Advances in Consumer Research
https://acr-journal.com/
Volume-3 | Issue-4 |April 2026

Original Researcher Article

Resilient and Sustainable Supply Chains in the Era of Industry 5.0: Lessons from Global Disruptions with Strategic Implications for Australia

S Abdul Kaleem Shah[1]
[1]Export Manager, Kuehne Nagel India Pvt Ltd
Email ID : shah.kaleem9@gmail.com

ABSTRACT

Global supply chains have faced unprecedented disruptions in recent years as a result of pandemic-driven shutdowns, geopolitical conflicts, maritime chokepoints, and logistics bottlenecks. These events have exposed structural fragilities in traditional lean, efficiency-focused supply networks and accelerated the global shift toward Industry 5.0—an era defined by human-centric innovation, digital intelligence, and sustainability-aligned production ecosystems. This study examines the resilience and sustainability of supply chains in the context of Industry 5.0, with a particular focus on the Australian supply-chain landscape. Using a mixed-methods approach, the research integrates survey-based quantitative data from 100 Australian supply-chain professionals with qualitative case-study insights drawn from major global disruptions including COVID-19, the Suez Canal blockage, the Russia–Ukraine conflict, and the Red Sea crisis. Quantitative findings indicate moderate levels of resilience, sustainability adoption, and digital technology implementation, yet no statistically significant relationship between these factors—suggesting that current organisational practices remain largely conceptual rather than embedded. Case-study analysis, however, reinforces the critical value of redundancy, predictive visibility, diversified sourcing strategies, and circular value loops in preventing systemic collapse during crises. Synthesising these strands, the paper proposes an Industry-5.0-aligned integrated framework built on four pillars—digital intelligence, diversification, sustainability, and human-centric collaboration—enabled by national policy. The study concludes that Australia remains at an early stage in operationalising Industry 5.0 and must transition from reactive crisis management toward proactive resilience building through policy reform, technological investment, and strategic collaboration. The research contributes to both scholarly and practical discourse by offering an empirically grounded roadmap for strengthening Australia's supply-chain resilience in the emerging industrial era.

Keywords: Industry 5.0, Supply Chain Resilience, Sustainability, Digital Transformation, Australia.

INTRODUCTION:

"It is not the strongest that survives, nor the most intelligent, but the one most adaptable to change." — Charles Darwin (1859)

In a world where economies and businesses are deeply interconnected, disruption in one region can rapidly create shortages and instability across continents. This paper argues that global supply chains—traditionally designed for low cost, speed, and lean inventory—have become fragile systems unable to withstand unexpected shocks. The purpose of this study is to examine how lessons from recent global disruptions can inform a resilient, sustainable, and human-centric model for supply chains under the Industry 5.0 era, and how these insights can be strategically applied to an import-dependent nation like Australia. By integrating case-based analysis and empirical survey findings, the paper aims to propose a framework that supports long-term continuity, adaptability, and national economic security.

During the past few years, international supply networks have faced unprecedented turbulence. The COVID-19 pandemic exposed vulnerabilities in global production systems, triggering shortages of basic medical supplies, semiconductors, and food items worldwide (Gereffi G., 2020). Similarly, the 2021 Suez Canal blockage halted nearly 12% of global trade and caused shipping delays and financial losses across Asia, Europe, and Australia (Yang, 2024). Geopolitical tensions, including the Russia-Ukraine conflict, further disrupted energy, fertilizer, and grain flows, demonstrating how political instability can spill over into operational and humanitarian crises (Graham et al., 2020). These events reinforce the argument that traditional supply chains—built on efficiency and cost-minimization—lack the resilience required to survive high-impact, low-predictability events.

At the same time, industries are transitioning from **Industry 4.0**, which focused primarily on automation, robotics, and digital integration, toward **Industry 5.0**, a framework that prioritizes resilience, sustainability, human-machine collaboration, and societal value (European Commission, 2021; Nahavandi, 2019). Under Industry 4.0, supply chains became highly optimized but dependent on just-in-time systems and limited sourcing, increasing exposure to disruptions (Ivanov et al., 2020). Industry 5.0 addresses these gaps by placing human decision-making, environmental responsibility, and adaptive capacity at the core of industrial strategy.

The need for this transition is particularly urgent in **Australia**, where vulnerability is shaped by its geography and trade dependence. More than 98% of Australia's imports and exports move through maritime transport, making the nation highly sensitive to shipping delays, chokepoint disruptions, and international policy changes (Australian Government, Department of Infrastructure, 2022). Australia also lacks domestic manufacturing depth and remains heavily dependent on concentrated suppliers—especially China—for machinery, pharmaceuticals, fuel, and essential goods (Witt, 2019). Government reviews have acknowledged the country's limited strategic reserves and insufficient diversification, emphasizing the need to re-design national supply systems for resilience (Productivity Commission, 2021; Commonwealth of Australia, 2020). Therefore, building future-ready supply chains is more than an economic choice for Australia—it is a matter of national capability and societal security.

