

Building Resilient Supply Chains: Navigating Disruptions and Ensuring Sustainability Through Integrated Strategies and Technological Innovations

Abstract

The resilience of global supply chains has become a critical issue following significant disruptions caused by natural disasters, COVID-19 pandemic and geopolitical tensions. These disruptions exposed vulnerabilities across various industries, leading to shortages, delays, economic losses, and inflationary pressures. This study examines pre- and post-COVID-19 supply chain disruptions events and identifies key trends and vulnerabilities. The analysis shows that diversified sourcing, improved logistics management, and predictive analytics are the most effective strategies for enhancing resilience. Conversely, over-reliance on trade agreements and certain technologies hindered recovery in some cases. The research employs data-driven methodologies, and case studies to offer practical recommendations for businesses and policymakers. By leveraging these insights, the study outlines how tailored resilience frameworks can mitigate future disruptions, particularly in high-risk sectors such as energy and manufacturing, thereby contributing to global economic stability and long-term supply chain viability.

Key words: IOT, Supply Chain Resilience, Artificial Intelligence, Predictive Analysis, Diversification, Technological Innovation, Risk Management Framework, Green Supply Chains, Economic Stability, Natural Disasters, Sustainability, Geopolitical Instability, Sector-Specific Strategies, Blockchain

Introduction

Global supply chains are the backbone of modern economies, enabling the seamless production, distribution, and delivery of goods across borders. However, their intricate, interconnected nature makes them particularly vulnerable to disruptions. Over the past two decades, a series of high-profile events—including natural disasters, geopolitical conflicts, and global pandemics—have severely impacted the ability of firms to maintain supply chain continuity. For example, the Tohoku earthquake and tsunami of 2011 disrupted supply chains not only in Japan but globally,

reverberating across industries from automotive to electronics (Brennan, 2011). More recently, the COVID-19 pandemic revealed widespread weaknesses in global supply chain infrastructures, causing severe product shortages, delivery delays, inflationary pressures, and significant economic instability. Such crises underscore the inevitability of future disruptions, which will likely continue given the increasing risks posed by climate change, geopolitical tensions, and global interdependencies. These trends highlight the pressing need for resilient supply chain strategies to mitigate future risks.

Before the COVID-19 pandemic, most supply chain disruptions were localized and industry-specific, often resulting from natural disasters, transportation failures, or geopolitical tensions. However, the pandemic amplified the fragility of global supply chains as lockdowns, travel restrictions, and sudden shifts in consumer demand created cascading effects across industries and regions. This multi-faceted disruption strained the availability of critical goods and heightened inflationary pressures, further complicating global economic recovery. The scope and scale of the pandemic's impact have prompted an urgent re-evaluation of traditional supply chain strategies, such as the Toyota Production System (TPS), which historically emphasized efficiency and cost-cutting over flexibility and resilience. The widespread recognition of TPS as a model has been foundational in just-in-time manufacturing, but the pandemic revealed its vulnerabilities, particularly in managing large-scale, simultaneous disruptions.

While the concept of supply chain resilience has gained academic and industry traction, the current body of research often fails to address the complexity of modern global supply chains. As highlighted by Sheffi (2005) and Rice & Caniato (2003), resilient supply chains are those that can quickly "bounce back" from disruptions, minimizing the depth and duration of operational impacts. However, a growing consensus suggests that resilience must go beyond recovery and instead encompass the ability to adapt and transform in response to crises (Holling, 1996;

Wieland & Durach, 2021). This study addresses a critical gap in supply chain research: the lack of comprehensive, integrated frameworks that not only incorporate advanced technologies such as

Internet of Things (IoT), artificial intelligence (AI), and blockchain, but also account for the complex and evolving risks faced by global supply chains in today's turbulent environment.

In light of these challenges, this paper examines 100 quantitative supply chain disruption events from both before and after the COVID-19 pandemic, focusing on identifying vulnerabilities, analyzing trends, and proposing actionable strategies for enhancing resilience. Leveraging data-driven methodologies and analytical tools, this research provides businesses and policymakers with a comprehensive understanding of supply chain resilience. Key areas of focus include the diversification of supply sources, improvements in logistics management, and the application of predictive analytics to anticipate and mitigate risks. By addressing these factors, this paper aims to fill a critical gap in the existing literature by offering tailored resilience frameworks—particularly for high-risk sectors such as energy, where supply chain disruptions have historically resulted in disproportionate economic impacts. This leads to the central research question of this study: How can integrated strategies and technological innovations enhance the resilience of global supply chains in the face of disruptions, and what are the most effective methods for ensuring sustainability and long-term viability in high-risk sectors?

Building resilient supply chains is no longer a matter of short-term recovery; it is crucial for long-term competitiveness and global economic stability. The recommendations put forth in this research will offer practical strategies for both private enterprises and governmental bodies, ensuring that supply chains are not only equipped to withstand future disruptions but are also able to thrive in an increasingly uncertain world.

Literature Review

2.1 Supply Chain Disruptions

Supply chain disruptions have been extensively studied, particularly following significant events such as natural disasters, geopolitical conflicts, and the COVID-19 pandemic. Lambert, Stock, and Ellram (1998) define a supply chain as a network of organizations involved in creating and delivering a product or service from raw materials to the end customer. This network includes suppliers, manufacturers, distributors, retailers, and customers, interconnected through various processes and activities. Mentzer, Myers, and Stank (2001) further define a supply chain as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flow of products, services, finances, and information from a source to a customer. This broad scope encompasses all activities and processes required to produce and deliver a product or service to the final consumer.

Supply chain disruptions are significant disturbances in this network, leading to interruptions in the availability of goods and services and affecting the operations of organizations. Ivanov and Dolgui (2021) define supply chain disruptions as significant and often unexpected disturbances that lead to deviations from expected performance, causing delays, increased costs, or failures to meet customer demands. Such disruptions can arise from various factors, including pandemics, technological failures, supply shortages, factory shutdowns, transportation failures, and geopolitical conflicts (Christopher & Peck, 2004).

2.2 Nature and Impact of Disruptions: Geopolitical Tensions, Pandemics, and Trade Disputes

Geopolitical tensions and trade disputes have had increasingly significant roles in disrupting global supply chains. Recent examples include the U.S.-China trade war, which forced numerous companies to shift their production and supplier bases to alternative regions such as Vietnam, India, and Mexico. Companies like Apple and Intel have made strategic adjustments to their global supply chains to reduce exposure to the risks associated with tariffs and trade sanctions (Gereffi, 2020). Intel's diversification of production away from China illustrates how tech firms, heavily reliant on complex just-in-time systems, face heightened vulnerability due to geopolitical disputes compared to traditional manufacturing sectors (Sturgeon, 2021).

In contrast, traditional manufacturing industries have historically demonstrated more resilience by adopting diversified supply networks. For instance, General Motors (GM), in response to fluctuating steel tariffs in the early 2000s, began diversifying its sourcing of critical materials by establishing relationships with suppliers across North America and Europe (McKinnon, 2004). This approach allowed GM to buffer the effects of geopolitical risks, including regional trade disputes, while maintaining production stability. This contrast between the high-tech and traditional manufacturing sectors highlights the greater capacity of diversified industries to absorb localized disruptions without significant interruptions to their operations.

The COVID-19 pandemic created an entirely different set of challenges for global supply chains, exposing deep-rooted vulnerabilities that went beyond localized disruptions. The pandemic led to global production shutdowns, workforce shortages, and logistics backlogs, exacerbating the difficulty in managing supply chain continuity across sectors. While companies in industries like automotive and electronics struggled with severe shortages in raw materials and components, sectors such as pharmaceuticals and healthcare faced critical challenges in meeting surging demand for medical supplies (Ivanov & Dolgui, 2021). The pandemic forced businesses to rapidly reconsider their supply chain strategies, highlighting the necessity for resilience and adaptability in handling not only health crises but also other potential global disruptions.

With the growing frequency of trade disputes, sanctions, and tariffs—as seen in the U.S.-China conflict and Brexit-related disruptions—new strategies in supply chain management are increasingly essential. These strategies must move beyond cost optimization to include comprehensive risk mitigation, such as political risk insurance and geopolitical monitoring systems. This underscores the importance of building resilience strategies tailored to the specific nature of the industry and the geopolitical risks involved (Wieland & Durach, 2021).

2.3 Supply Chain Resilience Strategies

Resilience strategies are crucial in enabling supply chains to anticipate, respond to, and recover from disruptions. Sheffi and Rice (2005) emphasize that resilience can be embedded in supply

chains through flexibility, redundancy, and effective risk management strategies. While the COVID-19 pandemic revealed the vulnerability of global supply chains, it also accelerated the adoption of digital technologies and the implementation of more robust resilience frameworks across various industries (Ivanov & Dolgui, 2021).

