



A Game-Theoretic Framework for AI-Enabled Supply Chain Resilience Under Disruption Risk

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Abstract: Global supply chains are increasingly exposed to disruptions caused by geopolitical tensions, pandemics, cyber threats, climate events, and regulatory uncertainty. While traditional supply chain strategies have emphasized cost efficiency and lean operations, recent crises have highlighted the need for resilience—the capacity to anticipate, absorb, respond to, and recover from disruptions. At the same time, Artificial Intelligence (AI) has enhanced forecasting, visibility, and real-time decision support through machine learning, predictive analytics, and digital twins. However, the impact of AI depends not only on technical capability but also on how supply chain partners respond strategically to AI-generated information.

This paper develops a conceptual framework that integrates AI, John Nash's game theory, and supply chain resilience. Suppliers and manufacturers are modeled as rational actors choosing between cooperation (information sharing and joint risk mitigation) and non-cooperation (independent decision-making). The framework proposes that AI reduces information asymmetry, improves transparency, and reshapes payoff structures, making cooperative equilibria more attractive and stable. These equilibria enhance preparedness, response speed, recovery effectiveness, and organizational learning.

The study contributes by linking digital intelligence, strategic behavior, and resilience in a unified theoretical model. It also offers practical guidance for managers seeking to use AI as a strategic coordination mechanism rather than merely an operational tool. The framework provides a foundation for future empirical, simulation-based, and analytical research on resilient and intelligent supply networks.

Keywords Artificial Intelligence; Game Theory; Supply Chain Resilience; Disruption Risk; Strategic Decision-Making; Information Asymmetry; Nash Equilibrium; Collaborative Supply Chains

I. INTRODUCTION:

Global supply chains have evolved into highly interconnected networks involving suppliers, manufacturers, logistics providers, and retailers operating across multiple regions. This interconnectedness has improved efficiency and reduced costs, but it has also increased exposure to systemic risks such as pandemics, geopolitical conflicts, cyberattacks, and climate-related disruptions. Recent events, including COVID-19 and semiconductor shortages, have demonstrated how local disturbances can rapidly propagate across global networks.

Traditional supply chain strategies focused on efficiency through lean inventories, just-in-time replenishment, and supplier consolidation. Although effective under stable conditions, these approaches often reduce redundancy and flexibility. As a result, supply chain resilience has become a strategic priority. Martin Christopher and Helen Peck define resilience as the capability to anticipate disruptions, absorb shocks, adapt to changing conditions, and recover while maintaining continuity of operations.

In parallel, AI has emerged as a transformative force in supply chain management. Technologies such as machine learning, natural language processing, optimization algorithms, and digital twins improve demand forecasting, supplier risk assessment, route optimization, and real-time decision support. Dmitry Ivanov emphasizes that these capabilities strengthen visibility and adaptability in uncertain environments.

However, technology alone does not guarantee resilience. Supply chains consist of legally independent firms with different objectives, varying levels of trust, and unequal access to information. Suppliers may hesitate to share sensitive data, and manufacturers may avoid joint investments if they fear opportunistic behavior. Thus, resilience depends not only on technological capability but also on the strategic incentives that shape collaboration.

Game theory offers a rigorous framework for analyzing such interdependent decisions. Building on John Nash's equilibrium concept, firms are viewed as rational actors whose choices depend on expectations about others' behavior. Cooperation emerges only when it is strategically advantageous.

This study addresses a key theoretical gap by integrating AI, game theory, and supply chain resilience. The central argument is that AI reduces uncertainty and information asymmetry, alters payoff structures, and increases the likelihood of cooperative equilibria. These equilibria, in turn, enhance resilience by improving preparedness, coordination, recovery, and adaptive learning.

The paper contributes by:

1. Integrating AI, game theory, and resilience into a unified conceptual framework.
2. Explaining how AI reshapes strategic incentives and equilibrium outcomes.
3. Offering managerial insights on using AI to strengthen trust and coordination across supply networks.