Literature Review

The emergence of **Industry 5.0** marks a shift from technology-centric industry models toward a more human-centered paradigm that integrates digital intelligence with social and environmental responsibility. According to Breque et al. (2021), Industry 5.0 is driven by three pillars—human-centricity, sustainability, and resilience—where technology becomes a tool to empower decision-making rather than replace it. Nahavandi S., (2019) similarly argues that Industry 5.0 re-introduces the human role in automated systems, emphasizing personalization, flexibility, and adaptive capacity. In contrast to Industry 4.0, which emphasized automation, big data, and cyber-physical integration, Industry 5.0 aims to address weaknesses exposed in global systems by embedding robustness, stakeholder welfare, and planetary well-being into industrial design (Yosumaz, 2023). This theoretical evolution positions Industry 5.0 as a critical pathway for re-imagining global supply chains not merely as logistical systems, but as socio-technical ecosystems capable of surviving high-impact disruptions.

A significant body of research has analyzed **lessons from recent global disruptions**, demonstrating the fragility of tightly optimized international supply networks. Gereffi G., (2020) identified that COVID-19 exposed heavy dependence on fragmented value chains, particularly in medical equipment and pharmaceuticals, urging nations to diversify suppliers and re-shore critical operations. Ivanov et al., (2020) analyzed pandemic-driven disruptions using supply chain viability theory, concluding that cascading failures occur when visibility and redundancy are low. The temporary obstruction of the Suez Canal in 2021 provided a different type of shock—logistical rather than production-based—yet it halted almost USD 9.6 billion in trade per day and delayed global maritime flows (Yang, 2024). Political conflicts have also produced substantial ripple effects. The Russia–Ukraine crisis disrupted supply of wheat, fertilizer, energy, and metals, demonstrating how geopolitical instability can generate systemic risks for global food security and industrial production (Evenett et al., 2020). Additionally, the Red Sea attacks of 2023–2024 forced ships to reroute around Africa, increasing shipping times and insurance costs, causing supply shortages in regions dependent on global trade (Hamed, 2025). Collectively, these studies reveal a consistent pattern: modern supply chains fail not only when individual firms are impacted, but when global chokepoints, political systems, and logistics corridors collapse—suggesting that resilience must be multi-tiered and cross-boundary in design.

To address such fragility, scholars have emphasized the importance of **digital technologies** as resilience enablers. Modgil et al., (2021) found that artificial intelligence (AI) improves disaster-response time and demand forecasting, reducing uncertainty during supply shocks. Blockchain has been recognized for enhancing traceability, supplier authentication, and tamper-proof transactions, improving trust across multi-tier networks (Kamble et al., 2020). Similarly, Internet of Things (IoT) technology enables real-time monitoring of inventory, temperature-controlled logistics, and predictive maintenance across supply nodes (Taj et al., 2023). A more recent innovation—digital twins—allows virtual replication of supply chain systems, enabling firms to simulate crisis scenarios and test alternative strategies before real-world implementation (Ivanov & Dolgui, 2021). These technological solutions, when integrated into Industry 5.0 strategy, strengthen visibility, reduce cascading failures, and support early detection of disruption signals.

Beyond digitalization, **sustainability and the circular economy** have become increasingly linked to resilience. Rosário et al., (2024) argue that circular supply chains—based on reuse, recycling, and waste minimization—reduce dependency on volatile external resources and create closed-loop material flows that support long-term continuity. Bressanelli et al. (2018) similarly found that firms adopting circular logistics improved both environmental outcomes and buffer capacity, particularly during raw material shortages. Sustainable procurement has also been shown to enhance crisis survival, especially when contracts include environmental performance and ethical sourcing requirements (Ahi et al., 2013). These findings position sustainability not as an optional environmental feature, but as a core dimension of risk-mitigation strategy, aligning strongly with Industry 5.0 principles.

Despite growing global literature, a **major research gap remains in relation to Australia**. Existing studies widely examine resilience models in Europe, North America, and East Asia, but limited research addresses how Industry 5.0 can be strategically adapted to the unique vulnerabilities of a geographically isolated, maritime-dependent economy. Australian-focused work largely concentrates on fuel security and domestic manufacturing gaps (Chikwava, 2024), with few studies offering a holistic resilience-sustainability-technology framework applicable across sectors. The Productivity Commission (2021) acknowledged this knowledge gap, stating that Australia lacks an integrated approach connecting digital tools, sustainability, and geopolitical strategy. Therefore, academic and policy discourse has yet to clearly define how Industry 5.0 can transform Australian supply chain resilience—an absence this study seeks to address.