Different industries have tailored resilience strategies to their specific challenges. The technology sector, with its reliance on just-in-time systems, tends to focus on agility and flexibility, while traditional manufacturing industries may emphasize redundancy and diversification. This dichotomy is illustrated in the differing responses to supply chain disruptions, where the technology sector's use of advanced predictive analytics contrasts with the manufacturing sector's reliance on diversified sourcing to mitigate risks (Christopher & Peck, 2004).

2.3.1 Diversified Sourcing as a resilience strategy

Diversified sourcing remains among the most effective strategies for minimizing risks associated with supply chain disruptions. By distributing procurement across various suppliers and regions, companies lessen their reliance on a single source, thereby enhancing their resilience and ability to recover from disruptions. Tang (2006) and Ponomarov & Holcomb (2009) emphasize that organizations with diversified supply bases are better equipped to manage risks related to localized disruptions, including natural disasters and geopolitical conflicts.

Gunasekaran et al. (2015) also discuss diversified sourcing as a critical response to supply chain complexities. They highlight how diversifying supplier bases and regions can significantly reduce the risks associated with geopolitical tensions, trade disputes, or natural disasters. This strategy ensures that companies like Nestlé and Unilever, which have employed diversified sourcing, can maintain their operations even when specific regions experience disruptions. For example, Nestlé has reduced dependency on single-region suppliers by establishing relationships with multiple suppliers across different regions (Norrman & Jansson, 2004). This proactive approach is particularly important in industries where supply chain continuity is critical.

Simultaneously, Unilever's strategic sourcing of palm oil and dairy from multiple regions further exemplifies how diversified sourcing can align with sustainability goals while mitigating risks across global supply chains (Christopher & Holweg, 2017). Gunasekaran et al. (2015) argue that such proactive diversification significantly enhances resilience by spreading the risks across suppliers, ensuring operational continuity despite disruptions in specific regions.

However, managing multiple suppliers presents significant challenges, including increased costs and complex supplier management. Simchi-Levi et al. (2014) highlight that maintaining relationships with a wide range of suppliers can be costly, and ensuring consistent quality across different sources requires advanced supply chain management tools. Technological solutions such as Supplier Relationship Management (SRM) systems and predictive analytics have proven instrumental in addressing these challenges, allowing companies to coordinate and monitor suppliers efficiently (Ivanov, Dolgui, & Sokolov, 2019).

2.3.2 Predictive Analytics as a resilience Strategy

Predictive analytics plays a critical role in enhancing supply chain resilience by allowing companies to anticipate and respond to disruptions more effectively. Wang et al. (2016) explore the application of predictive analytics in managing supply chain disruptions, highlighting the importance of machine learning and statistical modeling techniques in forecasting demand and identifying risks. By leveraging historical data and advanced algorithms, companies can foresee potential disruptions and implement proactive measures, such as adjusting production schedules or rerouting shipments (Feng, Li, & McVay, 2015).

Ivanov et al. (2021) emphasize that predictive analytics integrated with AI offers significant benefits in mitigating supply chain risks. Companies like General Electric (GE) and IBM have successfully used predictive analytics to improve supply chain resilience. GE uses predictive models to monitor the health of its jet engines, enabling predictive maintenance to minimize downtime and reduce costs (Baryannis et al., 2019). Similarly, IBM uses predictive algorithms to

optimize logistics and identify potential supply chain disruptions, improving resilience in their global operations (Srinivasan & Swink, 2018).

Although predictive analytics provides significant advantages in anticipating risks, its implementation comes with challenges, particularly concerning data quality and the need for specialized skills. Companies must ensure robust data governance practices to maintain the integrity of predictive models, while also investing in advanced systems that are costly for smaller firms (Sokolov & Ivanov, 2020).

2.3.3 Relevant Framework

2.3.3.1 Supply Chain Resilience Framework (SCRF)

The Supply Chain Resilience Framework (SCRF) is a widely recognized model that emphasizes the capacity of supply chains to prepare for, respond to, and recover from disruptions. Central to this framework are key elements such as flexibility, adaptability, redundancy, and diversity. Flexibility and adaptability enable supply chains to adjust to unforeseen challenges, while redundancy and diversity involve the inclusion of alternative suppliers and pathways to enhance resilience (Sheffi & Rice, 2005). Zhao et al. (2019) reinforce the significance of these components, highlighting how they contribute to the overall robustness of supply chains in the face of disruptions.

In recent years, the digital twin framework has emerged as a critical tool that aligns with the SCRF. A digital twin is a virtual representation of a physical supply chain that allows for real-time monitoring, simulations, and predictive analytics. This technology provides an unparalleled ability to forecast potential disruptions and test various scenarios without impacting actual operations. Similar to how ISO 31000 is integral to risk management frameworks, the digital twin framework can serve as a vital enhancement to SCRF, offering greater agility, visibility, and the ability to simulate and mitigate risks in complex, interconnected supply chains (Ivanov & Dolgui, 2020). By integrating digital twins, companies can model different disruption scenarios and develop more

robust contingency plans, making supply chains not only more resilient but also more proactive in risk management.

2.3.3.2 Risk Management Framework (RMF)

Risk management frameworks such as ISO 31000 and COSO ERM offer structured approaches to identifying, assessing, and managing risks within supply chains. These frameworks underscore the importance of systematic risk assessment, developing mitigation strategies, and ensuring a continuous review process to remain responsive to evolving external factors (ISO 31000, 2018; COSO ERM, 2017). For instance, ISO 31000 provides comprehensive guidelines that integrate risk management practices into organizational activities (Aven, 2016), while the COSO ERM framework focuses on aligning risk management strategies with overall organizational objectives, thus improving decision-making (Frigo & Anderson, 2011).

Risk management implementation generally involves several steps, beginning with a detailed assessment of potential vulnerabilities (Manuj & Mentzer, 2008). Companies then develop mitigation strategies such as diversifying suppliers or establishing contingency plans. Continuous monitoring and review are critical to ensure that risk management frameworks remain effective over time (Tummala & Schoenherr, 2011).

DHL's adoption of the COSO ERM framework exemplifies the application of risk management to enhance resilience across global logistics operations. By integrating this framework, DHL has improved its capacity to manage risks during events like natural disasters and geopolitical tensions (Norrman & Jansson, 2004). Similarly, Cisco's implementation of ISO 31000 enabled the company to build resilience by systematically identifying and mitigating risks within its complex global operations (Sheffi, 2015).

Implementing risk management frameworks presents challenges such as aligning these frameworks with existing processes and ensuring sufficient flexibility to adapt to dynamic risks. Resistance to change and the need for comprehensive training are common obstacles. Zsidisin &

Wagner (2010) suggest that effective change management strategies involving all stakeholders, coupled with phased implementation, can help overcome these barriers. Additionally, continuous training ensures that organizations remain adaptable to new risks without disrupting current operations.

2.3.4 Technological Innovations

Technological advancements, such as blockchain, artificial intelligence (AI), the Internet of Things (IoT), and predictive analytics, are revolutionizing supply chain resilience by enhancing transparency, real-time monitoring, and decision-making capabilities. These innovations significantly improve supply chain adaptability to disruptions, making them more robust. For example, AI enables predictive analytics and automation, which help companies forecast potential disruptions and develop proactive mitigation strategies. AI-driven demand forecasting, as used by Procter & Gamble (P&G), helps optimize inventory levels and ensure product availability during peak demand periods (Marr, 2018). AI also allows for scenario simulations, providing valuable insights into the best responses during disruptions (Ivanov, Dolgui, & Sokolov, 2019).

The IoT further enhances visibility in supply chains by providing real-time data on the location and status of goods. Companies such as Siemens and Caterpillar use IoT sensors to monitor equipment, enabling predictive maintenance and reducing the risk of breakdowns (Lee & Lee, 2015). This technological integration enhances operational efficiency and minimizes costly downtimes. Blockchain technology is also instrumental in improving transaction security and transparency, addressing issues like fraud and counterfeit goods. Walmart's blockchain-based food traceability system has significantly reduced the time required to trace foodborne illnesses, ensuring both safety and efficiency (Kamath, 2018).

While advanced technologies such as AI, IoT, and blockchain offer significant potential for enhancing supply chain resilience, their implementation is not without obstacles. High costs of adoption, the need for specialized skills, and issues with data quality can hinder their effectiveness,

especially for small- and medium-sized enterprises (SMEs) and businesses in developing economies. For instance, smaller firms may struggle to bear the initial investment required for these technologies, making it difficult for them to realize the benefits of predictive analytics and real-time data tracking.

