Digital Transformation: Unlocking Supply Chain Resilience through Adaptability and Innovation

Abstract

Recent disruptions have pushed the digitalisation of supply chains to the forefront of business challenges. This research investigates the mechanisms through which digital supply chains foster resilience. Using structural equation modelling, the study draws on two empirical investigations to provide a comprehensive understanding of these dynamics. In Study 1, we explore the role of supply chain innovation as a mediating factor between digital supply chains and resilience. Our findings confirm that digitalisation positively impacts resilience by enhancing supply chain innovation. Study 2 introduces supply chain adaptability as an additional mediating mechanism, uncovering more complex interactions. The results show that digitalisation affects resilience through the sequential mediation of supply chain adaptability and innovation. This model emphasises adaptability's essential role in translating digital advancements into resilient, innovative supply chains. These insights deepen the theoretical understanding of supply chain management amid disruptions and offer practical strategies for developing more resilient and adaptable supply chains in the digital era.

Keywords: Digital supply chains, supply chain innovation, supply chain resilience, supply chain adaptability, structural equation modelling.

1. Introduction

Digital technologies are reshaping businesses worldwide, impacting production processes, organisational structures, and relationships with external partners like suppliers and customers (Plekhanov et al., 2023; Singh et al., 2024). Through digital adoption, companies are better aligning with evolving customer expectations and optimising operations for improved efficiency and resilience (Hassan et al., 2024). The Covid-19 pandemic underscored the critical importance of digitalisation, with many supply chains learning this lesson the hard way (Tiwari et al., 2024). In the post-Covid era, the pace of supply chain digital transformation has accelerated, empowering organisations to boost flexibility, streamline operations, innovate value propositions, and swiftly respond to market demands. Additionally, digital transformation has become essential for sustaining market competitiveness and driving technological advancements (Feliciano-Cestero et al., 2023).

Recent research on digitalisation has increasingly focused on identifying mechanisms to shield supply chains from constant disruptions. Studies highlight the vital role of data in mitigating these challenges; by analysing data, supply chains can better identify risks, sharpen their competitive edge, and expedite recovery from disruptions (Cui et al., 2024). Digital tools not only streamline information flows but also enhance interconnectivity among diverse supply chain stakeholders and boost analytical capabilities, allowing firms to proactively respond to changes (Plekhanov et al., 2023). These factors collectively strengthen supply chain resilience (SCR). For example, during the Covid-19 pandemic, while supply chains across industries were heavily impacted, the degree of disruption varied significantly. A study by Klyver and Nielsen (2021) found that, in some severely affected sectors, certain firms were heavily impacted, while others managed to adapt or even thrived with minimal disruption. Some companies even leveraged the crisis to boost revenue (Stentoft et al., 2023). Anecdotal evidence suggests that firms with strong digital capabilities were the ones that prospered during the pandemic. Understanding the technologies and strategies that enable firms to succeed in large-scale disruptions is now essential for resilience in modern business.

Supply chain digitalisation (SCD) has emerged as a critical factor in building resilience against supply chain disruptions (Akhtar et al., 2022; Shi et al., 2023; Syed et al., 2024). Recent disruptions, including Covid-19, the Suez Canal blockage, and Houthi attacks in the Red Sea, have acted as catalysts, accelerating digital transformation initiatives in supply chains to mitigate disruptions caused by such crises (Amankwah-Amoah et al., 2021). Consequently, an expanding body of research has developed, focused on understanding the relationship between SCD and SCR (Alvarenga et al., 2023; Jiang et al., 2024; Shi et al., 2023; Yuan et al., 2024). However, some researchers argue that the findings in this area remain fragmented, highlighting the need for further research (e.g., see Hassan et al., 2024; Suali et al., 2024; Yuan et al., 2024). For example, a McKinsey report revealed that among firms implementing digital technologies prior to the Covid-19 outbreak, only 21% managed to establish SCR (Li, 2022). Furthermore, Yang et al. (2021) argued that digital technologies may actually increase supplier opportunism through enhanced integration. Therefore, further large-scale investigations are necessary to understand how digitalisation initiatives in supply chains influence resilience.

Our research contributes to this body of work by addressing the following research question:

> *RQ. What are the mechanisms through which supply chain digitalisation influences supply chain resilience?*

We posit that dynamic supply chain capabilities (Aslam et al., 2020; Teece, 2007) provide the mechanisms through which SCD influences SCR. Previous research has argued that the success of SCD depends on capabilities both internal and external to the firm. Identifying which capabilities are most critical to the success of SCD is essential for prioritising organisational efforts and improving the likelihood of success (Feliciano-Cestero et al., 2023; Tiwari et al., 2024). We examine the role of supply chain innovation (SCI) as an intervening mechanism between SCD and SCR. SCI has gained attention amid the surge in digital transformation (Zhang et al., 2024). By embracing innovation in technology, processes, and business models, firms can reconfigure their supply chains, identify weaknesses, and ultimately enhance their resilience (Mwangakala et al., 2024).

We also consider supply chain adaptability (SAD) as a second intervening mechanism in the relationship between SCD and SCR. SAD refers to the ability to adjust supply chain design in response to market changes (Lee, 2004), reflecting a firm's capacity to make structural changes that carry long-term strategic implications. By including SAD as an intervening mechanism, we address the call from researchers like Shi et al. (2023) to consider factors such as adaptability in the SCD-SCR relationship. Together, SAD and SCI shape the pathway through which SCD impacts SCR, highlighting the multifaceted nature of digital transformation in supply chains.