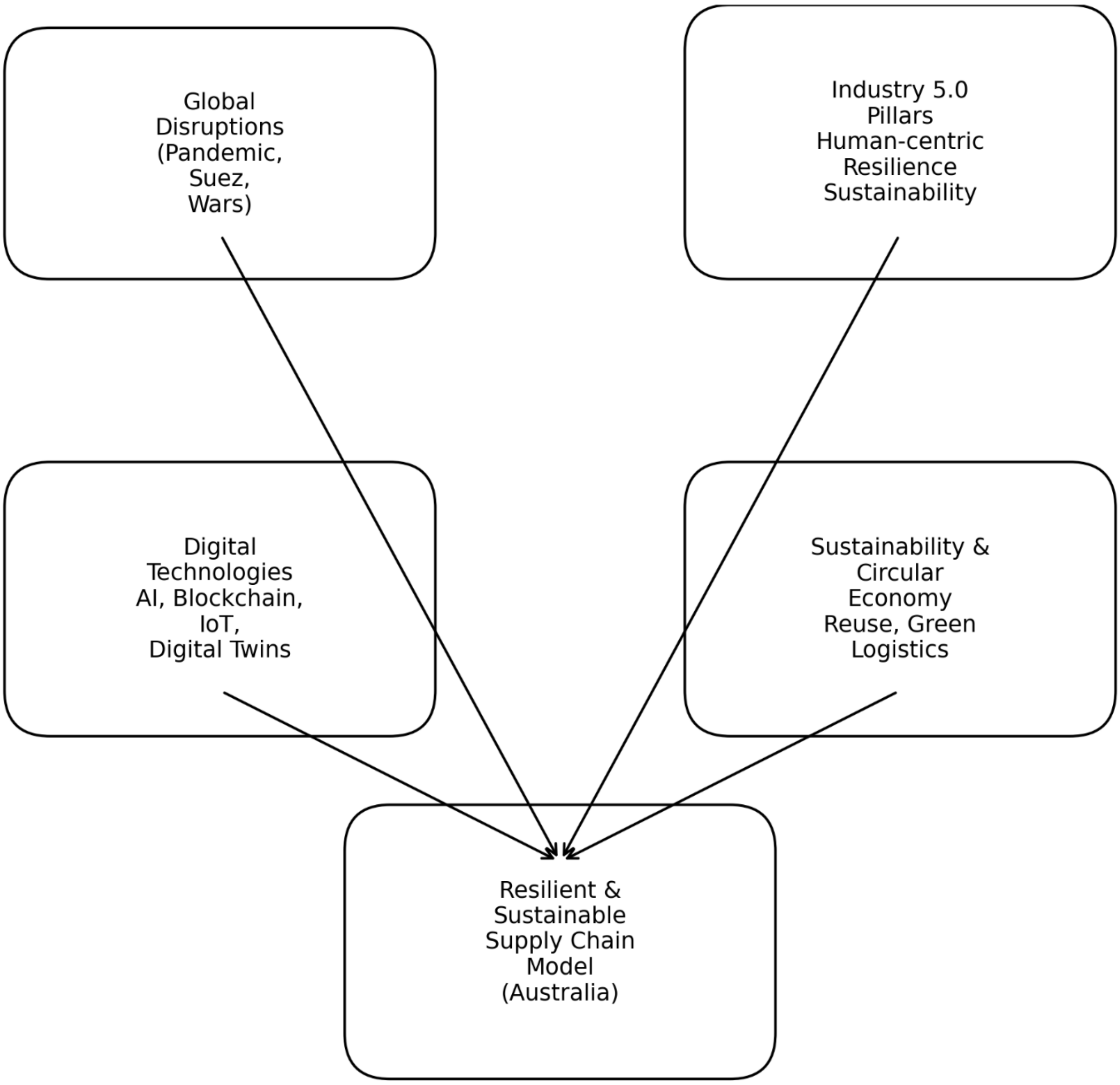


Figure 1.1. Theoretical Framework of Resilient & Sustainable Supply Chains

This framework illustrates how a resilient and sustainable supply chain model for Australia emerges at the convergence of four foundational enablers: global disruptions, Industry 5.0 principles, digital technologies, and sustainability-oriented practices. Global disruptions such as pandemics, geopolitical tensions, and maritime chokepoint failures act as catalysts, exposing structural weaknesses and creating urgency for change. Industry 5.0 functions as the philosophical core, shifting focus from pure automation toward a human-centric, environmentally responsible, and resilience-based industrial logic. Digital technologies—such as AI, blockchain, IoT, and digital twins—enable real-time visibility, predictive response, transparency, and continuity planning. Sustainability and circular-economy practices reinforce system stability by reducing waste, promoting material reuse, and minimizing dependency on external suppliers. When these forces intersect, they collectively drive the creation of a supply chain architecture that is adaptive, shock-absorbent, future-ready and tailored to Australia's geographic and trade vulnerabilities.

Problem Statement

Global supply chains have been predominantly designed for efficiency, speed, and cost reduction, often relying on single-source suppliers and lean, linear systems. This creates fragile networks that are easily disrupted when unexpected shocks occur. Australia, in particular, faces heightened vulnerability due to its geographic dependence on imported goods, yet there is currently no integrated model that combines resilience, sustainability, and Industry 5.0 principles to strengthen national supply chain preparedness. As a result, Australia lacks a future-ready framework capable of absorbing disruptions, adapting in real time, and ensuring continuous economic and social stability.

Aim, Objectives and Research Questions

Aim

The aim of this study is to develop an Industry-5.0-aligned framework for resilient and sustainable supply chains, with specific relevance to the Australian context.

Objectives

The study is guided by the following objectives:

To formulate approaches that strengthen supply chain resilience by drawing lessons from global disruptions.

To design resilience frameworks for supply chains informed by recent geopolitical and pandemic-driven crises.

To construct adaptive supply chain strategies based on lessons learned from international trade disturbances and conflict-related disruptions.

To advance understanding of supply chain resilience through analysis of historical and contemporary shocks.