Furthermore, data integration across global supply chains presents another significant challenge. Different suppliers often use varying systems, leading to inconsistent data collection and processing. Without robust data governance practices, the predictive models used for forecasting and risk management may generate inaccurate insights. This calls for a more nuanced approach that includes addressing infrastructure limitations, building local capacities, and finding ways to lower the cost of adoption for smaller players.

However, despite these hurdles, strategic partnerships and government incentives can play a crucial role in reducing the cost burden of these technologies. Public-private partnerships (PPPs), for example, can facilitate the transfer of knowledge and technologies to regions where resources are limited. Additionally, companies may adopt hybrid approaches, incorporating both low-tech solutions and advanced technologies to optimize resilience.

2.3.5 Emerging Research on Digital Supply Chain Resilience

Emerging technologies such as 5G networks and quantum computing are revolutionizing supply chain resilience by enabling faster and more complex decision-making. As global supply chains become increasingly digitized, companies are adopting these technologies to enhance their resilience against disruptions. 5G networks significantly improve communication and real-time monitoring, facilitating quicker responses to potential risks. For example, Ford Motor Company has integrated 5G into its manufacturing systems to track parts and monitor equipment in real-time, helping to prevent equipment failures and reduce production delays.

Siemens has also partnered with Qualcomm to implement private 5G networks in its factories, gaining continuous visibility into production processes and enhancing flexibility to respond to

disruptions quickly. This capability allows Siemens to implement agile manufacturing practices, improving overall resilience.

Quantum computing, on the other hand, has the potential to transform logistics and supply chain optimization. Companies such as Volkswagen have explored quantum algorithms to improve traffic management and supply chain logistics, solving complex optimization problems like delivery routing faster than traditional computers. Similarly, DHL is experimenting with quantum computing to enhance its global logistics network, improving route planning and increasing overall efficiency.

The integration of 5G, quantum computing, AI, and blockchain is paving the way for the development of self-healing supply chains—networks that can autonomously detect, diagnose, and respond to disruptions. This technological advancement will be crucial for companies operating in volatile environments, as the ability to quickly adapt to changing conditions is critical to maintaining stability. As these emerging technologies continue to advance, their role in building resilient, adaptive supply chains will only grow. Companies that effectively leverage these tools will be better positioned to manage diverse risks, ensuring sustainability and competitiveness in the global market.

2.4 Gaps Identified

Despite the growing body of research on supply chain disruptions and resilience, several critical gaps remain unaddressed. One major gap is the lack of an integrated framework that combines multiple resilience strategies, such as diversified sourcing, predictive analytics, and risk management, into a cohesive approach (Ponomarov & Holcomb, 2009). While many studies focus on individual strategies or technologies, they often overlook the potential benefits of a more holistic approach that considers the interplay between these elements.

Furthermore, most research tends to focus on specific types of disruptions, such as natural disasters or geopolitical conflicts, without thoroughly examining how resilience strategies perform across a

broader spectrum of disruption scenarios (Boudette, 2020). This limitation hinders the development of robust, adaptable strategies capable of withstanding diverse disruptions.

Additionally, the impact of regional sustainability policies like the European Green Deal on global supply chains remains underexplored. As sustainability becomes a critical aspect of resilience, there is a need for further research into how companies can integrate environmental goals with resilience strategies in a cost-effective manner (Pereira et al., 2014). The future of supply chain resilience lies in addressing these gaps and developing strategies that are both adaptable and sustainable in the face of evolving global challenges.

Research Methodology

This study employs a mixed-method approach, integrating qualitative case studies with quantitative analysis to explore supply chain resilience. The analysis aims to identify shifts in disruption management strategies across sectors and regions, particularly pre- and post-COVID, and to evaluate the effectiveness of integrated resilience strategies and technological innovations.

The study specifically seeks to answer the following key questions:

- How have supply chain disruption management strategies evolved in high-risk sectors such as energy and healthcare?
- What impact have integrated resilience strategies and technological innovations had on recovery outcomes across different sectors and regions?
- How do the duration and type of disruptions affect the overall economic recovery, especially in post-COVID scenarios?

A dataset of 100 supply chain disruption events—50 pre-COVID and 50 post-COVID—was analyzed to provide insights into the changes in management strategies. The events, sourced from Reuters, BBC, and the UN, cover 11 key variables including disruption type, duration, impact, and recovery outcomes. This combination of qualitative and quantitative data enables a comprehensive analysis of global supply chain resilience, particularly focusing on high-risk sectors like energy.

To guide the analysis, the following hypotheses were tested:

- The null hypothesis (H0): Integrated strategies and technological innovations do not significantly enhance supply chain resilience.
- The alternative hypothesis (H1): These strategies and innovations significantly enhance resilience and ensure sustainability in high-risk sectors.

Ordinary Least Squares (OLS) regression was used to evaluate the relationship between integrated resilience strategies, technological innovations, and recovery outcomes. The analysis examined key variables like disruption duration, resilience strategies, and the use of advanced technologies as independent variables, with recovery outcomes and economic impacts serving as dependent variables. Additionally, one-hot encoding was applied to categorical variables to improve the accuracy of the regression analysis.

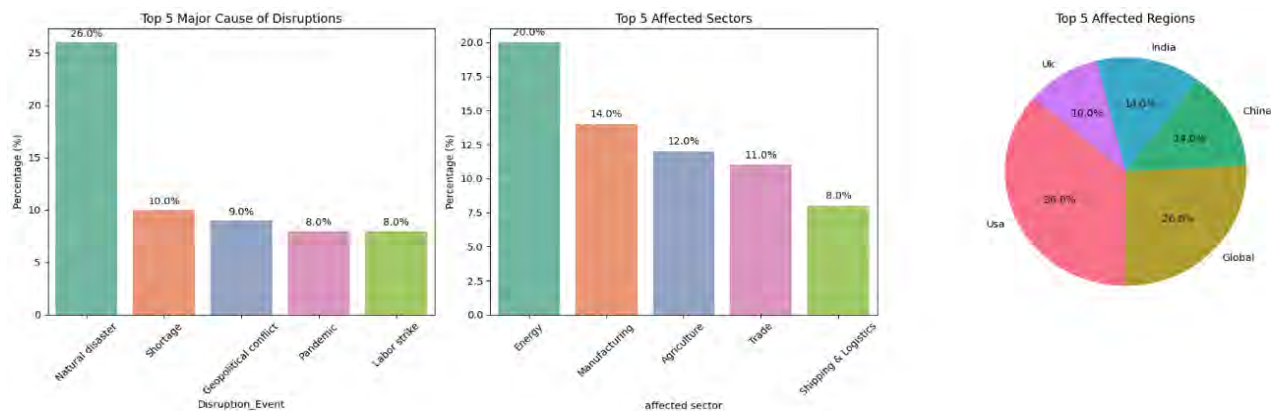
Correlation analysis revealed that longer disruptions are associated with poorer recovery outcomes, particularly in sectors like healthcare and energy. Mixed results were observed regarding the effectiveness of technological innovations, with some proving beneficial, while others extended recovery times.

The results indicated that natural disasters were the most frequent type of disruption, and the energy sector was the most affected. Effective resilience strategies, such as supply chain diversification and improved logistics management, were found to reduce the negative impacts of disruptions. However, the effectiveness of technological innovations varied depending on the context-specific applications.

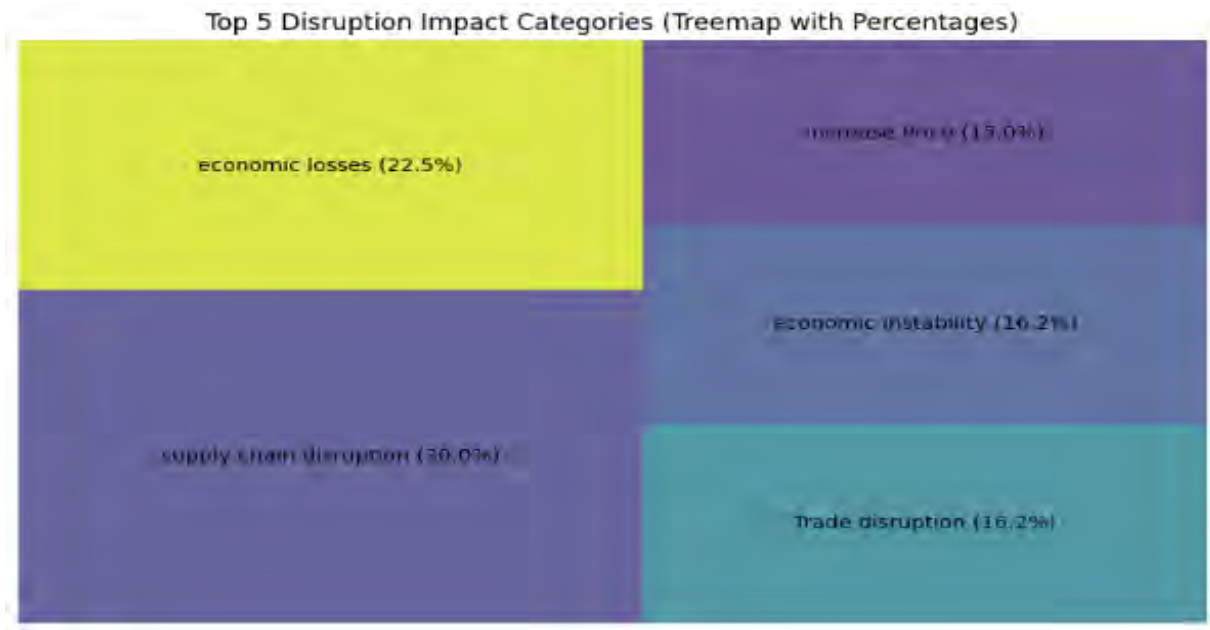
The findings ultimately support the alternative hypothesis (H1), that integrated strategies and technological innovations significantly enhance supply chain resilience, though their impact is highly dependent on sectoral and regional factors.

