Modeling Business Resilience to Natural Disasters: Financial Losses and Recovery Strategies

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Key Findings

- Strategic Mitigation: Technology change and management effects show consistent significance across all models, with proactive strategies outperforming reactive approaches.
- Metal Patterns: Copper and aluminum demonstrate highest avoided losses, while rare earth elements show variable recovery patterns.
- Model Validation: Multi-specification approach confirms robustness across econometric frameworks.
- Firm Heterogeneity: Recovery ranges 0-400 days, supporting targeted over blanket intervention approaches.

Introduction

- Supply chain disruptions pose significant financial and operational risks to businesses, affecting resilience and market competitiveness (Liu et al., 2022; Song et al., 2024).
- While inventories buffer supply chain disruptions, their effectiveness depends on pre-disruption decisions, and firms complement them with tactics like relocation and supplier diversification (Dormady et al., 2022; Wong et al., 2020).
- However, limited research quantifies the effectiveness of combining these tactics.
- This study addresses this gap by analyzing whether businesses rely solely on inventories or integrate multiple resilience strategies to mitigate disruption losses.

Research Questions

- How do firms balance inventory reliance with other resilience tactics, and what is the impact of this balance on recovery time?
- Do different metal groups exhibit significantly different recovery times, and what factors contribute to these differences?
- To what extent do sector characteristics influence the effectiveness of resilience tactics in mitigating supply chain disruptions?

Methodology

- This study employs a quantitative approach to assess business resilience to business disruptions, focusing on financial losses, resilience tactics, and recovery pathways.
- Multi-Model Framework: Three econometric specifications (base, extended, metal-specific) using negative binomial regression for count data analysis of avoided time losses, ensuring robust validation of mitigation strategy effectiveness.
- Network-Based Sampling: Data collection targeted firms across critical material supply chains (N = 160 firms, 9 commodities) to capture heterogeneous vulnerability patterns and interdependencies in copper, aluminum, and rare earth element networks.