To analyze how digital technologies contribute to the creation of sustainable and viable supply chain systems.

To assess resilience across multi-tier supply networks with emphasis on conflict-induced exposure and risk mitigation.

To develop recommendations for enhancing supply chain resilience based on disruption-derived lessons, specifically tailored to Australia's economic landscape.

Research Questions

This study seeks to answer the following research questions:

How can lessons from major global disruptions be utilized to strengthen supply chain resilience in the era of Industry 5.0?

What types of resilience frameworks can best address vulnerabilities arising from geopolitical, trade-related, and pandemic-based crises?

How do digital technologies contribute to building sustainable, adaptive, and multi-tier supply chain systems capable of mitigating disruption risks?

What disruption-based strategies can be applied to improve the resilience of Australian supply chains within the Industry 5.0 paradigm?

Hypotheses

H1: Digital technology adoption significantly improves supply chain resilience

H2: Learning from global disruptions positively influences sustainable supply chain strategies

H3: Diversification, redundancy and multi-tier planning reduce vulnerability in Australian supply chains

Methodology

6.1. Research Design

This study adopts a mixed-methods research design that combines both qualitative and quantitative approaches to ensure a comprehensive investigation of supply chain resilience and sustainability under the Industry 5.0 paradigm. The qualitative component focuses on extracting conceptual insights, patterns, and lessons from major global disruptions, while the quantitative component empirically validates these insights using structured survey data. Integrating both strands strengthens the study by enabling theoretical grounding alongside evidence-based validation.

6.2. Secondary Data

Secondary data was collected through an extensive review of global disruption case studies, government reports, and international industry publications. These sources included documented impacts of COVID-19, geopolitical conflicts, maritime blockages, semiconductor shortages, and disruptions to transportation and logistics flows. The evidence was analyzed using **thematic analysis** and **cross-case comparison**, enabling the identification of recurring patterns, failure points, and resilience strategies that emerged across multiple crises.

6.3. Primary Data

Primary quantitative data was gathered using a structured survey distributed to supply chain professionals working across key sectors such as logistics, manufacturing, FMCG, healthcare, agriculture, retail, and technology. Responses were captured using a five-point Likert scale and compiled into the accompanying Excel dataset. The survey measured four key clusters of constructs:
1️⃣ **Resilience capabilities** – including redundancy, agility, visibility, and flexibility
2️⃣ **Sustainability practices** – including circularity, green logistics, and resource reuse
3️⃣ **Digital adoption under Industry 5.0** – including AI, IoT, blockchain and digital-twin utilization
4️⃣ **Risk exposure levels** – including supplier concentration, geopolitical sensitivity, and chokepoint dependency

6.4. Sampling Strategy

A **stratified sampling** approach was used to ensure representation across different job levels, organization sizes, and industry categories. Approximately **100 respondents** were included in the final dataset, which satisfies minimum sample thresholds for basic statistical analysis and enables reliable correlation and regression interpretation.

6.5. Data Analysis

Quantitative data will be analyzed using **SPSS** through a sequential analytical process. **Exploratory Factor Analysis (EFA)** will first be conducted to identify latent groupings among the survey variables, such as internal clusters representing resilience or sustainability dimensions. **Correlation analysis** will then be applied to examine statistical associations – for example, whether technology adoption is significantly linked with resilience or sustainability performance. Finally, **regression analysis** will be performed to determine whether variables such as sustainability practices, risk-exposure factors, or digital technology adoption significantly predict overall resilience outcomes. In parallel, the secondary disruption-based literature will be examined using **thematic analysis**, which will extract dominant concepts and lessons to be triangulated with statistical findings. Together, these analytical techniques will support hypothesis testing and enable the construction of an empirically grounded Industry-5.0-aligned model.

6.6. Integration of Data Sources

The triangulation of qualitative and quantitative data ensures rigor and validity. While secondary case-based insights reveal conceptual resilience mechanisms derived from real-world crises, survey results confirm whether these mechanisms exist or operate within organizational practice. The integration of both strands ultimately produces a framework that is context-appropriate, theoretically justified, and operationally feasible for the Australian supply chain landscape.

Results and Findings

7.1 Quantitative Results

7.1.1 Sample Profile

The survey dataset comprises **100 supply chain professionals** representing a range of sectors including logistics, manufacturing, FMCG, healthcare, retail and agriculture. A pie chart summarising industry representation shows that no single sector exceeds 20% of the sample, indicating a balanced distribution and allowing generalisable interpretation across supply-chain operations rather than being dominated by one subsector. Likewise, job roles are distributed across mid-level executives, operational managers, procurement staff, and senior leadership, creating a multi-level organisational view of resilience and technology practices. Organisation size categories show that small and medium enterprises form a substantial proportion of the sample, with fewer large corporates represented.