Our research model is informed by the dynamic capabilities view (DCV) and information processing theory (IPT). We test our hypotheses using data from two studies within Pakistan's manufacturing sector. We collected data from manufacturing firms in Pakistan, as these firms often serve as key players within supply chains, offering a broad and integrated perspective on supply chain dynamics (Van Nguen et al., 2023). This research employed a two-study design using survey methods, aiming to enhance the validity and robustness of the findings. The rationale for conducting two separate studies lies in the added rigour it brings, allowing us to examine the proposed relationships across different contexts and strengthen the generalisability of the results

(Eden, 2002). Study 1 focused on exploring the role of SCI in the relationship between SCD and SCR. Study 2 extended this investigation by examining the same relationship within the context of SAD. This sequential approach not only improved the validation of our results but also offered a broader, more comprehensive understanding of the research model.

Context plays a crucial role in the development and deployment of capabilities for organisational success. Researchers have specifically called for investigations into digital initiatives across different geographic, economic, and industrial contexts (see e.g., Cui et al., 2024; Hassan et al., 2024). By conducting this research within a developing country context, we aim to provide valuable insights into the success factors of digitalisation initiatives, as the majority of existing studies have focused on developed regions.

Our research makes important contributions to the body of knowledge. *First*, it clarifies the mechanisms through which SCD enhances SCR, with a focus on the roles of SCI and SAD. *Second*, it empirically tests various mediation pathways through which SCD impacts SCR. *Third*, the study highlights the significance of SAD in utilising digital supply chain technologies to build resilience. *Finally*, our findings offer actionable insights for organisations aiming to develop more resilient and adaptable supply chains in the digital era.

2. Theory Development

2.1 Information processing theory

Information Processing Theory (IPT), initially proposed by Galbraith (1974), conceptualises organisations as open systems striving to manage uncertainty by processing information effectively. According to IPT, organisations face varying degrees of uncertainty from their external environment, and to perform optimally, they must develop appropriate structures and mechanisms to collect, interpret, and respond to information (Galbraith, 1974; Munir et al., 2022). In the context of modern supply chains, this theoretical lens is particularly relevant because supply chains today are characterised by volatility, complexity, and rapid technological change (Rao & Goldsby, 2009; ur Rehman et al., 2020; Liu et al., 2024). When environmental uncertainty increases, firms must expand their information-processing capabilities to make better decisions under uncertainty (Almheiri et al., 2025; Birkel et al., 2023; Zhu et al., 2018). This necessitates not only gathering more information but also enhancing the quality, speed, and integration of information flows across organisational boundaries (Munir et al., 2022; Wong et al., 2020). Therefore, IPT argues that firms that build superior information-processing structures will be better positioned to improve their agility, innovation, and resilience.

While prior studies have validated the relevance of IPT in digitalisation and risk management contexts (Bag et al., 2025; Yan and Li, 2022), there is limited research connecting IPT directly to dynamic capabilities such as supply chain innovation and adaptability. Specifically, how real-time information processing translates into resilient supply chain capabilities remains underexplored. This study addresses this gap by linking information processing mechanisms to the development of innovation (Bag et al., 2021), adaptability (Yang et al., 2022), and resilience (Naghshineh and Carvalho, 2025; Bag et al., 2025) outcomes in supply chains. Importantly, IPT highlights how digitalisation improves firms' capacity to process information faster, which directly supports dynamic capabilities (Fan et al., 2017).

2.2 Supply chain digitalisation

SCD involves the integration of digital technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), and Blockchain, into supply chain operations (Yang et al., 2021; Zhou et al., 2023; Dadsena et al., 2024). It is described as a digitally driven infrastructure that a firm establishes "for the consistent and high-velocity transfer of supply chain-related information within and across its boundaries" (Rai et al., 2006). This concept aligns with the premise of Information Processing Theory (IPT), which posits that firms acquire a larger volume of high-quality information to reduce environmental uncertainty and focus on building information-processing capabilities for effective decision-making (Fan et al., 2017). Zhou et al., (2023) elaborate on how digitalisation improves supply chain performance by enhancing traceability and agility, while Wang and Prajogo (2024) argue that agility and innovation capabilities are essential enablers for maintaining competitiveness in an evolving market. According to IPT, an organisation functions as an open socio-economic system that can enhance performance not only by developing its information-processing capabilities but also by improving the quality of information it receives (Galbraith, 1973; Premkumar et al., 2005). The literature further underscores that SCD plays a crucial role in strengthening these capabilities (Belhadi et al., 2024). Digital technologies enhance traceability and performance, providing the real-time data necessary for better responsiveness and innovation (Zhou et al., 2023). Moreover, IPT argues that the better a firm's information-processing systems, the more likely it is to develop dynamic capabilities, such as SCI and SAD, which in turn enable resilience (Tiwari et al., 2024).