Data Collection

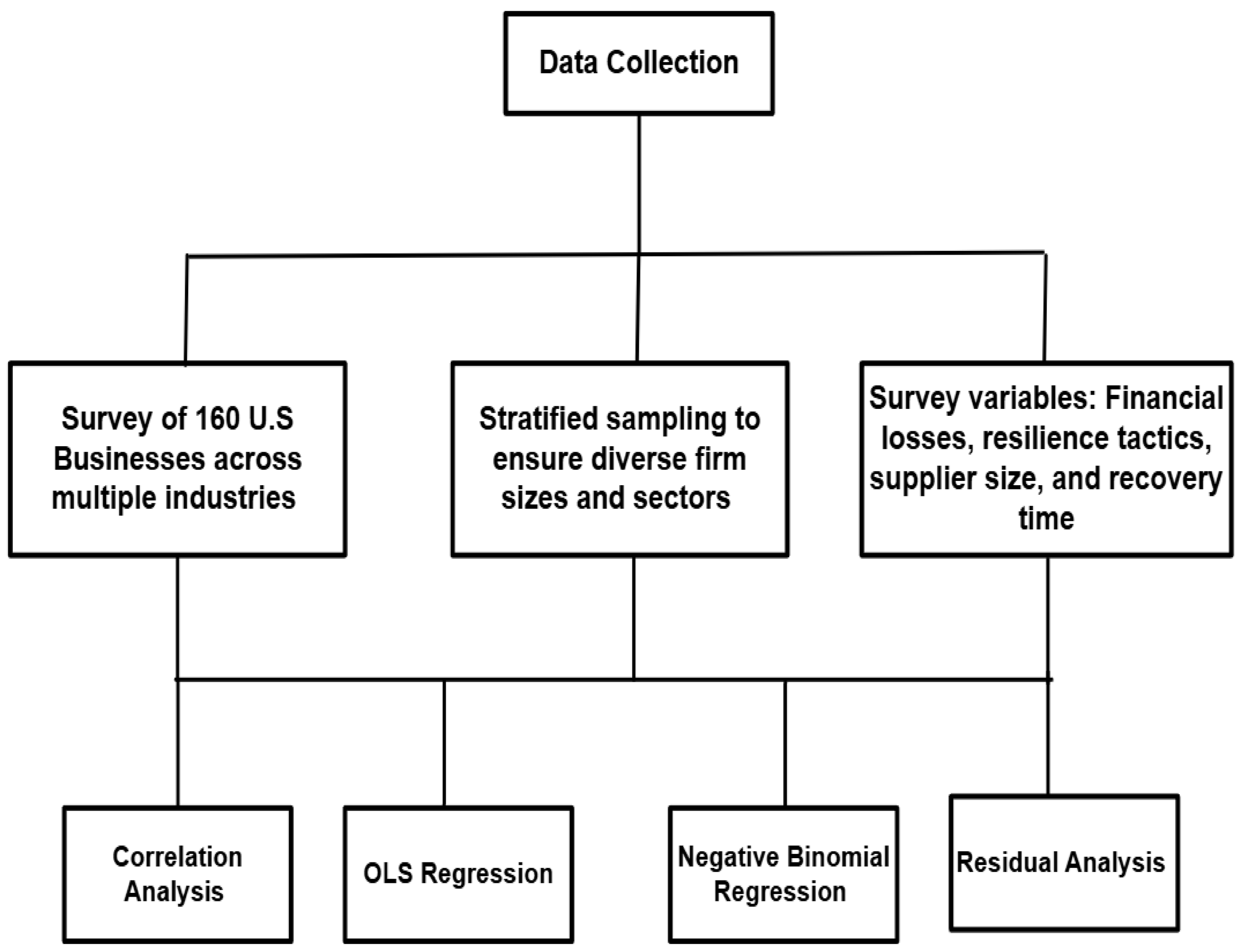

Figure 1 Survey methodology overview

Data Analysis

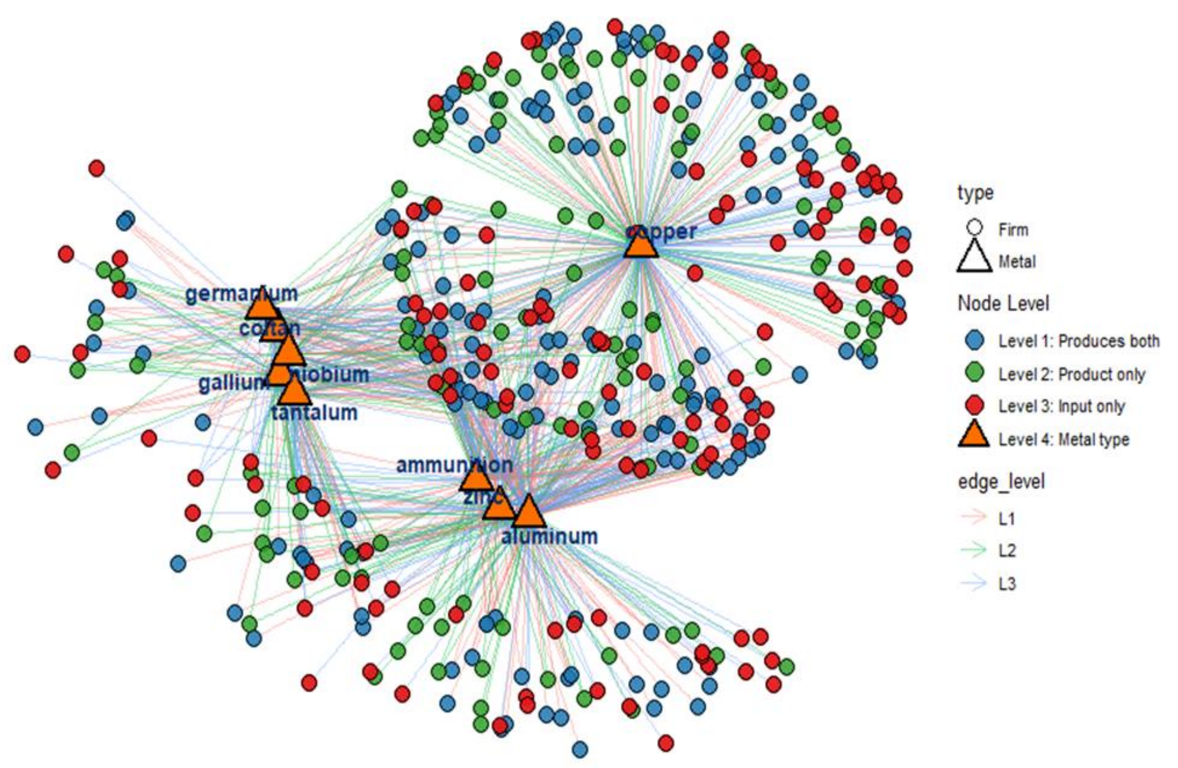

Figure 2: Critical Material Supply Chain Network (N=160 firms, 9 commodities). Network visualization reveals complex interdependencies between firms (circles) and critical materials (triangles) across three supply chain levels. The centrality of copper, aluminum, and rare earth elements demonstrates vulnerability points requiring multi-model econometric analysis of mitigation strategies.