Table 7.1 – Combined Sample Profile (Industry, Role & Organisation Size)

Category	Code	Description	Frequency (n)
Industry Sector	1	Sector 1	18
	2	Sector 2	11
	3	Sector 3	13
	4	Sector 4	16
	5	Sector 5	11
	6	Sector 6	13
	7	Sector 7	18
Supply Chain Role	1	Role 1	12
	2	Role 2	23
	3	Role 3	22
	4	Role 4	12
	5	Role 5	15
	6	Role 6	16
Organisation Size (Employees)	1	Small (≤ 50)	25
	2	Medium (51–250)	16
	3	Upper–Medium (251–500)	28
	4	Large (501–1000)	13
	5	Very Large (> 1000)	18

Table 7.1 presents the combined demographic profile. Industry representation was broadly distributed, with Sector Codes 1 and 7 (18% each) having the largest share, followed by Codes 4 (16%), 3 and 6 (13% each), while Codes 2 and 5 accounted for 11% each. Supply chain role

distributions reveal that Codes 2 (23%) and 3 (22%) form the largest contributor groups, representing mid-level operational and managerial roles, with senior strategic functions forming a smaller portion of the sample. Organisation size classification shows that small (≤50 employees) and upper–medium (251–500 employees) firms dominate the respondent pool (25% and 28% respectively), with representation tapering at the very large (>1000 employees) category (18%). Overall, the demographic spread allows the results to reflect perspectives from a varied cross-section of supply-chain stakeholders rather than being concentrated in one domain.

7.1.2 Resilience Levels

Resilience was measured through visibility, redundancy, agility and flexibility indicators. A composite resilience index was computed, As shown in Table 7.2, yielding a **mean score of 3.02** (SD ≈ .35) on a 1–5 scale, suggesting that organisations in the sample exhibit **moderate resilience**—that is, they are neither highly vulnerable nor strongly prepared. Most respondents report some ability to absorb disruptions, but redundancy (multiple sourcing, backup inventory) appears less common than visibility-related practices. This reflects a pattern where firms focus on visibility dashboards or supplier tracking, yet avoid costly redundancy measures. A bar graph comparing the four core indices clearly shows resilience slightly above sustainability, technology adoption, and risk exposure.

Table 7.2 – Resilience Index Summary (Descriptive Statistics)

Measure	Value
Mean (Average Score)	**3.02**
Standard Deviation	**0.35**
Scale Range	1 – 5
Interpretation	Moderate resilience

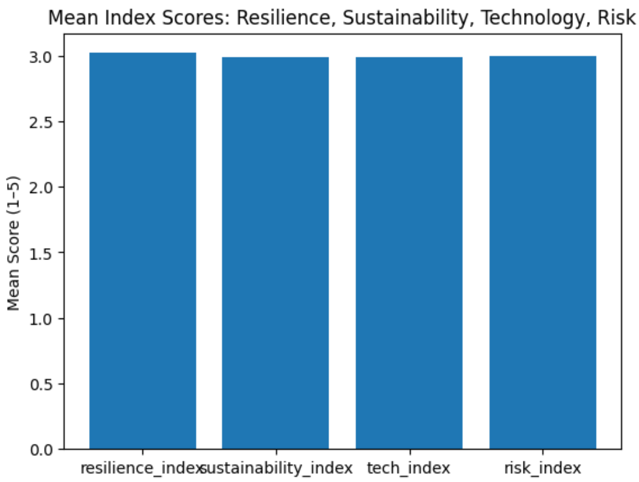


Figure 7.1 Mean Index Score Comparison (Resilience vs Other Indices)

7.1.3 Sustainability Adoption

Sustainability adoption was evaluated across environmental and social dimensions. The **sustainability index** averaged **2.99** (SD ≈ .43), again reflecting **mid-range performance**. Firms appear more active in **green logistics**—such as route optimisation or fuel-efficiency initiatives—while **circular economy practices** (waste recovery, material reuse, closed-loop processes) are less frequently implemented. The small overall mean difference between sustainability and resilience suggests sustainability is acknowledged but not yet structurally embedded. A supplementary sustainability item-level bar chart (optional) can showcase variation between environmental versus social actions.

Table 7.3 – Sustainability Index Summary

Measure	Value
Mean (Average Score)	**2.99**
Standard Deviation	**0.43**
Scale Range	1 – 5
Interpretation	Sustainability moderately adopted; uneven implementation

7.1.4 Industry 5.0 Technology Adoption

Technology adoption under an Industry 5.0 lens includes automation, IoT-enabled tracking, AI-driven forecasting, blockchain traceability, and digital-twin modelling. The **technology index**, like sustainability, averages **2.99**, but has a **larger spread** (SD ≈ .65), indicating a **digital divide** among respondents: a few organisations are experimenting with advanced tools while others remain at very early adoption stages. IoT and automated tracking appear most common, while blockchain and digital twins remain largely unfamiliar or unimplemented. This suggests that the **technological transition towards Industry 5.0 is emerging but not mature**, and therefore cannot yet strongly enhance resilience outcomes.

Table 7.4 – Technology Adoption Index Summary

Measure	Value
Mean (Average Score)	**2.99**
Standard Deviation	**0.65**
Scale Range	1 – 5
Interpretation	Early-stage, uneven adoption across firms

7.1.5 Hypothesis Testing (Reliability, Correlation, Regression)

Reliability checks showed **low internal consistency** among resilience, sustainability and technology scale items—indicating they function more like standalone indicators than tightly correlated measurement constructs. This is important when interpreting results because it means each score reflects a **broad perception trend**, not a fully unified concept.