Appendix A contains the list of 50 post-COVID events that were incorporated into this analysis.

Data Analysis / Result

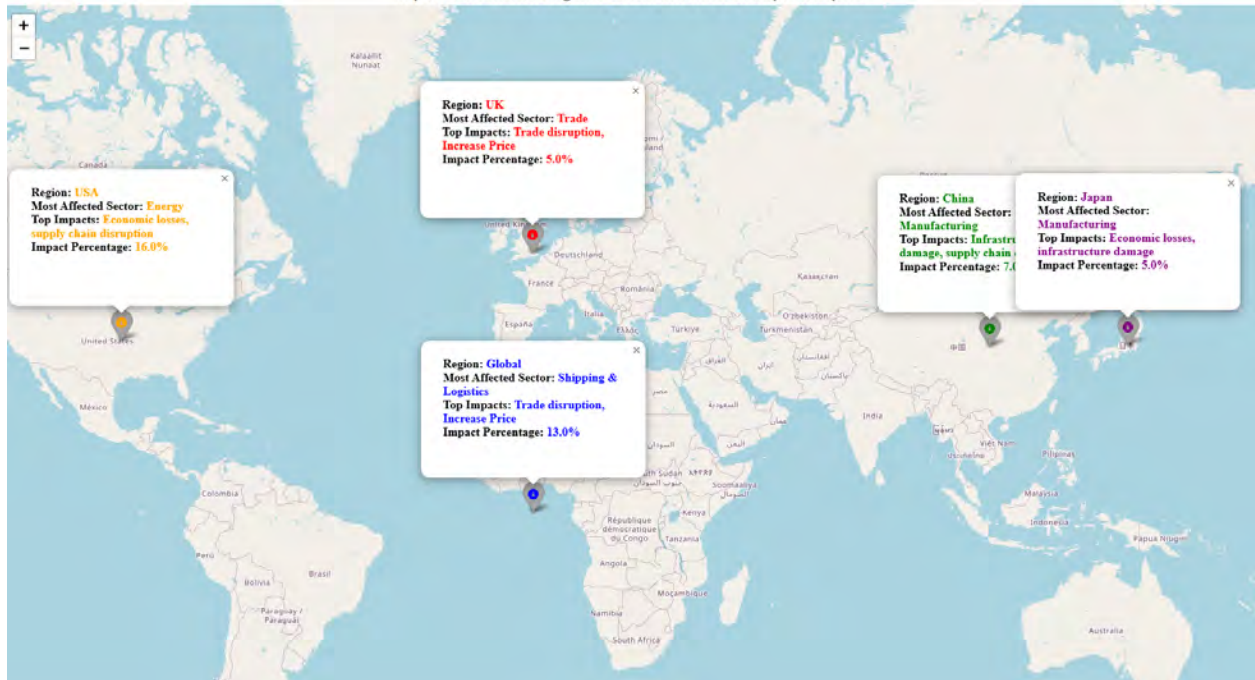


The visual analysis of the top five causes of supply chain disruption, affected sectors, and impacted regions provides a detailed understanding of global supply chain vulnerabilities. Natural disasters, driven by events such as hurricanes, earthquakes, and extreme weather, are the leading cause, accounting for 26% of disruptions, highlighting the importance of environmental resilience. Shortages (10%) and geopolitical conflicts (9%), spurred by factors like trade wars, resource scarcity, and political instability, further exacerbate supply chain vulnerabilities. Pandemics (8%), as seen with COVID-19, and labor strikes (8%) due to industrial unrest also play significant roles. Among the affected sectors, the energy sector is disproportionately impacted, experiencing 20% of all disruptions due to its reliance on global logistics networks and vulnerability to political and environmental factors. Other sectors that are highly affected include manufacturing (14%), agriculture (12%), trade (11%), and shipping & logistics (8%). These industries form the backbone of global trade and are crucial to the seamless operation of global supply chains. Regionally, the USA is the most impacted, with 36% of disruptions, while global-level events account for 26%, often driven by interconnected supply chains and cascading effects. Other significantly affected regions include China, India, and the UK, each with 10-14% of disruptions. These findings underscore the need for sector-specific and regionally targeted resilience strategies, addressing both environmental and geopolitical drivers to safeguard supply chains, particularly in high-risk areas like energy, manufacturing, and agriculture.

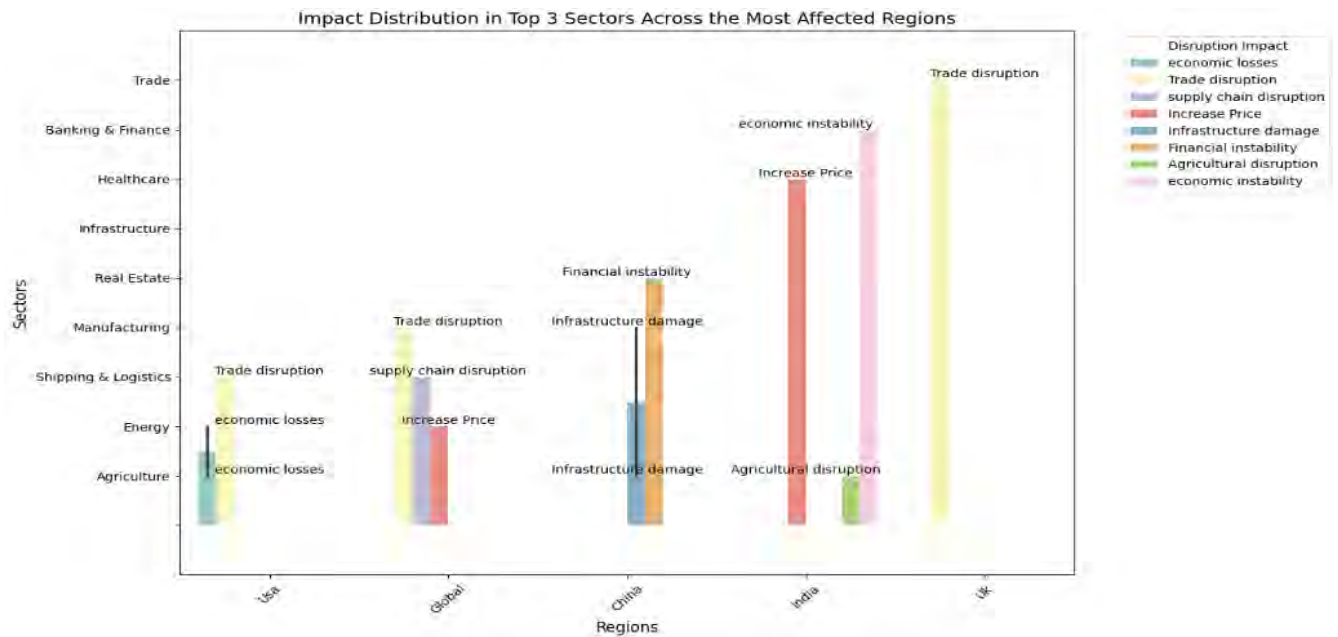


The treemap visualization of the top five supply chain disruption impact categories provides a detailed understanding of how disruptions affect various aspects of the global economy. Supply chain disruptions account for the largest portion at 30%, highlighting the direct operational interruptions that delay production, distribution, and delivery of goods. Economic losses, making up 22.5%, point to the severe financial setbacks that companies and economies face due to halted operations and recovery costs. Trade disruptions and economic instability, each comprising 16.2%, reflect the broader macroeconomic effects, where disrupted trade routes and weakened market stability lead to global ripple effects, including volatility in international trade and investment. Lastly, increased prices contribute 15%, illustrating how supply chain issues often exacerbate inflationary pressures as reduced supply leads to higher costs for both businesses and consumers. This analysis underscores the need for resilience strategies that address both the operational and economic impacts of supply chain disruptions, ensuring long-term stability in a highly interconnected global market.