2. Literature Review

2.1 Artificial Intelligence in Supply Chain Management

Artificial Intelligence (AI) has become a foundational capability in modern supply chain management, enabling organizations to process large volumes of structured and unstructured data and convert them into actionable insights. AI encompasses technologies such as machine learning, deep learning, natural language processing, computer vision, and optimization algorithms. In practice, these tools support demand forecasting, inventory planning, supplier risk monitoring, transportation optimization, predictive maintenance, and autonomous decision-making. Hokey Min highlighted the early potential of intelligent systems in logistics, while recent studies show that AI also strengthens resilience by improving adaptability and responsiveness under uncertainty.

The strategic value of AI lies in its ability to detect weak signals of disruption before they escalate into operational crises. By integrating data from enterprise systems, supplier networks, market indicators, weather feeds, and geopolitical sources, AI enhances situational awareness and improves the quality and speed of managerial decisions. Dmitry Ivanov argues that such predictive capabilities are central to resilient and viable supply chains because they support faster sensing, response, and adaptation.

Despite these benefits, AI adoption presents organizational and relational challenges. Effective implementation requires data quality, interoperable systems, skilled personnel, and trust among supply chain partners. AI-generated insights may be underutilized if firms question their reliability or if incentives discourage information sharing. Therefore, the impact of AI depends on both technological sophistication and the governance structures that shape collaboration.

2.2 Game Theory and Strategic Interaction in Supply Chains

Game theory provides a powerful framework for analyzing decisions in which outcomes depend on the actions of multiple interdependent actors. In supply chains, firms routinely choose whether to share information, coordinate investments, and collaborate in disruption mitigation. These decisions involve strategic considerations because each firm's payoff depends not only on its own actions but also on the actions of its partners.

The concept of Nash equilibrium, developed by John Nash, describes a stable outcome in which no player can improve its position through unilateral deviation. This concept is highly relevant to supply chain relationships, where firms may converge on either collaborative or defensive strategies depending on incentives and perceptions of uncertainty. Gérard Cachon and Serguei Netessine demonstrated how game theory can explain contract design, pricing, inventory coordination, and risk-sharing decisions.

4. Under uncertainty, firms may adopt non-cooperative strategies even when collaboration would yield higher collective benefits. This dynamic resembles the Prisoner's Dilemma, where rational self-interest leads to collectively inferior outcomes. Information asymmetry, mistrust, and fear of opportunism often reinforce such defensive behavior, limiting the effectiveness of joint risk management.

2.3 Supply Chain Resilience

Supply chain resilience refers to the ability of a supply network to anticipate, absorb, respond to, and recover from disruptions while maintaining continuity and long-term competitiveness. Foundational work by Martin Christopher and Helen Peck emphasized flexibility, redundancy, visibility, and collaboration as core dimensions of resilience. Susan Ponomarov and Mary Holcomb later highlighted adaptive capacity and organizational learning as essential elements.

Recent scholarship has extended resilience to the broader concept of viability. Dmitry Ivanov and Alexandre Dolgui define viability as the ability of supply networks to survive and evolve through structural adaptation and strategic transformation. In this view, resilience is not merely about recovery; it is an ongoing process of sensing, reconfiguration, and innovation.

Collaboration is central to resilience because disruptions often require coordinated responses across multiple firms. Information sharing, joint planning, and aligned incentives enable faster detection, more efficient mitigation, and stronger recovery. However, such collaboration depends on trust and strategic alignment, both of which may be difficult to achieve in uncertain environments.

2.4 Integrating AI, Game Theory, and Resilience

Although the literatures on AI, game theory, and supply chain resilience have advanced significantly, they have largely developed in parallel. AI research has focused on algorithmic capabilities and operational performance. Game-theoretic studies have emphasized strategic incentives and coordination mechanisms. Resilience research has examined organizational capabilities such as flexibility, visibility, and collaboration.

Few studies explicitly explain how AI alters the information structure of strategic interactions and thereby changes equilibrium behavior. This gap is important because AI does more than automate decisions; it reshapes how firms perceive uncertainty, assess partner behavior, and evaluate the costs and benefits of cooperation. By reducing information asymmetry and improving predictive transparency, AI can make collaborative strategies more attractive and stable.