Pearson correlation analysis showed that **relationships between key indices are close to zero**: technology–resilience (r ≈ –0.046), sustainability–resilience (r ≈ –0.019), and risk–resilience (r ≈ .032). This means that, in this dataset, organisations that report higher digital adoption or higher sustainability do **not** necessarily report stronger resilience. Regression analysis confirmed this outcome: technology (p=.633), sustainability (p=.813), and risk exposure (p=.752) **do not significantly predict resilience**, meaning **none of the hypotheses are statistically supported in this sample**. This does not invalidate the conceptual hypotheses themselves; rather, it suggests that (a) Australian firms may still be too early in adoption for effects to be measurable, and/or (b) resilience is driven by unobserved factors such as leadership culture, government policy, and supplier relationships not captured in the current scale.

Table 7.5 – Correlation Matrix (Pearson r)

Variable 1	Variable 2	Correlation (r)
Resilience	Technology	–0.046
Resilience	Sustainability	–0.019
Resilience	Risk Exposure	0.032

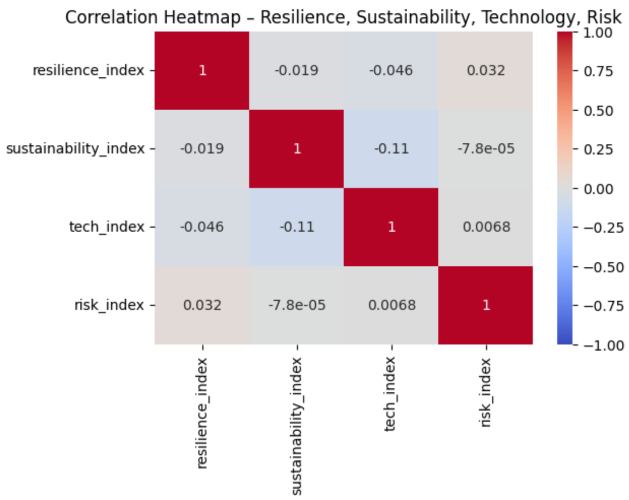


Figure 7.2 displays the correlation heatmap illustrating no strong linear relationships between the variables, as all values cluster near zero.

Table 7.6 – Regression Summary (Dependent Variable = Resilience Index)

Predictor	Coefficient (β)	p-value
Technology Index	–0.026	0.633
Sustainability Index	–0.020	0.813
Risk Exposure Index	0.023	0.752

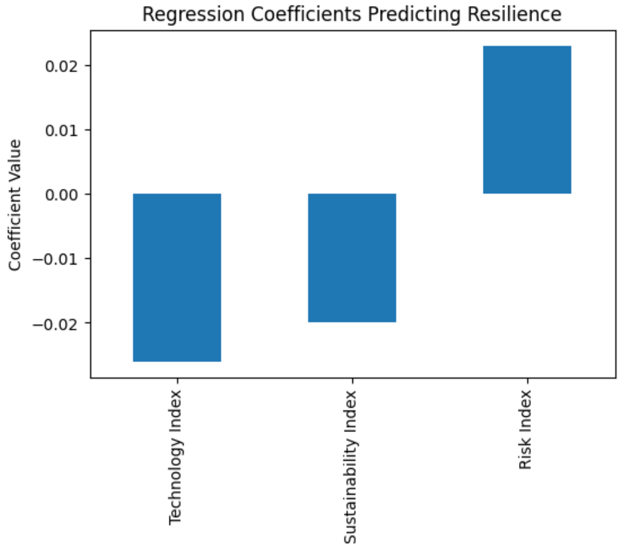


Figure 7.3 presents regression coefficients for the predictors of resilience. All coefficients remain close to zero, visually confirming the lack of predictive effect.

7.2 Case Study

The first major disruption examined is the **COVID-19 pandemic**, which triggered one of the most extensive global supply chain crises in recent history. Beginning in early 2020, widespread lockdowns, factory shutdowns, port closures, and labour shortages caused production slowdowns and freight bottlenecks worldwide. The pandemic exposed the vulnerability of lean, just-in-time supply chains that lacked buffer capacity, revealing systemic fragility in sectors as varied as automotive, electronics, pharmaceuticals, and food (2021–2023 Global Supply Chain Crisis, 2025). Ports experienced chronic congestion, delays in cargo handling, and mismatches between demand and capacity as countries tightened movement restrictions and workers fell ill, leading to reshuffled demand patterns and extended lead times. The resilience lesson from COVID-19 is that over-optimised systems must incorporate flexibility, stock buffers, diversified sourcing, and robust demand-forecasting mechanisms. For Australia—highly dependent on imported goods and distant supply networks—these lessons highlight the need for domestic emergency stockpiles, diversified regional suppliers, and digital visibility tools to quickly adapt to demand shocks and logistic disruptions in the future.

