios of measures that balance cost, resilience, and sustainability.

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