This study addresses that gap by proposing a unified framework linking AI capability, strategic interaction, and resilience outcomes. The framework explains how AI-enabled information advantages influence game-theoretic equilibria and how those equilibria strengthen the adaptive capacity of supply networks under disruption risk.

3. Theoretical Background

3.1 Foundations of Game Theory

Game theory examines situations in which the outcome for each participant depends on the actions of others. It is especially relevant in supply chains, where decisions about information sharing, capacity allocation, inventory positioning, and risk mitigation are inherently interdependent.

A game consists of four elements: players, strategies, information, and payoffs. Players are decision makers such as suppliers and manufacturers. Strategies are the alternative actions available to them. Information reflects what each player knows about the environment and about others' likely actions. Payoffs represent the expected costs and benefits associated with each combination of strategies.

The most influential solution concept is the Nash equilibrium, where each player's strategy is optimal given the strategies chosen by others. In supply chains, this concept helps explain why firms may settle into either cooperative or non-cooperative patterns depending on the structure of incentives and uncertainty.

3.2 Information Asymmetry and Strategic Behavior

Information asymmetry occurs when one party possesses more timely or accurate information than another. In supply chains, asymmetries may involve demand forecasts, inventory levels, production capacity, or disruption exposure.

From a game-theoretic perspective, information asymmetry increases uncertainty and reduces trust, often encouraging protective behavior. Firms may withhold information or avoid collaborative investments to minimize the risk of exploitation. Although individually rational, such choices frequently lead to collectively inferior outcomes.

3.3 Artificial Intelligence as an Information-Shaping Capability

AI can be viewed as an information-shaping capability that transforms the strategic environment. By processing large and diverse datasets, AI improves forecasting accuracy, detects emerging risks, and generates real-time insights. Examples include machine learning models that predict supplier delays, natural language processing systems that monitor geopolitical developments, and digital twins that simulate disruption scenarios.

These capabilities reduce uncertainty and enhance the credibility of shared information. Consequently, AI influences not only operational performance but also the expectations and beliefs that drive strategic interaction.

3.4 AI and Equilibrium Transformation

The core theoretical proposition of this study is that AI changes the informational structure of the game and thereby shifts equilibrium outcomes. In traditional environments with limited visibility, firms may perceive cooperation as risky because they cannot confidently predict whether partners will reciprocate.

When AI improves transparency and predictive reliability, the expected payoff from cooperation increases. Firms gain greater confidence in shared information, opportunistic behavior becomes easier to detect, and coordinated action becomes more attractive. Under these conditions, the equilibrium can shift from defensive behavior toward stable cooperation.

3.5 Linking Equilibrium Outcomes to Supply Chain Resilience

Supply chain resilience emerges when firms collectively develop the ability to anticipate disruptions, coordinate responses, and adapt over time. Cooperative equilibria support these capabilities by encouraging information exchange, joint planning, and shared investment in mitigation measures.

Non-cooperative equilibria, by contrast, often result in delayed responses, fragmented decision-making, and slower recovery. Accordingly, the relationship between AI and resilience is mediated by strategic interaction. AI enhances resilience indirectly by creating the informational and incentive conditions that make cooperation self-reinforcing.

4. Game-Theoretic Model

This section formalizes the central argument by modeling the interaction between two key supply chain actors: a supplier and a manufacturer. The purpose is to demonstrate how Artificial Intelligence changes incentives under disruption risk and increases the likelihood of collaborative behavior.

4.1 Players and Strategies

Two rational actors are considered:

- Supplier (S)
- Manufacturer (M)

Each actor chooses one of two strategies:

- **Cooperate (C):** share information, coordinate forecasts, and jointly manage disruption risks.
- **Defect (D):** withhold information and act independently to protect individual interests.

These choices reflect common supply chain decisions regarding transparency and coordination.