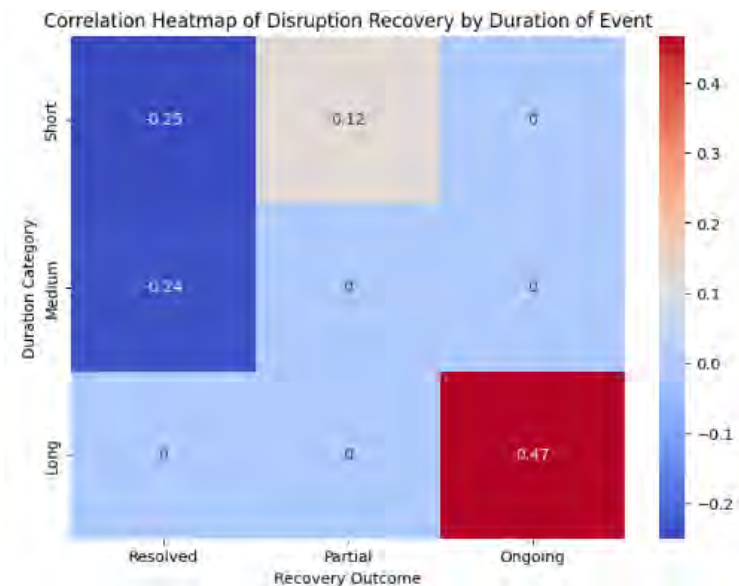
Top 6 Most Affected Regions' Sector and Their Disruption Impact



The map visualization shows the Top 6 Most Affected Regions and highlights their corresponding sectors and disruption impacts. Findings highlight that the energy sector in the USA experienced the highest level of disruption, accounting for 16% of the overall impact, driven by economic losses and supply chain disruptions. The global shipping and logistics sector followed, with 13% of the impact caused by trade delays and increased costs. China's manufacturing sector faced 7% of disruptions, primarily due to infrastructure damage and supply chain interruptions. Both the UK and Japan saw 5% impacts; the UK's trade sector was affected by trade disruptions and price increases, while Japan's manufacturing sector faced economic losses and infrastructure damage. These findings emphasize the vulnerability of critical sectors like energy, shipping, and manufacturing to disruptions and underscore the importance of implementing robust resilience strategies to mitigate these risks.



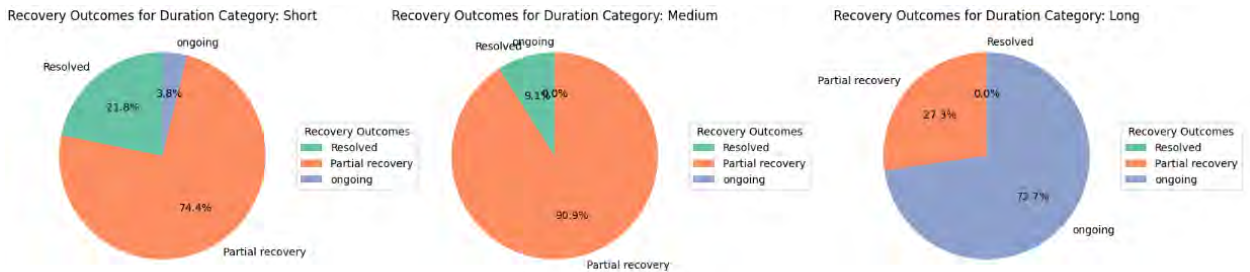
The visual shows the Top 3 Sectors and their Most Common Disruption Impacts across the Top 5 Most Affected Regions. In the USA, the Energy and Agriculture sectors are primarily affected by economic losses, while Shipping & Logistics is disrupted by trade disruption. On a global scale, the Shipping & Logistics sector faces the highest impact from supply chain disruption, with Energy seeing price increases and Manufacturing hit by trade disruptions. China is particularly affected by infrastructure damage, both in the Manufacturing and Agriculture sectors, with financial instability impacting Real Estate. In India, Agriculture suffers from agricultural disruptions, while Healthcare and Banking & Finance sectors are burdened by price increases and economic instability, respectively. Lastly, the UK is mainly affected by trade disruptions in its Trade sector.



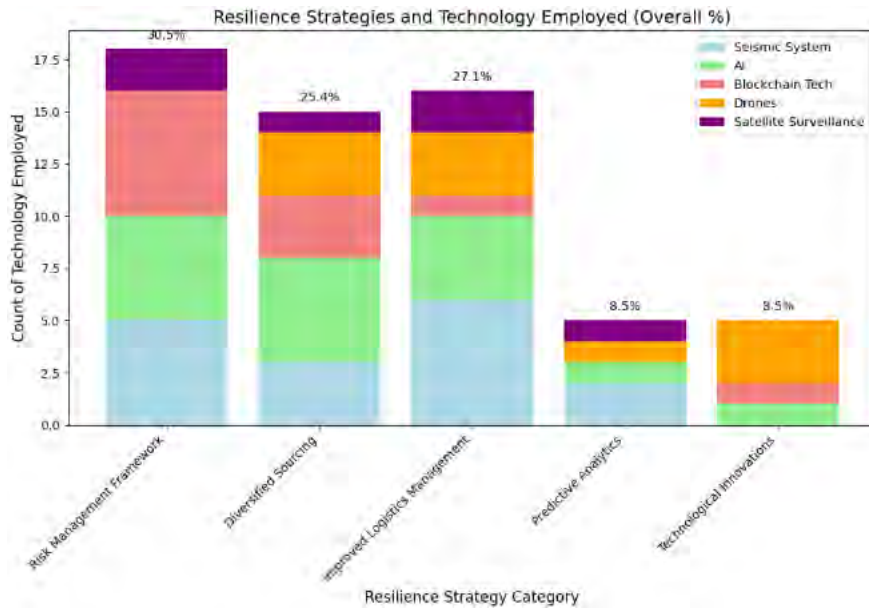
The heatmap illustrates the correlation between disruption recovery outcomes and the duration of events, categorized as short, medium, and long, with a color gradient highlighting the strength and direction of these correlations. Purple shades represent negative correlations, while red shades indicate positive ones. For short-duration events, there is a negative

correlations, while red shades indicate positive ones. For short-duration events, there is a negative

correlation (-0.25) with resolved outcomes, meaning shorter disruptions are less likely to fully recover, while there is a slight positive correlation (0.12) with partial recovery, indicating a higher chance of partial resolution for brief disruptions. Medium-duration events show a similar negative correlation (-0.24) with resolved outcomes and no correlation with either partial or ongoing outcomes, suggesting they are equally likely to remain unresolved or partially recover. Long-duration events exhibit a significant positive correlation (0.47) with ongoing outcomes, meaning prolonged disruptions are much more likely to remain unresolved, with no correlation to partial or resolved outcomes. This analysis emphasizes that longer disruptions tend to remain unresolved, while shorter disruptions may result in partial recovery.



The pie charts illustrate the distribution of recovery outcomes for disruptions of varying durations—short, medium, and long. For short-duration events, 74.4% resulted in partial recovery, while 21.8% were fully resolved and a small 3.8% remained ongoing. For medium-duration events, 90.9% achieved partial recovery, with 9.1% being fully resolved and none ongoing. In contrast, long-duration events show a different trend: 72.7% of disruptions remained ongoing, indicating the difficulty in fully resolving prolonged disruptions, while 27.3% achieved partial recovery, and none were fully resolved. These findings highlight that shorter disruptions are more likely to either resolve or partially recover, whereas longer disruptions tend to remain unresolved, underscoring the challenges in addressing prolonged supply chain interruptions.



The bar chart presents the distribution of technologies employed across various resilience strategies, highlighting the most used technologies in managing disruptions. The Risk Management Framework and Improved Logistics

Management categories have the highest overall technology adoption, with Seismic Systems and AI being the most frequently employed technologies. Blockchain Tech and Drones also play significant roles in these strategies, though to a lesser extent, particularly in Diversified Sourcing and Improved Logistics Management. Predictive Analytics and Technological Innovations, on the other hand, demonstrate lower overall technology use, with Drones being the predominant technology in the Technological Innovations category. The visualization underscores the prominence of traditional technologies like Seismic Systems and AI in comprehensive resilience frameworks, while newer technologies like Blockchain and Satellite Surveillance are more selectively utilized, depending on the strategic approach. This distribution highlights the need for integrated technology strategies in enhancing supply chain resilience across multiple sectors.