Another case is the **2021 Suez Canal blockage**, when the Ever Given container ship became lodged in the waterway for six days, halting traffic through one of the world's most critical maritime routes. The blockage affected over 400 vessels scheduled to transit between Asia and Europe, costing the global economy an estimated USD 9–17 billion in delays, increased freight costs, and logistical chaos (Challenges in the Red Sea and Suez Canal, 2024; Wan et al., 2023). This event exposed the "bottleneck effect" of key maritime chokepoints: a single point of failure can cascade through global trade networks, delaying inputs and finished goods for weeks. The resilience lesson from the Suez blockage is the importance of alternative routing strategies, advanced risk modelling, and cooperative contingency plans among shipping alliances and national policymakers. For Australia—situated at the end of long East–West supply chains depending heavily on sea freight—this underlines the value of securing multiple ocean routes, strengthening air and land transport partnerships, and maintaining strategic inventories of critical components and resources.

The **Russia–Ukraine war**, which began in February 2022, represents a geopolitical disruption with far-reaching supply chain consequences. The conflict directly impeded Black Sea shipping, prevented Ukrainian seaborne exports, and triggered sanctions that disrupted energy, agriculture, and industrial commodity flows (How the Russia-Ukraine war has impacted logistics, 2024). Disruptions in grain, fertilizer, and critical materials markets, coupled with sanctions on Russian hydrocarbon exports, led to price volatility, constrained production inputs, and longer delays as firms sought alternative sources. The resilience lesson emerging from this conflict is that reliance on a limited set of geopolitically sensitive suppliers creates systemic risk; effective resilience strategies require **multi-tier diversification** of suppliers and markets as well as proactive geopolitical risk assessment. For Australia—highly exposed to global energy markets and dependent on imported commodity inputs—this underscores the urgency of diversified energy portfolios, increased domestic capacities, and geopolitical intelligence integration in supply planning.

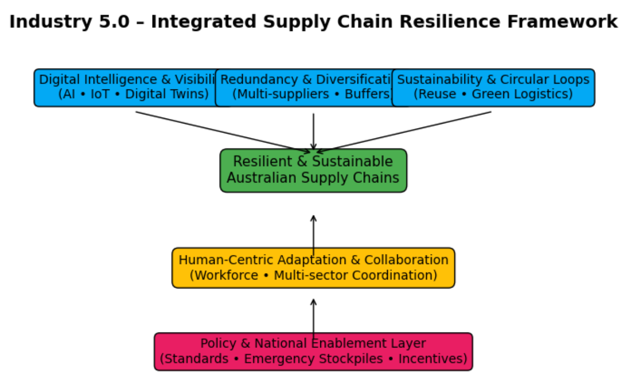
A more recent maritime disruption is the **Red Sea crisis**, which emerged in late 2023 and continued through 2024, involving repeated attacks by Houthi forces on commercial vessels in key shipping lanes. The resulting security risks forced many carriers to reroute through the longer Cape of Good Hope maritime path, significantly increasing transit times, freight rates, and operational costs while reducing throughput through traditional chokepoints (IMF, 2024; Acuity Knowledge Partners, 2025). These diversions highlighted how sustained security threats in strategically critical maritime corridors can rapidly erode supply chain predictability and increase exposure to geopolitical risk. The key resilience lesson is the necessity of both **maritime risk planning and real-time threat monitoring**, alongside robust risk sharing between shippers and insurers. For Australia, which depends on sea routes for over 98% of inbound and outbound trade, these disruptions underscore the importance of coordinated international security cooperation, alternative logistics networks, and investment in predictive risk technology.

Across these diverse case studies, a thematic synthesis reveals common lessons for building resilience: **redundancy and diversification reduce dependency on single routes or suppliers, digital visibility and predictive analytics enable faster adaptation to disruptions, and multi-stakeholder coordination—from firms to governments—strengthens collective response capacity**. Each case demonstrates that extreme efficiency without buffer capacity and flexibility leaves supply chains vulnerable to "black swan" events, whether health-related, geopolitical, or security-driven. Australia's strategic supply chain planning must incorporate these lessons by investing in domestic buffers, diversified global suppliers, advanced digital risk monitoring tools, and stronger regional partnerships to enhance both short-term adaptability and long-term sustainability of supply flows.

7.3 Integrated Framework

The integration of quantitative findings and case-based disruption lessons provides a combined understanding of the current maturity of supply-chain resilience in the Australian context. Quantitative survey results reveal that resilience, sustainability, and technology adoption all remain at moderate, early-stage levels, with no significant statistical relationships between them. In other words, although organisations are aware of the importance of digital tools and sustainability initiatives, these practices are not yet sufficiently embedded or advanced to produce measurable resilience outcomes. By contrast, case-based findings drawn from major disruptions such as the COVID-19 pandemic, the Suez Canal blockage, the Russia–Ukraine conflict, and the Red Sea shipping crisis demonstrate clearly that shock events have real-world impacts when supply chains lack redundancy, diversified sourcing, or visibility. The lived lessons of global disruptions therefore highlight what the quantitative data alone could not: that resilience does not arise automatically from technology presence but from the **strategic integration** of technology, sustainability, multi-tier sourcing, stock buffering, and rapid decision-making capability.