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2.3 Dynamic capability view

Teece et al. (1997) introduced the Dynamic Capability View (DCV) as an extension of the Resource-Based View (RBV) of the firm. The RBV posits that firms within the same industry perform differently due to variations in their resources and capabilities (Barney, 1991; Peteraf, 1993). However, RBV is considered inadequate for explaining competitive advantage in dynamic market environments because it provides a static perspective (Priem and Butler, 2001). Maintaining competitive advantage is an ongoing, dynamic process (Hung et al., 2010; Stadfeld et al., 2024). Therefore, researchers argue that to remain competitive, firms must develop specific capabilities and embrace continuous learning (Teece, 2007; Zott, 2003; Markovich et al., 2025). This makes DCV better suited to understanding competitive advantage in rapidly evolving market conditions. Teece et al. (1997) define a dynamic capability as a firm's ability to integrate, develop, and reconfigure internal and external expertise to adapt to fast-changing environments. Dynamic capabilities are the result of acquiring, integrating, and recombining resources to formulate new strategies (Grant, 1996) and are critical in creating new pathways for competitive advantage (Teece et al., 1997). In this research, we consider SCI and SAD as dynamic capabilities that enable firms to achieve and sustain competitive advantage (i.e., SCR) in disruptive market conditions.

SCI is a complex process designed to address environmental uncertainties and meet customer demands by utilising new technologies to enhance organisational processes (Lee et al., 2011). It is crucial in maintaining competitive advantage and enhancing organisational performance (Liu et al., 2024). It involves distributing activities and making new investments among channel participants to boost revenue through improved service effectiveness and maximise shared profits by reducing costs through enhanced operational efficiency (Bello et al., 2004). SCI incorporates both the product and the process aspects of innovation (Lee and Schmidt, 2017). Product innovation involves enhancing the design, which could be incorporating new features (Qi et al., 2020). It involves the stages of *ideation*, *evaluation*, *design and development*, testing and validation, *launch and ramp-up*, *maintenance*, and *end-of-life management* (Lee and Schmidt, 2017). The process innovation centres around novel methods for producing and delivering products (Cherrafi et al., 2018). The main goal is to improve the aspects pertaining to cost and performance (Qi et al., 2020).

On the other hand, SAD is the ability to respond to structural changes by reconfiguring the supply chain design (Yang et al., 2022). It is associated with making long-term (strategic) adjustments in the supply chain. The concept of adaptability has its origins in the manufacturing sector and was later adopted, encompassing the whole organisation (Yang et al., 2022). Tuominen et al. (2004) argued that adaptability becomes a source of competitive advantage for organisations. However, due to changing, dynamic, complex, and turbulent business environments, focusing only on the manufacturer will not serve the organisation. Instead, a holistic approach needs to be adopted by considering the cross-organisational efforts to enhance SAD.

2.4 Supply chain resilience

Supply chain resilience is a multifaceted concept within the supply chain context. Brandon-Jones et al. (2014) define it as "the ability of a system to return to its original state, within an acceptable period, after being disturbed." This implies that when a system experiences disruption, it possesses an inherent capacity to either restore itself to its original state or evolve to an improved one. In the literature, the ability to adjust to unexpected changes is a key aspect of SCR (Krause et al., 2009; Ralston and Blackhurst, 2020). SCR can also be understood through the lens of the DCV in the context of supply chains. When a supply chain is disrupted by external environmental uncertainties, SCR ensures that operations are restored within an acceptable timeframe (Mackay et al., 2019; Wieland and Wallenburg, 2012; Ivanov, 2024).

While SCR literature has evolved significantly in the past decade, much of the focus has been on identifying external enablers (e.g., technology, collaboration) rather than unpacking the internal dynamic capabilities that build resilience. Furthermore, there is limited empirical validation of sequential relationships between adaptability, innovation, and resilience in the context of digitalised supply chains. This study addresses these gaps by proposing and testing a novel capability-development path from digitalisation to resilience through SAD and SCI.

3. Hypotheses Development

3.1 Supply chain digitalisation and supply chain innovation

SCD has gained significant attention due to the integration of advanced digital technologies like IoT, AI, cloud computing, and blockchain into supply chain processes (Li et al., 2024). In relatively stable environments, firms have limited need for real-time information sharing as uncertainty is minimal (Chi et al., 2020; Wang et al., 2022). However, under uncertain and dynamic conditions, IPT posits that organisations must enhance their information-processing capabilities to effectively manage complexity (Galbraith, 1974; Birkel et al., 2023).

SCD strengthens these capabilities by facilitating real-time information sharing, reducing information asymmetry, and improving the quality, speed, and transparency of supply chain data (Munir et al., 2022; Yin et al., 2024). By lowering barriers to information flow and enabling data-driven decision-making, SCD empowers supply chain partners to identify customer needs more precisely, collaborate on new ideas, and develop innovative solutions (Fernando et al., 2018; Tan et al., 2015). Thus, from an IPT perspective, SCD acts as a critical enabler that transforms raw information into strategic insights, fostering SCI. Thus, we hypothesise:

H1: *SCD has a positive impact on SCI.*

3.2 Supply chain innovation and supply chain resilience

SCI represents a dynamic capability that enables firms to respond proactively to changing environmental conditions and recover quickly from disruptions (Kamalahmadi and Mellat-Parast, 2016; Wong and Ngai, 2024; Bhatnagar et al., 2025). According to the DCV, dynamic capabilities such as innovation are critical for firms to build sustainable competitive advantages in volatile and turbulent environments (Teece, 2007; Lin and Wu, 2014).