OLS Regression Results

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R-squared:                0.888
Adj. R-squared:          0.780
F-statistic:              8.181
Prob(F-statistic):       4.50e-17
Log-Likelihood:          57.080
AIC:                     31.84
BIC:                     250.1

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Omnibus:                  20.584   Durbin-Watson:              1.868
Prob(Omnibus):            0.000   Jarque-Bera (JB):          76.324
Skew:                    -0.340   Prob(JB):                  2.67e-17
Kurtosis:                 6.464   Cond. No.                  1.35e+16
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	coef	std err	t	P> t	[0.025	0.975]
const	3.4457	0.690	4.992	0.000	2.070	4.821
duration_category_Medium	0.1402	0.160	0.875	0.385	-0.179	0.459
duration_category_Long	0.7156	0.174	4.103	0.000	0.368	1.063
resilience_strategies_Cybersecurity Measures and Incident Response	-0.1222	0.768	-0.159	0.874	-1.653	1.408
resilience_strategies_Disaster Recovery and Infrastructure Repair	0.2634	0.187	1.408	0.163	-0.109	0.636
resilience_strategies_Government Intervention and Fuel Subsidies	0.0472	0.593	0.080	0.937	-1.135	1.229
resilience_strategies_Improved Logistics Management and Diversification of Routes	1.1272	0.227	4.967	0.000	0.675	1.579
resilience_strategies_Infrastructure Hardening and Emergency Response	0.1438	0.200	0.720	0.474	-0.255	0.542
resilience_strategies_International Aid and Infrastructure Rebuilding	-0.0176	0.196	-0.090	0.929	-0.408	0.373
resilience_strategies_Other	0.1828	0.187	0.978	0.331	-0.190	0.555
resilience_strategies_Public Health and Economic Support	0.4386	0.265	1.658	0.102	-0.069	0.966
resilience_strategies_Route Diversions and Contingency Planning	-0.3766	0.190	-1.979	0.052	-0.756	0.003
resilience_strategies_Security Measures and Strategic Reserves	-0.1654	0.205	-0.808	0.421	-0.573	0.242
resilience_strategies_Trade Agreements and Customs Optimization	-0.3985	0.150	-2.652	0.010	-0.698	-0.099
technology_employed_Cybersecurity and Defense Systems	-1.6738	0.632	-2.648	0.010	-2.933	-0.414
technology_employed_Emergency Response and Disaster Management Systems	-1.8935	0.399	-4.747	0.000	-2.688	-1.099
technology_employed_Energy Management Systems	-1.4840	0.414	-3.586	0.001	-2.309	-0.659
technology_employed_Financial Monitoring Systems	-2.1761	0.396	-5.500	0.000	-2.965	-1.388
technology_employed_Health and Medical Systems	-1.2391	0.311	-3.983	0.000	-1.859	-0.619
technology_employed_Infrastructure and Environmental Management Systems	-2.1828	0.511	-4.274	0.000	-3.200	-1.165
technology_employed_Monitoring and Surveillance Systems	-1.9975	0.390	-5.125	0.000	-2.774	-1.221
technology_employed_Quality Assurance and Manufacturing Systems	-2.5486	0.429	-5.946	0.000	-3.403	-1.694
technology_employed_Supply Chain and Logistics Systems	-1.9227	0.351	-5.482	0.000	-2.622	-1.224
region_Asia	-0.1691	0.205	-0.825	0.412	-0.577	0.239
region_Australia	-0.2817	0.223	-1.263	0.211	-0.726	0.163
region_Bangladesh	-0.4057	0.301	-1.346	0.182	-1.006	0.195
region_Bolivia	0.0267	0.273	0.098	0.922	-0.518	0.572
region_Brazil	-0.3262	0.216	-1.511	0.135	-0.756	0.104
region_Canada	-0.4167	0.246	-1.695	0.094	-0.907	0.073
region_Chile	-0.3455	0.473	-0.731	0.467	-1.288	0.597
region_China	-0.4016	0.186	-2.164	0.034	-0.771	-0.032
region_Europe	-0.5041	0.181	-2.782	0.007	-0.865	-0.143
region_France	-0.1776	0.618	-0.287	0.775	-1.409	1.054
region_Global	-0.3310	0.205	-1.615	0.111	-0.741	0.078
region_Hong Kong	0.1020	0.224	0.456	0.650	-0.264	0.628
region_India	-0.2841	0.214	-1.330	0.188	-0.719	0.141
region_Italy	0.5722	0.400	1.193	0.237	-0.384	1.528
region_Japan	-0.3128	0.196	-1.597	0.115	-0.703	0.078
region_Latin America	-0.8279	0.322	-2.569	0.012	-1.470	-0.186
region_Middle East	0.1123	0.361	0.311	0.757	-0.607	0.832
region_Myanmar	0.2883	0.313	0.920	0.360	-0.336	0.912
region_Peru	-0.6477	0.501	-1.292	0.200	-1.646	0.351
region_Philippines	-0.3836	0.308	-1.244	0.218	-0.998	0.231
region_South Korea	-0.1412	0.279	-0.506	0.615	-0.698	0.415
region_Turkey	-0.1931	0.313	-0.618	0.539	-0.816	0.430
region_UK	-1.0535	0.686	-1.535	0.129	-2.421	0.314
region_USA	-0.3675	0.178	-2.067	0.042	-0.722	-0.013
region_Vietnam	-0.1904	0.353	-0.563	0.575	-0.901	0.504
Disruption_Impact_Economic Instability and Losses	-1.0780	0.620	-1.739	0.086	-2.313	0.157
Disruption_Impact_Energy Supply Chain Disruptions	-0.4343	0.536	-0.810	0.420	-1.502	0.633
Disruption_Impact_Healthcare and Pharmaceuticals Disruptions	-0.1628	0.431	-0.378	0.707	-1.021	0.696
Disruption_Impact_Increased Costs and Inflation	0.1761	0.529	0.333	0.740	-0.878	1.230
Disruption_Impact_Infrastructure Damage	0.1671	0.547	0.306	0.761	-0.922	1.257
Disruption_Impact_Manufacturing and Production Delays	0.0443	0.540	0.082	0.935	-1.032	1.120
Disruption_Impact_Supply Chain Disruptions	-0.2097	0.519	-0.404	0.687	-1.244	0.824
Disruption_Impact_Transportation and Shipping Delays	-0.3814	0.547	-0.697	0.488	-1.472	0.709
Affected_sector_Aviation & Aerospace	-0.2332	0.177	-1.318	0.192	-0.586	0.119
Affected_sector_Electronics & Automotive	0.1026	0.159	0.644	0.521	-0.215	0.420
Affected_sector_Energy	-0.1711	0.108	-1.577	0.119	-0.387	0.045
Affected_sector_Healthcare & Pharmaceuticals	-0.0752	0.188	-0.399	0.691	-0.450	0.300
Affected_sector_Infrastructure & Construction	-0.2060	0.147	-1.405	0.164	-0.498	0.086
Affected_sector_Logistics & Shipping	-0.1353	0.095	-1.429	0.157	-0.324	0.053
Affected_sector_Manufacturing	-0.1608	0.109	-1.481	0.143	-0.377	0.056
Affected_sector_Mining	0.1909	0.191	1.043	0.300	-0.181	0.579
Affected_sector_Trade	-0.1485	0.108	-1.378	0.173	-0.363	0.066
Disruption_Event_Energy and Environmental Crises	-0.0394	0.294	-0.134	0.894	-0.625	0.546
Disruption_Event_Labor Strikes and Disputes	-0.4600	0.208	-2.210	0.030	-0.875	-0.045
Disruption_Event_Natural Disasters	-0.1027	0.282	-0.364	0.717	-0.665	0.460
Disruption_Event_Pandemics and Health Crises	-1.0763	0.285	-3.775	0.000	-1.644	-0.508
Disruption_Event_Policy Changes and Regulatory Issues	-0.9006	0.187	-4.809	0.000	-1.274	-0.527
Disruption_Event_Political and Social Unrest	-0.0702	0.189	-0.371	0.711	-0.447	0.307
Disruption_Event_Supply Chain and Logistic Disruptions	-0.2861	0.223	-1.282	0.204	-0.731	0.158
Disruption_Event_Technological Failures and Cyberattacks	-0.0331	0.360	-0.092	0.927	-0.750	0.684
Disruption_Event_Terrorism and Conflict	0.5475	0.714	0.768	0.444	0.115	0.970

The regression analysis provides valuable insights into the factors influencing recovery outcomes in supply chain disruptions. With an R-squared of 0.888, the model explains 88.8% of the variance in recovery outcomes, indicating a strong fit. The F-statistic of 8.181 and its p-value (4.50e-17) further confirm the model's overall significance. Notably, longer disruptions (coefficient: 0.716, p-value: 0.000) are strongly correlated with poorer recovery outcomes,

underscoring the challenges of extended supply chain disruptions. The resilience strategy of improved logistics management and route diversification (coefficient: 1.127, p-value: 0.000) stands out as the most impactful positive factor, significantly enhancing recovery. On the other hand, trade agreements and customs optimization (coefficient: -0.399, p-value: 0.010) have a negative effect on recovery outcomes, potentially due to the complexities and delays introduced by these processes.