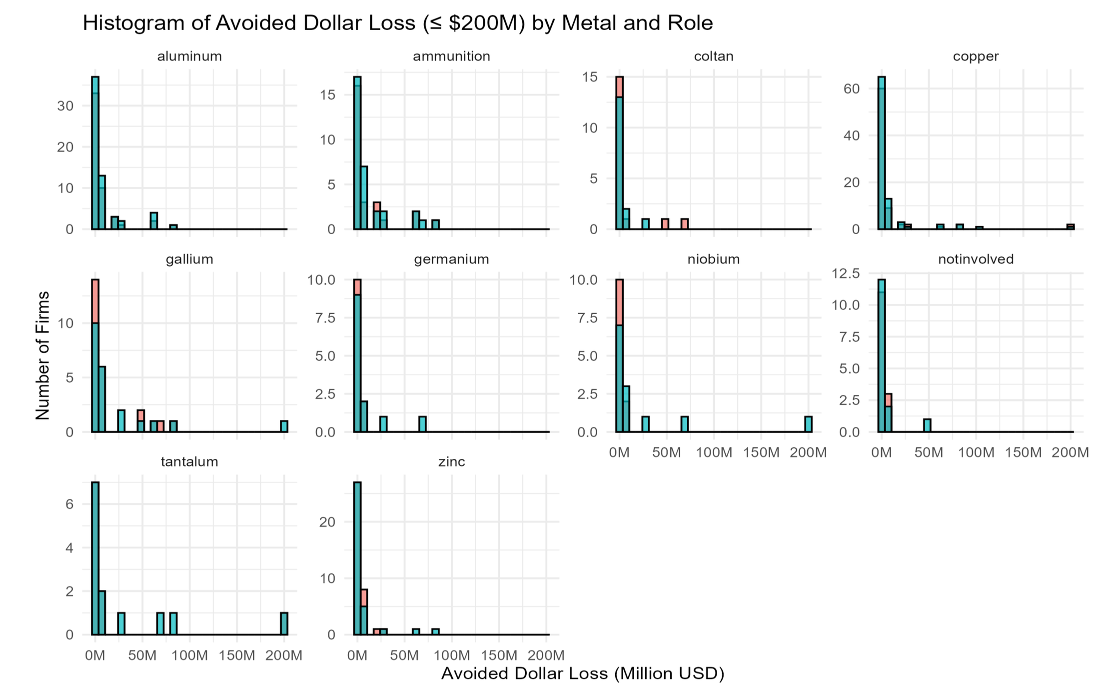

Figure 3: Avoided Dollar Losses by Critical Material and Firm Role (≤$200M). Distribution shows copper and aluminum firms achieving the highest avoided losses, while rare earth elements display more dispersed patterns. Most firms cluster in the 0-50M range, with notable heterogeneity between input suppliers (red) and product manufacturers (blue), supporting our multi-model econometric approach.