From an IPT perspective, innovation is a direct consequence of enhanced information-processing capabilities. By acquiring, analysing, and disseminating high-quality, timely, and relevant information across supply chain partners, organisations are better able to identify emerging risks and opportunities (Galbraith, 1974; Munir et al., 2022). In this sense, SCI can be seen as a manifestation of improved information-processing structures that enable firms to sense changes in the environment, learn rapidly, and create novel responses to supply chain disruptions.

Thus, SCI plays a dual role, i.e., from IPT perspective, it operationalises the firm's ability to use superior information processing to generate adaptive solutions. From DCV lens, it represents a higher-order capability that facilitates resilient responses to environmental volatility.

Prior literature also suggests that firms can enhance supply chain resilience (SCR) through various means such as robustness (Brandon-Jones et al., 2014), efficiency (Golgeci et al., 2020), integration (Liu and Lee, 2018), and agility (Christopher and Rutherford, 2004). However, innovative processes are particularly important because they allow supply chains to go beyond merely recovering from disruptions to transforming and improving their operations.

Therefore, building SCI through better information-processing capacity and dynamic capability development becomes central to achieving resilience. Thus, we hypothesise that:

H2: *SCI has a positive impact on SCR*

3.3 The mediating role of supply chain innovation

From a DCV perspective, firms operating in volatile environments must continuously develop and reconfigure their resources and capabilities to sustain competitive advantage (Teece, 2007; Lin and Wu, 2014). In this context, SCI serves as a critical dynamic capability that allows firms to proactively adapt to external disruptions and changing market demands.

From the lens of IPT, supply chain digitalisation, by enhancing information flows, visibility, and real-time responsiveness, provides the necessary foundation for building such dynamic capabilities. Digitalisation allows firms to sense changes in customer preferences, supply disruptions, and technological opportunities more quickly, which then catalyses innovation in both products and processes (Wong and Ngai, 2024; Fernando et al., 2018). Thus, SCD does not just enable operational improvements; it also fosters the learning, reconfiguration, and transformation processes that define dynamic capabilities.

Following the logic of DCV, dynamic capabilities act as transmission mechanisms through which resources and enabling factors, such as digitalisation, lead to superior performance outcomes like resilience (Teece et al., 1997; Zollo and Winter, 2002). In our model, SCI is positioned as a dynamic capability that emerges through digitalisation and subsequently strengthens supply chain resilience (SCR) by enhancing the organisation's ability to innovate and adapt under disruption. Thus, we hypothesise:

H3: *SCI mediates the relationship between SCD and SCR.*

3.4 Supply chain digitalisation and supply chain adaptability

SCD helps organisations adapt and reconfigure their operations to meet changing market dynamics by leveraging available technologies and utilising real-time information, thereby enhancing visibility, traceability, and agility (Yang et al., 2022). This aligns with IPT, which views organisations as open systems needing to align their information processing capabilities with operational demands to optimise performance (Galbraith, 1973; Tushman and Nadler, 1978). Digitalisation enables the processing of vast amounts of data, supporting both decision-making and coordination across supply networks (Fan et al., 2017). Enhanced information systems and collaboration enable organisations to proactively address disruptions and reconfigure operations to meet evolving demands (Belhadi et al., 2024; Rashid et al., 2025), strengthening their information processing capabilities and adaptability through digital SC initiatives. Thus, we hypothesise:

H4: *SCD has a positive impact on SAD*

3.5 Supply chain adaptability and supply chain resilience

SAD is critical to enhancing SCR by enabling organisations to reconfigure operations in response to disruptions, ensuring rapid recovery and continuity. Information processing theory lends an understanding of enhanced SAD that has a positive impact on operational performance Yang et al., 2022). Adaptability goes beyond cost efficiency and responsiveness to market shifts (Lee, 2004); it prevents organisations from becoming locked into rigid structures, instead allowing them to return to their original form or reach an improved state (Brandon-Jones et al., 2014). This ability to reconfigure bolsters resilience, helping organisations withstand, absorb, and recover from disruptions (Krause et al., 2009). Such disruptions present opportunities for improvement rather than mere recovery (Wieland and Wallenburg, 2012). In essence, SAD equips firms with the flexibility and agility necessary to mitigate risks, maintain operational continuity, and achieve a competitive advantage, all of which are essential for resilient supply chains. Thus, we hypothesise:

H5: *SAD has a positive impact on SCR*

3.6 The mediating role of supply chain adaptability

IPT posits that organisations are open systems that must effectively process information to manage environmental uncertainty and improve performance (Galbraith, 1974; Tushman & Nadler, 1978). In dynamic and unpredictable environments, firms need to enhance their ability to gather, interpret, and act on real-time information to remain competitive. SCD enables organisations to strengthen their information-processing capacity by improving the speed, accuracy, and visibility of information flows across supply chain partners (Yang et al., 2021; Zhou et al., 2023). By utilising digital tools such as IoT, blockchain, and cloud computing, firms can more effectively monitor environmental changes, identify risks, and detect emerging opportunities.