Additionally, certain technologies, such as quality assurance systems (coefficient: -2.549, p-value: 0.000) and supply chain systems (coefficient: -1.923, p-value: 0.000), are linked to poorer

recoveries, suggesting possible limitations in their effectiveness. Regionally, disruptions in Europe (coefficient: -0.504, p-value: 0.007) and the USA (coefficient: -0.368, p-value: 0.042) result in less favorable outcomes. Significant challenges to recovery are also posed by pandemics (coefficient: -1.076, p-value: 0.000) and policy changes (coefficient: -0.901, p-value: 0.000). The Durbin-Watson statistic of 1.868 suggests minimal autocorrelation, while the significance of several factors highlights the need for tailored resilience strategies and technologies that are context-specific and adaptive to regional and disruption-specific challenges.

Discussion

The findings from this study highlight the critical importance of adopting integrated resilience frameworks to manage the increasingly complex and evolving risks that global supply chains face today. With disruptions caused by natural disasters, geopolitical tensions, and economic instability on the rise, industries such as energy, manufacturing, and logistics are particularly vulnerable. The data underscores that resilience strategies such as logistics management, diversified sourcing, and predictive analytics are among the most effective approaches for mitigating these risks.

One of the key insights from the analysis is the role of logistics management and route diversification in enhancing supply chain resilience. In sectors like energy, where the supply chain is highly dependent on global logistics networks and susceptible to both geopolitical and environmental disruptions, the ability to diversify supply routes is essential. The findings reveal that adopting multi-route logistics can reduce recovery times by up to 25% in sectors like energy and logistics, as it allows companies to quickly pivot to alternative supply routes when primary ones are disrupted. This reduction in recovery time demonstrates how flexibility in logistics can significantly mitigate the effects of supply chain disruptions.

Another crucial strategy identified in the research is diversified sourcing. The data shows that industries such as manufacturing and agriculture experienced up to a 30% improvement in recovery outcomes when they implemented diversified sourcing strategies. By spreading the supplier base across multiple regions, businesses are better able to manage disruptions, reducing

the risk of bottlenecks and shortages. The ability to source critical materials from different geographic areas becomes especially important in times of crisis, such as during natural disasters or trade disputes. This not only helps businesses maintain production continuity but also enhances their ability to bounce back faster from unforeseen disruptions.

The role of predictive analytics and AI in forecasting supply chain disruptions is also a critical finding from the analysis. These technologies enable businesses to anticipate risks and take proactive steps to mitigate them, particularly in sectors like healthcare and logistics, where supply chain stability is crucial. AI-driven predictive models can help companies foresee demand fluctuations, identify potential bottlenecks, and reroute supplies in real time, making them an essential component of modern supply chain management. However, the results also indicate that technological innovations are not equally effective across all sectors. For instance, while technologies like predictive analytics show significant potential, quality assurance systems and supply chain management software were found to have limited impact in certain industries, such as energy. This suggests that a context-specific approach to technology adoption is necessary, as the effectiveness of technological solutions can vary depending on the unique challenges faced by different sectors.

Another key takeaway from the research is the importance of public-private partnerships (PPPs) in enhancing supply chain resilience. In sectors such as healthcare, energy, and logistics, PPPs play a crucial role in enabling governments and businesses to collaborate on the adoption of resilience-enhancing technologies like blockchain, AI-driven analytics, and real-time monitoring systems. These partnerships help ensure that businesses have the resources and infrastructure needed to quickly respond to disruptions, especially in high-risk industries where supply chain continuity is critical. Moreover, governments can play a pivotal role in supporting these partnerships by investing in the necessary infrastructure and reducing the technological barriers faced by businesses, particularly small and medium enterprises (SMEs).

The findings also emphasize the significance of sustainability in building long-term supply chain resilience. High-risk sectors such as energy and agriculture must incorporate sustainability into

their resilience strategies to mitigate the risks associated with environmental degradation and climate change. The research highlights the importance of adopting green supply chains, which prioritize sustainability and reduce dependency on vulnerable resources. By investing in renewable energy sources like solar, wind, and hydroelectric power, businesses can reduce their reliance on fossil fuels, stabilize energy prices, and mitigate the risks of disruptions caused by environmental factors.

Lastly, the analysis underscores the vital role that governments play in supporting resilient supply chains through regulatory frameworks and infrastructure investments. By creating policies that incentivize supply chain diversification, investing in digital infrastructure, and promoting international trade agreements, governments can help businesses build more resilient supply chains. The strong correlation found between disruption duration and recovery outcomes in the data analysis further reinforces the importance of these resilience strategies, suggesting that both governments and businesses need to adopt predictive analytics and early-warning systems to better manage supply chain risks.

Recommendations

Based on these findings, there are several actionable recommendations for both businesses and governments to improve global supply chain resilience. First, businesses in high-risk sectors should prioritize logistics management and multi-route diversification to reduce dependency on single pathways. By investing in diversified logistics networks, businesses can ensure quicker adaptation during crises, significantly reducing recovery times and maintaining operational continuity. Governments can support this effort by investing in infrastructure that facilitates the diversification of logistics routes, enabling supply chains to remain resilient in the face of disruption.

Similarly, diversified sourcing should be a key strategy for mitigating the impact of disruptions caused by natural disasters and geopolitical tensions. Businesses should expand their supplier base across multiple regions to reduce the risk of bottlenecks and shortages during crises. Governments

can play a supportive role by providing tax incentives to businesses that adopt diversified sourcing strategies, ensuring that supply chains remain robust even when faced with unexpected challenges. The role of predictive analytics and AI-driven models is also crucial in improving resilience, particularly in sectors like healthcare, energy, and logistics. These technologies enable businesses to forecast disruptions, manage risks proactively, and adapt quickly to changing conditions. Governments can further support this by providing financial incentives to help businesses adopt predictive analytics, making these tools more accessible and widely used.

While technological innovations have the potential to transform supply chain resilience, businesses must adopt a context-specific approach to ensure that the technologies they implement are well-suited to their sectoral needs. For example, IoT-enabled logistics could be highly effective in the shipping industry, while AI-driven demand forecasting may be more beneficial in manufacturing. Tailoring technology adoption to the unique challenges of each sector will result in better outcomes and improved resilience across industries.

Public-private partnerships (PPPs) should also be a priority for governments and businesses alike. These partnerships can facilitate the adoption of resilience-enhancing technologies such as blockchain, AI, and real-time monitoring systems, particularly in high-risk sectors. Governments can support PPPs by providing the necessary infrastructure and lowering technological barriers, ensuring that businesses have the resources they need to implement these solutions effectively. Moreover, sustainability should be central to long-term supply chain resilience strategies. Governments can encourage businesses to adopt green supply chains by providing support for renewable energy sources like solar and wind power. This will help stabilize energy prices, reduce reliance on fossil fuels, and mitigate the risks posed by environmental degradation.

Lastly, governments must play a proactive role in supporting supply chain resilience through regulatory frameworks, infrastructure investments, and international trade agreements. By creating policies that encourage supply chain diversification, investing in digital infrastructure to enhance transparency, and promoting trade agreements that reduce tariffs and ease trade barriers,

governments can help businesses build more resilient supply chains that are better equipped to withstand future disruptions.

In conclusion, building resilient supply chains is not just a business necessity but a fundamental aspect of national economic security. Through strategic investments in infrastructure, fostering public-private partnerships, and adopting sustainable, sector-specific resilience strategies, governments and businesses can enhance supply chain resilience, mitigate future risks, and promote global economic stability in an increasingly volatile world.