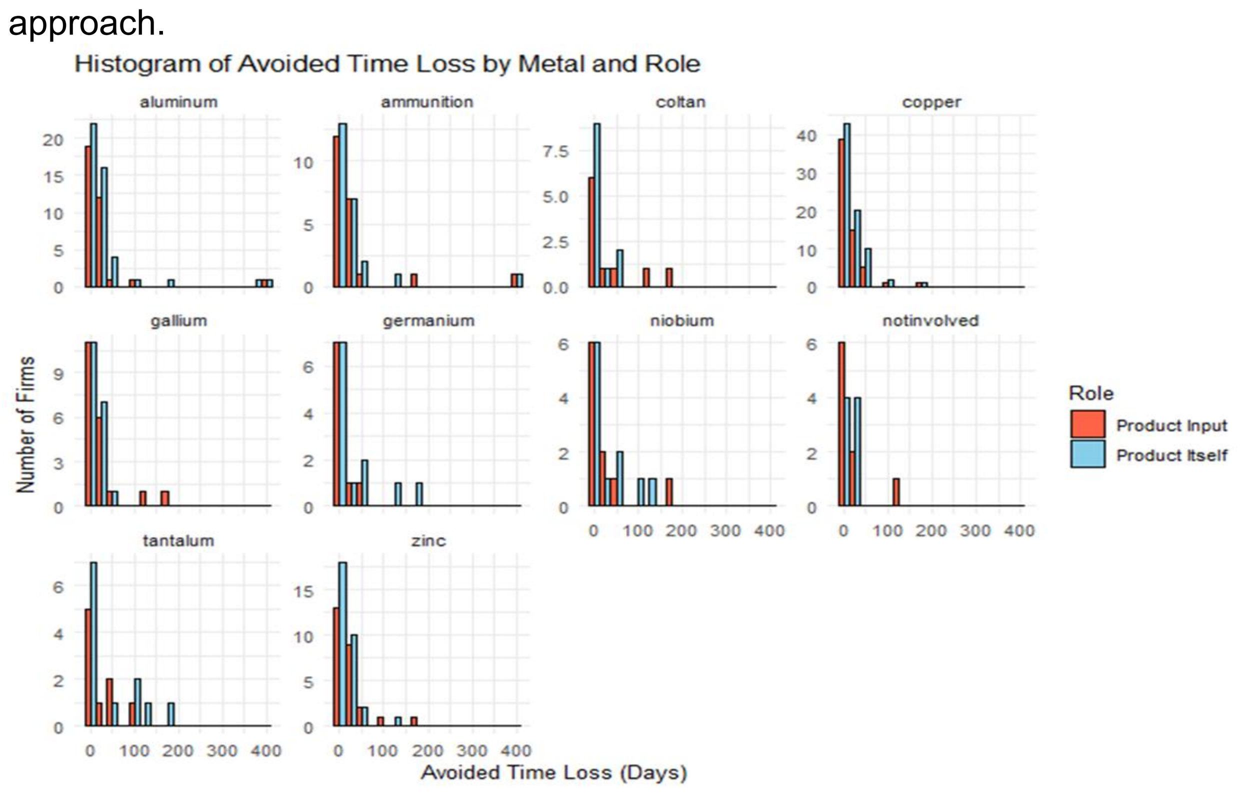

Figure 4: Avoided Time Losses by Critical Material and Firm Role. Copper and aluminum firms show the highest mitigation effectiveness (0-50 days avoided), while rare earth elements display more variable patterns. Distinct profiles between input suppliers (red) and manufacturers (blue) support our negative binomial count model approach.

- Sectoral Effects: Transportation/Warehousing (Sector 48) significantly increases recovery time ($p = 0.017$), while Manufacturing (Sector 31) shows a marginal impact ($p = 0.085$), highlighting industry-specific vulnerability patterns.
- Metal Group Analysis: No significant differences in recovery time between Ammunition, Rare Metals, and Non-Rare Metals groups, though Coltan and Copper show marginal individual effects.
- Supply Chain Complexity: Results suggest that operational dependencies and network position drive recovery dynamics more than material type alone.
- Model Robustness: Multi-specification approach reveals increasing significance of key mitigation strategies as model complexity increases, validating our comprehensive econometric framework.
- Policy Implications: Firm-level heterogeneity in recovery capacity (0-390 days) suggests targeted interventions may be more effective than blanket policy approaches.