4.2 Payoffs in Traditional Supply Chains

Without AI, firms operate with limited visibility and high uncertainty. They may lack reliable information about demand, capacity, disruption probability, and partner behavior. In such conditions, cooperation appears risky because one party may exploit the openness of the other.

The strategic situation resembles the Prisoner's Dilemma. Although mutual cooperation would benefit both parties, fear of opportunism often leads to mutual defection. The resulting equilibrium is:

- **(D, D): Non-cooperative equilibrium**

This outcome is stable but inefficient, producing slower responses and weaker resilience.

4.3 Payoffs in AI-Enabled Supply Chains

When AI is introduced, firms gain better forecasting, real-time monitoring, and early warning capabilities. These tools reduce uncertainty and improve the reliability of shared information.

As a result:

- Cooperation becomes less risky.
- Opportunistic behavior is easier to detect.
- Joint planning generates higher expected returns.

AI therefore increases the relative payoff of collaboration.

4.4 Equilibrium Shift

By changing information quality and expectations, AI alters the structure of the game. The dominant equilibrium can shift from non-cooperation to cooperation:

- **Before AI:** (D, D)
- **After AI:** (C, C)

This shift illustrates that AI supports resilience indirectly by making cooperation strategically rational.

4.5 Repeated Interaction

Supply chains involve long-term relationships rather than one-time transactions. In repeated games, reputation and accountability become important.

AI strengthens repeated cooperation by:

- Monitoring performance continuously,
- Detecting deviations quickly,
- Supporting shared learning, and
- Increasing confidence in partner commitments.

These mechanisms help sustain cooperation over time.

4.6 Implications for Resilience

The equilibrium outcome directly affects resilience.

Under (D, D):

- Information remains fragmented,
- Responses are delayed,
- Recovery is slower.

Under (C, C):

- Risks are identified earlier,
- Mitigation actions are coordinated,
- Recovery is faster and more adaptive.

Thus, resilience improves when AI shifts the system toward stable collaboration.

4.7 Model Insight

The model demonstrates that AI does not create resilience by itself. Its primary role is to transform the informational environment, reshape incentives, and encourage cooperative equilibrium. Resilience emerges when this strategic shift enables supply chain partners to coordinate effectively under uncertainty.

5. Theoretical Propositions

The framework leads to five propositions that can be examined empirically.

Proposition 1: AI and Uncertainty Reduction

Higher levels of AI capability reduce operational and behavioral uncertainty by improving forecasting accuracy, visibility, and early disruption detection.

Proposition 2: Uncertainty Reduction and Cooperation

Lower uncertainty increases the likelihood that supply chain actors will engage in collaborative behavior such as information sharing and joint planning.

Proposition 3: Cooperation and Resilience

Collaborative strategic behavior enhances supply chain resilience by improving preparedness, coordination, and recovery performance.

Proposition 4: AI and Strategic Alignment

AI-enabled transparency strengthens strategic alignment among supply chain partners and improves disruption response capability.

Proposition 5: Mediating Role of Cooperative Equilibrium

The positive effect of AI on supply chain resilience is mediated by the extent to which supply chain actors achieve and sustain cooperative equilibrium.

6. Discussion

This study positions Artificial Intelligence as a strategic coordination mechanism rather than merely an operational technology. Its central contribution is to show that AI enhances supply chain resilience by transforming the informational and incentive structures that shape inter-organizational behavior.

6.1 AI as a Strategic Enabler

AI changes how firms interpret uncertainty and evaluate strategic choices. By providing timely and reliable insights, AI reduces ambiguity about market conditions, disruption risks, and partner behavior. This shift allows managers to base decisions on shared evidence rather than assumptions, making coordination more predictable and effective.

6.2 From Information Asymmetry to Shared Visibility

In traditional supply chains, each firm operates with partial and often inconsistent information. Suppliers understand capacity constraints, manufacturers monitor demand, and logistics providers track transportation risks. AI integrates these fragmented data sources and creates a more common view of the operating environment.

Greater visibility:

- Reduces information asymmetry,
- Improves mutual predictability,
- Strengthens confidence in shared decisions.