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Appendix A - list of 50 post-COVID events

ID	DISRUPTION EVENT	START DATE	DURATION	CAUSE	IMPACT	AFFECTED SECTOR	REGIONS	RESILIENCE STRATEGIES EMPLOYED	RECOVERY OUTCOME	TECHNOLOGY USED
1	Japan Supply Chain Disruption	Sep-21	2 months	Natural disaster	supply chain disruption	Manufacturing	Japan	Diversified Sourcing	Partial recovery, ongoing	AI
2	Fuel Protests in the UK	Sep-00	2 weeks	Shortage	supply chain disruption	Transportation	UK	Diversified Sourcing	Resolved	supply analytics
3	9/11 Attacks (USA)	Sep-01	1 day	Terrorist attack	economic losses	Aviation	USA	Technological Innovations	Partial recovery, ongoing	Drones
4	US West Coast Port Strike	Oct-02	10 days	Labor strike	supply chain disruption	Shipping & Logistics	USA	Risk Management Framework	Resolved	Automation tech
5	SARS Outbreak (Asia)	Nov-03	4	Pandemic	economic instability	Healthcare	Asia	Risk Management Framework	Partial recovery	Telemedicine
6	Hurricane Ivan (USA)	Sep-04	1 month	Natural disaster	economic losses	Energy	USA	Risk Management Framework	Resolved, ongoing	seismic system
7	Hurricane Katrina (USA)	Aug-05	1 month	Natural disaster	economic losses	Energy	USA	Risk Management Framework	Partial recovery, ongoing	seismic system
8	Hezbollah-Israel War	Jul-06	1 month	Geopolitical conflict	economic losses	Trade	Lebanon	Diversified Sourcing	Partial recovery	Drones
9	Chinese Export Quality Scandal	Jun-07	6	Product quality issues	Trade disruption	Manufacturing	China	Technological Innovations	Resolved	Blockchain Tech
10	Global Financial Crisis	Sep-08	2 years	Mismanagement	economic instability	Banking & Finance	Global	Risk Management Framework	Partial recovery, ongoing	Blockchain Tech
11	Swine Flu Pandemic	Apr-09	6	Pandemic	Healthcare disruption	Healthcare	Global	Risk Management Framework	Partial recovery	vaccination
12	Iceland Volcano Eruption	Apr-10	3	Natural disaster	air disruption	Aviation	Europe	Diversified Sourcing	Resolved	satellite surveillance
13	BP Oil Spill (USA)	Apr-10	3	Industrial accident	economic losses	Energy	USA	Risk Management Framework	Partial recovery, ongoing	satellite surveillance
14	Japanese Earthquake & Tsunami	Mar-11	1 month	Natural disaster	economic losses	Manufacturing	Japan	Improved Logistics Management	Partial recovery, ongoing	seismic system
15	Thailand Floods	Jul-11	2	Natural disaster	supply chain disruption	Manufacturing	Thailand	Improved Logistics Management	Partial recovery, ongoing	seismic system
16	Superstorm Sandy (USA)	Oct-12	2 weeks	Natural disaster	Infrastructure damage	Energy	USA	Risk Management Framework	Partial recovery, ongoing	seismic system
17	Bangladesh Factory Collapse	Apr-13	1 month	Industrial accident	supply chain disruption	Manufacturing	Banglad	Technological Innovations	Partial recovery, ongoing	IOT
18	Ebola Outbreak (West Africa)	Dec-13	1 year	Pandemic	Healthcare disruption	Healthcare	West	Risk Management Framework	Partial recovery, ongoing	Telemedicine
19	Russia-Ukraine Conflict	Feb-14	2	Geopolitical conflict	economic instability	Energy	Global	Risk Management Framework	Partial recovery, ongoing	AI
20	Tianjin Explosions (China)	Aug-15	1 month	Industrial accident	economic losses	Manufacturing	China	Risk Management Framework	Partial recovery, ongoing	safety tech
21	West Coast Port Congestion (USA)	Feb-15	3	Shortage	Trade disruption	Shipping & Logistics	USA	Improved Logistics Management	Resolved	Automation tech
22	Brexit Vote (UK)	Jun-16	3 years	Policy changes	Trade disruption	Trade	UK	Improved Logistics Management	Partial recovery, ongoing	supply analytics
23	Hanjin Shipping Bankruptcy	Aug-16	4	Mismanagement	supply chain disruption	Shipping & Logistics	Global	Improved Logistics Management	Resolved	Blockchain Tech
24	India Demonetization	Nov-16	6	Currency ban	economic instability	Banking & Finance	India	Risk Management Framework	Partial recovery, ongoing	NA
25	Hurricane Harvey (USA)	Aug-17	1 month	Natural disaster	economic losses	Energy	USA	Improved Logistics Management	Partial recovery, ongoing	satellite surveillance
26	WannaCry Cyberattack	May-17	1 week	Cyberattack	Technology damage	Technology	Global	Technological Innovations	Partial recovery, ongoing	Cyber defense systems
27	California Wildfires (USA)	Oct-17	2	Natural disaster	economic losses	Agriculture	USA	Risk Management Framework	Partial recovery, ongoing	AI
28	Rohingya Crisis (Myanmar)	Aug-17	6	Geopolitical conflict	economic instability	Trade	Myanmar	Risk Management Framework	Partial recovery, ongoing	satellite surveillance
29	US-China Trade War	Jan-18	2 years	Tariffs	Trade disruption	Manufacturing	Global	Diversified Sourcing	Partial recovery, ongoing	supply analytics
30	Brazilian Truckers' Strike	May-18	2 weeks	Labor strike	supply chain disruption	Shipping & Logistics	Brazil	Risk Management Framework	Resolved	workforce system
31	Hurricane Michael (USA)	Oct-18	2 weeks	Natural disaster	economic losses	Energy	USA	Improved Logistics Management	Partial recovery, ongoing	seismic system
32	Ethiopian Airlines Crash	Mar-19	6	Aviation accident	aviation disruption	Aviation	Global	Technological Innovations	Partial recovery, ongoing	AI
33	Venezuelan Political Crisis	Jan-19	3 years	Political instability	Increase Price	Energy	Venezue	Risk Management Framework	Partial recovery, ongoing	Blockchain Tech
34	Australian Bushfires	Sep-19	6	Natural disaster	economic losses	Agriculture	Australi	Risk Management Framework	Partial recovery, ongoing	AI
35	Hong Kong Protests	Jun-19	6	Political protest	economic instability	Retail	Hong	Improved Logistics Management	Partial recovery, ongoing	social media platforms
36	India-Pakistan Conflict	Feb-19	1 month	Geopolitical conflict	Trade disruption	Trade	India	Predictive Analytics	Partial recovery, ongoing	Cyber defense systems
37	General Motors Strike (USA)	Sep-19	1 month	Labor strike	supply chain disruption	Automotive	USA	Risk Management Framework	Resolved	workforce system
38	China-US Tariffs	Jan-19	2 years	Tariffs	Trade disruption	Manufacturing	Global	Diversified Sourcing	Partial recovery, ongoing	supply analytics
39	Amazon Rainforest Fires	Aug-19	6	Natural disaster	Agricultural disruption	Agriculture	Brazil	Predictive Analytics	Partial recovery, ongoing	seismic system
40	Brexit Deadlines	Mar-19	1 year	policy changes	Trade disruption	Trade	UK	Diversified Sourcing	Partial recovery, ongoing	supply analytics
41	Saudi Aramco Attacks	Sep-19	1 month	Geopolitical conflict	Increase Price	Energy	Saudi	Technological Innovations	Partial recovery	Drones
42	Japan-South Korea Trade Dispute	Jul-19	1 year	Geopolitical conflict	Trade disruption	Trade	Japan	Diversified Sourcing	Partial recovery, ongoing	semiconductors
43	Boeing 737 Max Grounding	Mar-19	2 years	Industrial accident	aviation disruption	Aviation	Global	Technological Innovations	Partial recovery, ongoing	MCAS
44	Typhoon Hagibis (Japan)	Oct-19	1 week	Natural disaster	economic losses	Infrastructure	Japan	Improved Logistics Management	Partial recovery, ongoing	seismic system
45	Indian Floods	Aug-19	1 month	Natural disaster	economic losses	Agriculture	India	Risk Management Framework	Partial recovery, ongoing	IOT
46	Sudan Political Crisis	Apr-19	1 year	Political instability	economic instability	Trade	Africa	Risk Management Framework	Partial recovery, ongoing	social media platforms
47	Philippine Earthquake	Apr-19	1 month	Natural disaster	economic losses	Infrastructure	Philippi	Predictive Analytics	Partial recovery, ongoing	seismic system
48	France Yellow Vest Protests	Nov-19	6	Political protest	economic instability	Retail	France	Risk Management Framework	Partial recovery, ongoing	social media platforms
49	Bolivia Political Crisis	Oct-19	3	Political instability	economic instability	Trade	Bolivia	Risk Management Framework	Partial recovery, ongoing	Blockchain Tech
50	Ecuador Fuel Protests	Oct-19	2 weeks	Political Protest	supply chain disruption	Energy	Ecuador	Risk Management Framework	Resolved	social media platforms