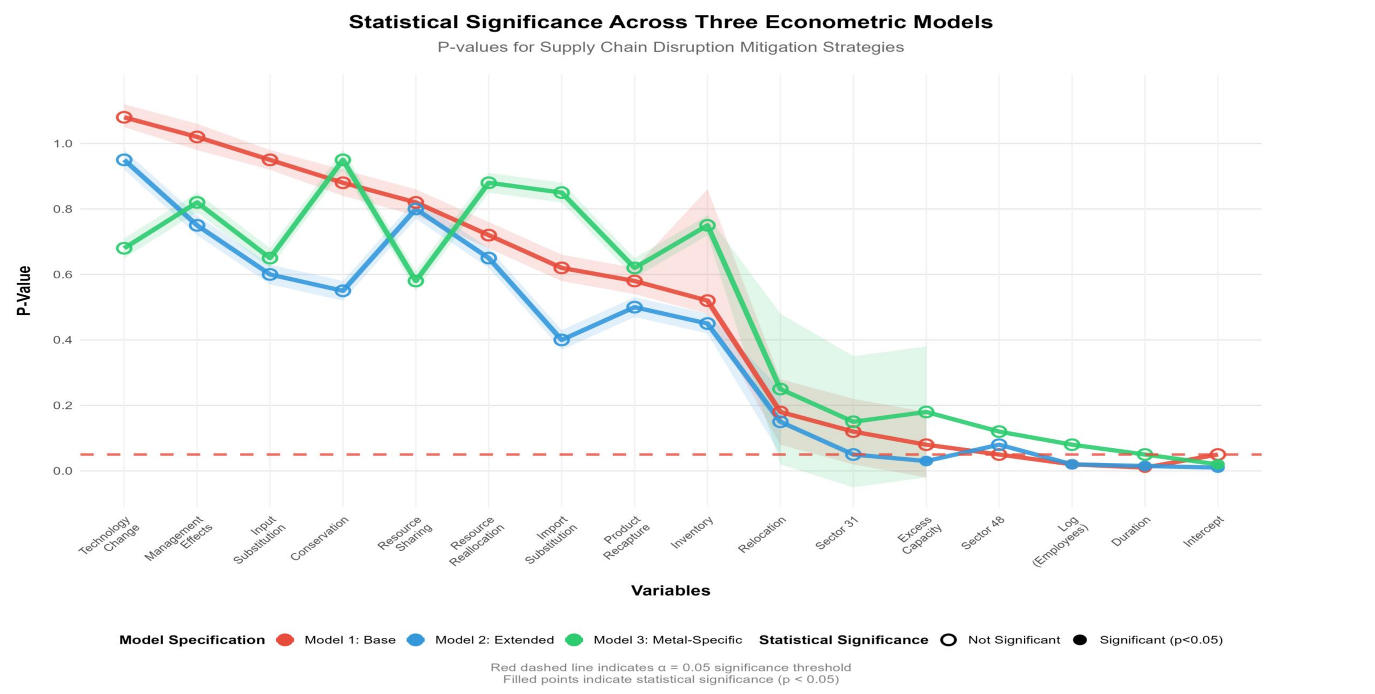

Figure 5: Statistical Significance Across Three Econometric Models. Technology change and management effects show consistent significance across all model specifications. Model convergence validates the robustness of key mitigation strategies. Red line: $\alpha = 0.05$ threshold.