However, merely having access to better information does not guarantee resilience. According to IPT, it is the organisational response to processed information that determines performance outcomes. Supply chain adaptability (SAD) embodies this responsive capability: it refers to a firm's ability to reconfigure supply chain structures, reassign resources, and adjust operations based on new information and environmental shifts (Yang et al., 2022; Belhadi et al., 2024).

Thus, SAD acts as the behavioural and structural response mechanism through which digitalisation-driven information processing is translated into effective action. Firms with higher adaptability can proactively respond to disruptions and recover faster, thereby enhancing supply chain resilience (SCR). Thus, we hypothesise:

H6: *SAD mediates the relationship between SCD and SCR.*

3.7 The sequential mediation of SAD and SCI

DCV posits that environmental uncertainties drive firms to deploy key resources to develop superior capabilities, enhancing performance across multiple dimensions (Teece, 2007; Jajja et al., 2018; Jat et al., 2023; Rehman and Jajja, 2022; Luo et al., 2024). Furthermore, IPT-driven digital supply chain mechanisms foster transparent, open information sharing across supply chain members to enhance performance (Tiwari et al., 2024; Yu et al., 2021). This study provides a holistic understanding of these two phenomena by proposing sequential mediation through SAD and supply chain innovation (SCI) between SCD and SCR. In theory, information sharing across the supply chain aids firms in building dynamic capabilities, such as adaptability and innovation, which positively influence SCR as a key performance dimension. Thus, we hypothesise:

H7: *SAD and SCI sequentially mediate the relationship between SCD and SCR.*

4. Research methods

4.1 Sample and data collection

Data for hypothesis testing was collected from manufacturing firms operating in Pakistan. Prior to data collection, a pilot test was conducted to ensure the clarity and reliability of the survey instrument. A group of 25 Executive MBA students, all holding managerial positions across various industries, was engaged to review the survey and identify any ambiguities or inconsistencies. In addition, the instrument was reviewed by university professors specialising in supply chain management to further validate its content. No major issues were identified during this phase. The pilot testing results indicated that the reliability coefficients (Cronbach's alpha) for all constructs exceeded the recommended threshold of 0.70, demonstrating acceptable internal consistency.

The data collection process encountered typical challenges associated with conducting research in developing countries, particularly the lack of a comprehensive and accessible sampling frame for manufacturing firms in Pakistan (Bulut et al., 2022; Aslam et al., 2020). Similar challenges have been acknowledged in prior management research in emerging markets (Hoskisson et al., 2000). To address this, a sampling frame was developed by consolidating information from professional platforms such as LinkedIn, the Pakistan Readymade Garments Manufacturers and Exporters Association (PRGMEA), and alumni networks of local universities, resulting in a list of 500 firms.

Given the lack of a formal registry, this approach allowed us to identify relevant firms and decision-makers in the absence of official databases. We targeted individuals who were supply chain managers or senior executives overseeing end-to-end supply chain operations. This focus on knowledgeable and experienced respondents ensured that the insights collected were both contextually grounded and reflective of current industry practices. While constructing a sampling frame in this manner presents challenges, such as potential limitations in coverage and representativeness, it also offers important benefits. Most notably, it allows for more efficient access to informed participants who are in a position to provide meaningful responses. By prioritising relevance and expertise, this approach enhanced the practical value and reliability of the data collected, despite the constraints imposed by the research environment.

The finalised online survey questionnaire was sent to the selected firms, and data were collected in two phases (*Study 1* and *Study 2*) with an interval of approximately two months. Study 1 yielded 133 usable responses, and Study 2 yielded 154 usable responses. To evaluate the potential for nonresponse bias, we followed the methodology of Armstrong and Overton (1977), comparing early and late responses to assess any significant differences. A t-test was conducted on employee experience and firm sales data; results showed no statistically significant differences between early and late respondents ($p > 0.05$) in both studies, indicating an absence of significant bias. Table 1 provides a description of the final samples for both studies.

Table 1. Respondents and Firm Information

	Study 1		***Study 2***	
	Frequency	*Percentage %*	*Frequency*	*Percentage %*
Industry				
Textile	36	27.1	41	26.6
FMCG	22	16.5	23	14.9
Pharmaceutical	14	10.5	11	7.1
Automobile	10	7.5	12	7.8
Chemical	9	6.8	10	6.5
Others	42	31.6	57	37
Number of employees				
less than 100	57	42.9	69	44.8
100 to 500	35	26.3	32	20.8
more than 500	41	30.8	53	34.4
Annual sales				
Less than 10 million	20	15	28	18.2
10 to 100 million	52	39.1	58	37.7
101 to 1000 million	43	32.3	42	27.3
more than 1000 million	18	13.5	26	16.9
Employee Experience				
less than 3 years	22	16.5	40	26
3 to 5 years	24	18	30	19.5
5 to 10 years	42	31.6	41	26.6
more than 10 years	45	33.8	43	27.9
Respondent's designation				
Lower Management	8	6	15	9.7
Middle Management	61	45.9	83	53.9
Top Management	64	48.1	56	36.4

4.2 Measures

We used existing measures for the constructs in this study. SCD was measured on a seven-item scale adapted from the work of Papanagnou et al., (2022). The scale aids in understanding the degree of digitalisation being implemented, allowing for the identification of changes within the supply chain related to inventory, customer preferences, delivery alterations, and more. SCI was measured as a second-order scale, comprising two first-order scales: process innovation and product innovation. These scales were adapted from the studies by Möldner et al., (2020), Shu et al., (2012), and Schoenherr and Swink (2015), respectively. This scale assesses the capabilities and efforts of supply chains in enhancing their products and innovation, such as the emphasis on the research and development rate of introducing new technologies and techniques. To measure SCR we used a four-item scale developed by Ambulkar et al., (2015). This scale evaluates the ability to handle uncertain situations and how quickly a firm can adapt and respond to such uncertainties. Finally, SAD was measured using a nine-item scale based on the studies by Whitten et al., (2012) and Feizabadi et al., (2021). The scale helped measure the ability of a firm to adjust to changes in demand and supply by adjusting its resources.