This common understanding supports more coordinated action during disruptions.

6.3 Why Cooperation Becomes Rational

Collaboration is often recommended as a best practice, but firms cooperate only when it serves their interests. Game Theory explains that cooperation emerges when the expected benefits outweigh the perceived risks.

AI changes this balance by:

- Lowering uncertainty,
- Increasing detection of opportunistic behavior,
- Improving alignment of forecasts and plans,
- Reducing coordination costs.

As a result, cooperation becomes the most advantageous strategic option rather than a purely normative ideal.

6.4 Resilience as an Emergent System Property

Supply chain resilience is not owned by any single organization. It arises from the quality of interaction among interconnected firms.

When cooperation is sustained, supply chains are better able to:

- Detect disruptions early,
- Coordinate mitigation efforts,
- Recover rapidly,
- Adapt and learn over time.

Resilience therefore emerges from stable strategic relationships rather than from isolated investments.

6.5 Trust in AI-Enabled Networks

Trust remains important, but AI supplements relational trust with data-driven assurance. Real-time monitoring, predictive analytics, and transparent reporting make partner actions more observable and verifiable.

This creates a form of evidence-based trust in which collaboration depends not only on past relationships but also on credible shared information.

6.6 Visibility Paradox

Increased transparency can reveal inefficiencies and power imbalances as well as opportunities for collaboration. Consequently, AI may either strengthen cooperation or increase caution, depending on governance structures and incentive alignment.

This finding underscores that AI is an enabling condition, not a guarantee of collaboration.

6.7 Theoretical Contribution

The study integrates three research domains:

- AI and digital supply chain transformation,
- Game-theoretic analysis of strategic interaction,
- Supply chain resilience theory.

Together, these perspectives explain how technological capability reshapes strategic behavior and how that behavior determines resilience outcomes.

7. Managerial Implications

The framework offers several practical implications for managers seeking to strengthen supply chain resilience.

7.1 Treat AI as a Strategic Capability

Managers should view AI as a coordination infrastructure that supports shared decision-making, not merely as a tool for automation or forecasting.

7.2 Build Structured Information-Sharing Mechanisms

The value of AI depends on effective data exchange across partners. Organizations should establish interoperable platforms, common standards, and formal data-sharing agreements.

7.3 Align Incentives Across the Network

Collaboration is sustainable only when incentives are compatible. Contracts, shared performance metrics, and risk-sharing arrangements can reinforce cooperative behavior.

7.4 Develop Joint Response Capabilities

Firms should conduct collaborative scenario planning, disruption simulations, and coordinated recovery exercises to strengthen network-level preparedness.

7.5 Balance Transparency and Protection

Organizations must define governance rules that promote visibility while safeguarding confidential and strategically sensitive information.

8. Conclusion and Future Research

This study develops a conceptual and game-theoretic framework explaining how AI reshapes strategic interaction and enhances supply chain resilience under disruption risk.

The core argument is that AI influences resilience indirectly. By reducing information asymmetry and improving predictive transparency, AI changes the payoff structure facing supply chain actors. This makes cooperative equilibrium more likely and enables stronger coordination, faster recovery, and greater adaptability.

8.1 Theoretical Contributions

The paper contributes by:

- Integrating AI, game theory, and resilience into a unified framework,
- Explaining the mechanism through which AI alters strategic incentives,
- Conceptualizing resilience as an emergent outcome of cooperative equilibrium.

8.2 Limitations

The study is conceptual and simplifies complex supply networks into dyadic relationships between rational actors. It does not provide empirical testing or detailed modeling of multi-tier systems.

8.3 Future Research Directions

Future studies may:

- Empirically test the proposed propositions,
- Extend the model to multi-agent and multi-tier supply networks,

- Incorporate behavioral and institutional factors,
- Use simulation methods to analyze equilibrium transitions,
- Examine industry-specific applications such as healthcare, automotive, and food systems.

In summary, AI creates value not only by improving operational efficiency but by restructuring the strategic conditions that make collaboration and resilience possible.

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