Synthesising these insights, an Industry 5.0–aligned resilience and sustainability framework for Australia should be built around four interdependent pillars. First, **Digital Intelligence and Visibility**, where IoT sensors, predictive analytics, and digital-twin simulations provide real-time supply-chain monitoring to anticipate bottlenecks before they escalate. Second, **Structural Redundancy and Diversification**, which involves maintaining secondary suppliers, alternative logistics routes, geographically varied sources, and buffer stocks for critical goods. Third, **Sustainability and Circular Value Loops**, where environmentally conscious practices such as material recovery, green logistics, and circular supply-chain models reduce dependence and improve long-term resource stability. Fourth, **Collaborative Governance and Human-Centric Adaptation**, reflecting Industry 5.0's ethos of blending technology with human expertise, enabling cross-sector coordination, shared contingency planning, and workforce-led agile responses during crises. At the centre of this framework sits an enabling layer of national and organisational policy, which aligns incentives, standards, and emergency response capacity.



Discussion

The findings of this study present a contrasting picture between theoretical global lessons and the current empirical reality represented in the Australian survey dataset. Quantitative survey results indicated that resilience, sustainability, and digital technology adoption are still at moderate and early-stage maturity levels across Australian supply chains. More importantly, no statistically significant association was found between resilience and predictors such as technology adoption, sustainability practices, or risk exposure. This suggests that while organisations may be aware of Industry 5.0 principles and sustainability objectives, these practices are not yet deeply embedded in operations to deliver measurable resilience outcomes. This contrasts with global discourse which assumes strong performance benefits from advanced digitalisation and sustainability integration.

When viewed alongside secondary case-study findings, however, a more nuanced interpretation emerges. Case evidence clearly demonstrated that digital tools, diversification, stock buffers, and circular value loops play a strategic role in preventing systemic breakdowns under crisis conditions (as seen in COVID-19, Suez Canal, Russia–Ukraine and Red Sea disruptions). The contrast between the observed global lessons and Australia's limited empirical maturity highlights a key interpretation: Australian supply chains conceptually recognise Industry 5.0 priorities but have not yet operationalised them at a scale sufficient to influence resilience metrics.

Comparing this outcome to existing literature, most research strongly argues that digital transformation, particularly AI-driven forecasting, IoT visibility platforms, blockchain traceability, and cyber-physical systems, increases adaptability and recovery speed during disruptions. Similarly, sustainability literature suggests that circular supply chains reduce vulnerability to shortages and enable long-term resilience by lowering dependence on virgin resources. However, the present findings challenge these universal claims by showing that technology and sustainability alone do not automatically produce resilience unless organisational structures, policy support, workforce capabilities, and diversification strategies are simultaneously strengthened. This aligns with Industry 5.0 theory, which emphasises human-centric orchestration and system-level integration, not technology-centric transformation alone.

The implications of this study for Australia are therefore significant. There is a need for national-level enablement, including stronger policy direction, incentives for technological adoption, emergency stockpile programs, and mandatory resilience audits for critical industries. Organisations must also transition from "awareness stage" to "integration stage," where digital tools are actively connected to operational decisions and risk-response mechanisms. Workforce training and multi-sector collaboration will be critical, given Industry 5.0's foundational principle that humans and intelligent systems work collaboratively, rather than technology replacing human expertise. Finally, the findings imply that resilience for Australia cannot rely solely on global market forces; instead, Australian-focused regional supply hubs, diversified logistics corridors, and circular resource programs should form the backbone of strategic transformation.

The discussion reveals that Australia is at the early phase of embracing Industry 5.0, and while global disruptions highlight clear lessons, tangible resilience gains will require interconnected actions across technology, governance, sustainability, human expertise and structural redundancies. Australia's future supply-chain resilience therefore depends not on isolated innovations, but on strategic, multi-layered integration of Industry 5.0 principles at national and organisational levels.

Conclusion and Future Outlook

This study found that although Australian organisations recognise the relevance of resilience, sustainability, and digital transformation, these elements are not yet sufficiently integrated to generate measurable resilience outcomes. Quantitative results showed no strong relationships between technology, sustainability, and resilience, indicating that adoption remains mostly conceptual rather than operational. In contrast, global disruption case studies demonstrate that resilience succeeds only when digital intelligence, diversified sourcing, circular practices, and human-centric coordination operate together. Thus, the core conclusion is that Australia remains in an early phase of Industry 5.0 implementation, and resilience must be understood as a system-wide strategy, not an isolated activity.

Future Outlook

Over the next decade, Australia's supply-chain performance will depend on proactive investment in digital capability, regionalised sourcing hubs, sustainability-based resource loops, and strong policy alignment. Technologies such as predictive analytics, AI-enabled logistics, and cyber-risk monitoring will become critical, while climate shocks, geopolitical tensions, and cyber risks will heighten the need for coordinated resilience planning. Australia now has a window of opportunity to shift from reaction to preparedness, positioning itself as a potential leader in resilient and sustainable supply-chain design.

Recommendations

To strengthen future resilience in line with Industry 5.0, the following actions are recommended:

Government level: Establish national resilience standards, build emergency stockpile programs, incentivise digital adoption, and invest in regional manufacturing and logistics corridors.

Industry level: Diversify suppliers and transport routes, embed AI-based forecasting tools, and develop circular practices to reduce dependence on single inputs.

Organisational level: Train workforces in Industry 5.0 skills, integrate sustainability and technology into operational decisions, and conduct regular stress-testing of supply-chain vulnerabilities.

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