4.3 Common method bias and endogeneity

Common method bias (CMB) refers to the bias that can arise from the method used for data collection (MacKenzie and Podsakoff, 2012). To mitigate the potential issue of CMB, we implemented several preventative measures suggested by MacKenzie and Podsakoff (2012). First, we refined the survey items based on qualitative feedback from expert specialists. Second, we ensured that the respondents clearly understood the survey questions. Additionally, the survey was conducted anonymously to protect respondents' anonymity. To further minimise CMB, we used different scales, such as "Very low" to "Very high" and "Not at all" to "To a very large extent."

A two-stage least squares (2SLS) test was conducted to address the potential issue of endogeneity, which refers to the presence of potentially omitted variables that may explain the variance in the dependent variable (Ketokivi & McIntosh, 2017). We identified supply chain agility as an instrumental variable in both Study 1 and Study 2. It was chosen as an instrumental variable because it was related to the independent variables, such as SCI (Study 1) and SAD and SCI (Study 2), but not related to the error term of SCR. For study 1, in the first stage, we regressed SCI on our instrumental variable. In the second stage, we regressed SCR on the predicted value of SCI. We found that the beta value for the second equation was significant ($p < 0.05$). For Study 2, in the first stage, we regressed SCI and SAD on the instrumental variable, and in the second stage, we regressed SCR on the predicted values of SCI and SCD. The beta values in this case were also significant ($p < 0.05$). The results indicate that endogeneity is not a potential concern in either of our studies (Ketokivi & McIntosh, 2017).

5. Results

5.1 Measurement model evaluation

We analysed the assumptions for multivariate data analysis for Study 1 and Study 2 before moving to confirmatory factor analysis (CFA). To ensure normality within the data, we calculated skewness and kurtosis coefficients, which were well within the prescribed limits of -3 to +3 and -7 to +7, respectively (Curran et al., 1996). We assessed homoscedasticity using standardised residual plots and observed consistent variability of residuals across the regression line, confirming that homoscedasticity was present. Furthermore, all variance inflation factor (VIF) values were well below the threshold of 10, indicating that multicollinearity was not a significant concern (Hair et al., 2014).

We performed CFA for Study 1 and Study 2 using SPSS AMOS v24 to establish construct validity. The overall model fit for Study 1 (χ^2/df = 1.827, $p < 0.05$, CFI = 0.905, SRMR = 0.071, RMSEA = 0.079) and Study 2 (χ^2/df = 1.655, $p < 0.05$, CFI = 0.905, SRMR = 0.068, RMSEA = 0.070) for the measurement models were adequate (Hu and Bentler, 1999). The average variance extracted (AVE) values for all constructs exceeded the threshold of 0.5 in both studies, confirming convergent validity, and the square root of the AVE values for each construct was higher than the corresponding bivariate correlations, confirming discriminant validity (Fornell & Larcker, 1981). The composite reliability (CR) for all constructs exceeded the threshold of 0.7, demonstrating appropriate reliability levels (Hair et al., 2014). Table 2 provides information about the convergent validity and reliability on Study 1 and Study 2. Tables 3 and Table 4 provide information about the discriminant validity in the two studies.

Table 2. Convergent validity and reliability

Constructs / indicators (CR, AVE)	**Standardised Loadings Study 1**	**Standardised Loadings Study 2**
Supply chain digitalisation, Study 1 (CR = 0.900, AVE = 0.565), Study 2 (CR = 0.900, AVE = 0.566).		
Uses digitalisation to set up alerts for fast supply and delivery changes.	0.873	0.762
Uses digital technology to create various ways of notifying about quick changes in inventory and warehouse levels.	0.817	0.795
Uses digitalisation for maintaining real-time customer sales fulfilment.	0.778	0.808
Uses digitalisation to stay alert to fast-changing customer expectations.	0.727	0.760
Identifies changes in customer profiles and behaviours with the use of digital technology.	0.691	0.709
Modifies resources and processes in the dynamic environment using digital technology.	0.675	0.711
Exchanges information and data (e.g., forecasts, delivery schedule) with key partners.	0.681	0.668
Supply chain innovation, Study 1 (CR= 0.921, AVE=0.853), Study 2 (CR= 0.920, AVE=0.852).		
Product innovation	0.906	0.952
A high rate of new products are developed by using the firm's own resources and capabilities.	0.637	0.632
Internal R&D managers and staff who implement innovation projects have strong innovation abilities.	0.749	0.779
We emphasise research and development.	0.787	0.792
We are fast to introduce new techniques and technologies.	0.716	0.624
Process innovation	0.929	0.740
Invested in R&D specifically dedicated to process improvement or process innovation.	0.736	0.638
Invested in purchasing new technology for manufacturing processes.	0.735	0.622
Implemented entirely new processes or radical process innovations.	0.608	0.680
Has frequently improved manufacturing or operational processes.	0.600	0.643
Has made significant efforts to reduce resource consumption.	0.614	0.629