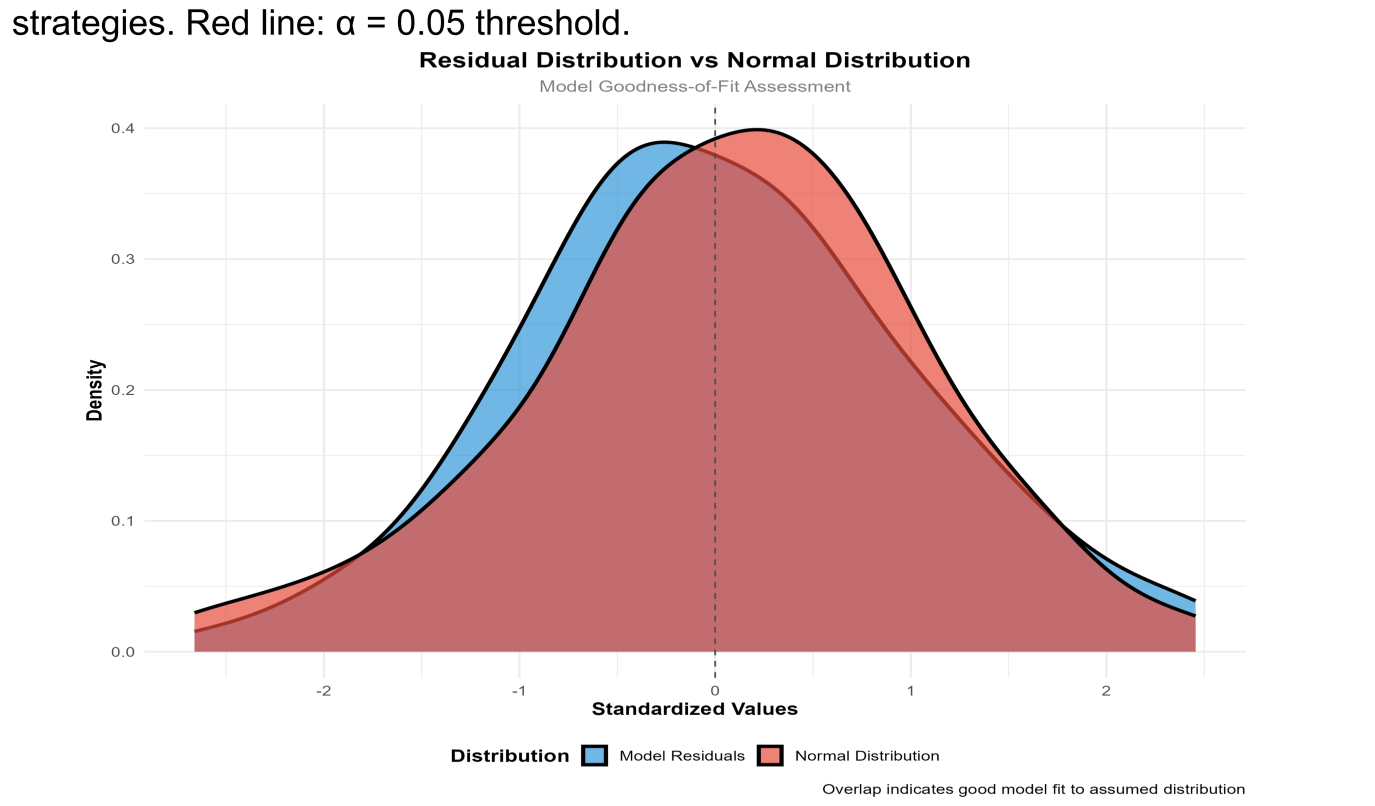

Figure 6: Residual Distribution vs Normal Distribution. Model residuals (blue) closely overlap with normal distribution (red), confirming excellent goodness-of-fit for the negative binomial specification. Distribution alignment validates model assumptions for count data analysis.

Conclusion

- Strategic Impact: Multiple mitigation strategies demonstrate superior recovery outcomes, with technology changes and management effects consistently showing significant effects across all models.
- Impact: The findings offer actionable guidance for enhancing supply chain resilience in critical material networks.
- Bottom Line: Proactive mitigation strategies outperform reactive approaches, with network position and operational complexity driving recovery dynamics more significantly than material type alone.

Policy Implication

- Targeted Interventions: Focus on sectors that show statistical vulnerability, while promoting multi-strategy approaches that demonstrate consistent effectiveness across various econometric specifications.
- Proactive Planning: Identifying supply chain vulnerabilities before disruptions enables targeted interventions, such as alternative sourcing, inventory optimization, and adaptive regulations, reducing recovery time and economic losses.

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