Supply chain resilience, Study 1 (CR = 0.890, AVE = 0.670), Study 2 (CR = 0.890, AVE = 0.669)		
We are able to cope with changes brought by the supply chain disruption.	0.852	0.779
We are able to adapt to the supply chain disruption easily.	0.878	0.813
We are able to provide a quick response to the supply chain disruption.	0.789	0.815
We are able to maintain high situational awareness at all times.	0.748	0.810
Supply chain adaptability, Study 2 (CR = 0.943, AVE = 0.648)		
Regularly determines where companies' products stand in terms of technology cycles and product life cycles.	-	0.773
Creates flexible product designs.	-	0.827
Evaluates the needs of ultimate consumers, not just immediate customers.	-	0.785
Can modify its supply chain resources to respond to long-term changes in supply	-	0.823
Can modify its supply chain resources to respond to long-term changes in demand	-	0.864
Can modify its supply chain resources to respond to long-term changes in its environment (e.g. currency fluctuations, economic policies, political changes).	-	0.817
We can usually better adjust our supply chain resources to long-term changes in supply.	-	0.872
We can usually better adjust our supply chain resources to long-term changes in demand.	-	0.886
We can usually better adjust our supply chain resources to long-term changes in our environment (e.g. currency fluctuations, economic policies, political changes).	-	0.821

Table 3. Discriminant validity (Study 1)

	Supply Chain Digitalisation	**Supply Chain Resilience**	**Supply Chain Innovation**
Supply Chain Digitalisation	**0.752**		
Supply Chain Resilience	0.492***	**0.818**	
Supply Chain Innovation	0.570***	0.743***	**0.923**

Table 4. Discriminant validity (Study 2)

	Supply Chain Digitalisation	**Supply Chain Resilience**	**Supply Chain Adaptability**	**Supply Chain Innovation**
Supply Chain Digitalisation	**0.752**			
Supply Chain Resilience	0.358**	**0.818**		
Supply Chain Adaptability	0.409**	0.644**	**0.805**	
Supply Chain Innovation	0.393***	0.610**	0.662**	**0.923**

5.2 Structural model evaluation

After assessing the measurement model, we evaluated the structural model's fit for Study 1 and Study 2, Study 1 ($\chi^2 = 1.822$, $p < 0.05$, CFI = 0.905, SRMR = 0.072, RMSEA = 0.079), Study2; ($\chi^2 = 1.656$, $p < 0.05$, CFI = 0.904, SRMR = 0.068, RMSEA = 0.070), were adequate. We started by testing the hypotheses from Study 1. Our initial Hypothesis H1 proposed that SCD positively affects SCI, which was confirmed ($\beta = 0.323$, $p < 0.05$). The second hypothesis, H2, proposed that SCI positively impacts SCR; this hypothesis was also supported ($\beta = 1.117$, $p < 0.05$). Moreover, the third hypothesis, H3, suggesting the mediating role of SCI between SCD and SCR, was also confirmed ($\beta = 0.361$, $p < 0.05$). The effect of control variables, i.e., job level ($\beta = 0.024$, $p > 0.05$) and employee experience ($\beta = 0.029$, $p > 0.05$) on SCR remained insignificant. To validate and extend the results of Study 1, we conducted another study. Our first hypothesis for Study 2 (H4) proposed that SCD positively impacts SAD, which was confirmed ($\beta = 0.367$, $p < 0.05$). Hypothesis H5, stating that SAD positively impacts SCR, was also confirmed ($\beta = 0.236$, $p < 0.05$). Hypothesis H6, proposing a mediating role of SAD between SCD and SCR, was not confirmed ($\beta = 0.087$, $p > 0.05$). Finally, hypothesis H7 proposing the sequential mediation (SCD → SAD → SCI → SCR) was confirmed ($\beta = 0.142$, $p < 0.05$). Additionally, an interesting finding in Study 2 was that, with the inclusion of SAD in the model, hypotheses H1 and H3 were not significant ($\beta = 0.111$, $p > 0.05$) and ($\beta = 0.074$, $p > 0.05$), respectively. Additionally, hypothesis H2 in Study 2 remained significant ($\beta = 0.666$, $p < 0.003$). In Study 2, control variables also remained insignificant.

Table 5. Study 1 results

Hypothesised relation	**Estimate**	***p*-value**
Direct effects		
SCD → SCI	0.323	0.000
SCI → SCR	1.117	0.000
Indirect effects		
SCD → SCI → SCR	0.361	0.000
Control variables		
Job Level → SCR	0.024	0.796
Employees Experience → SCR	0.029	0.580

Table 6. Study 2 results

Hypothesised relation	**Estimate**	***p*-value**
Direct effects		
SCD → SCI	0.111	0.056
SCI → SCR	0.666	0.003
SCD → SCA	0.367	0.000
SCA → SCR	0.236	0.000
Indirect effects		
SCD → SCI → SCR	0.074	0.058
SCD → SCA → SCR	0.087	0.314
SCD → SCA → SCI → SCR	0.142	0.002
Control variables		
Job Level → SCR	0.020	0.758
Employees Experience → SCR	-0.015	0.686

Fig 1. Study 1 hypothesised model and results

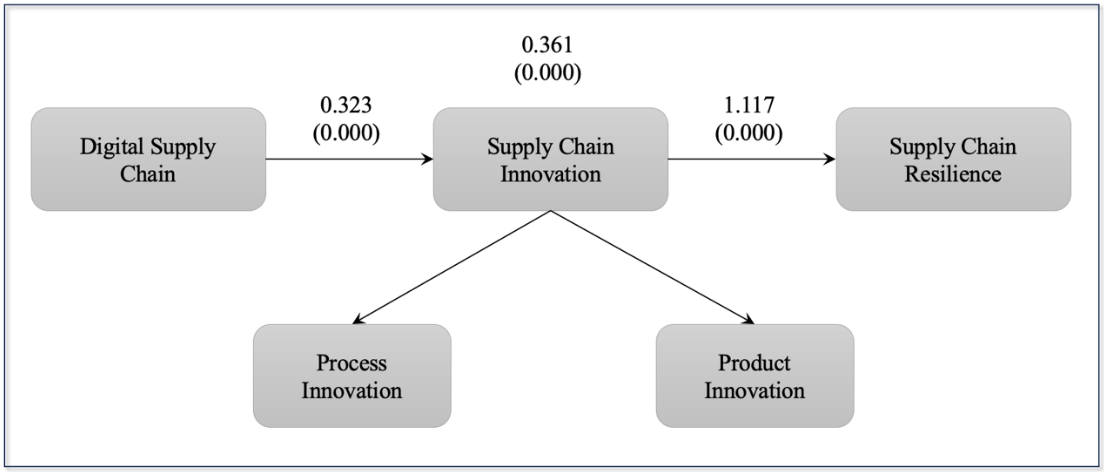
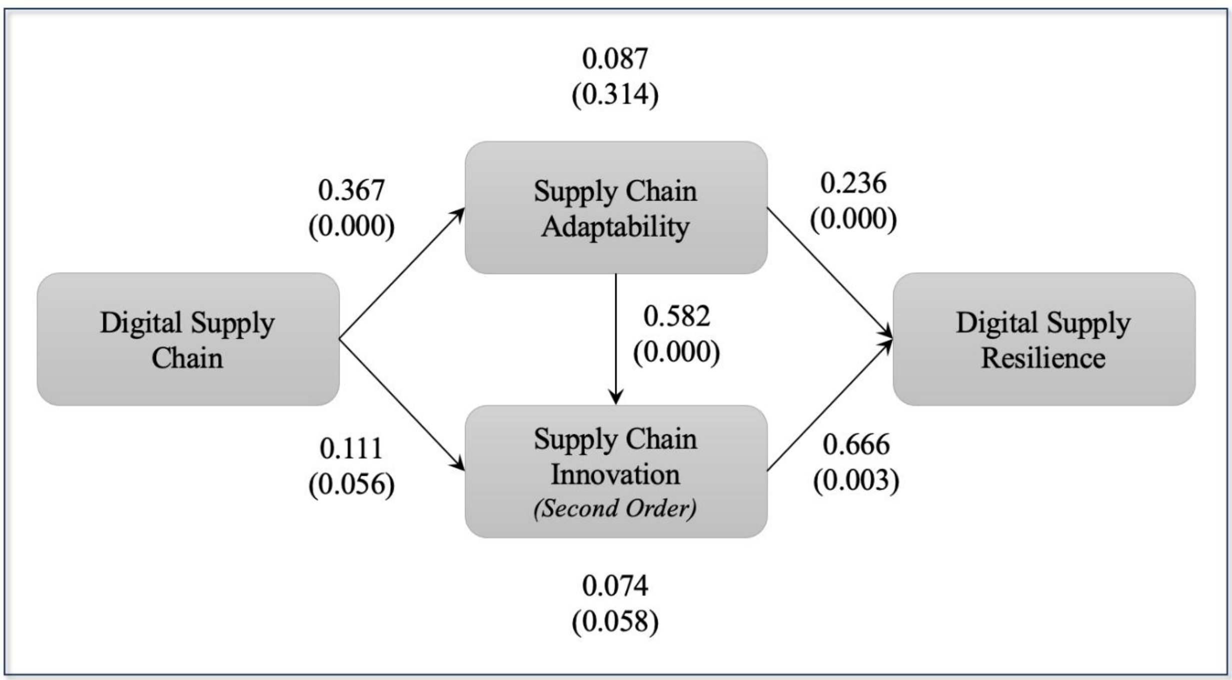


Fig. 2 Study 2 hypothesised model and results



6. Discussion

Our study presents an empirically developed framework that examines the impact of SCD on SCR, with a focus on the mediating effects of SAD and SCI. Specifically, we aim to determine whether SCD enhances SCI and SAD, which subsequently contribute to improving SCR. This research extends prior work by integrating these components into a cohesive framework, addressing a significant gap in the literature that has typically analysed the relationships between SCD, SCR, and SCI in isolation (Bhatti et al., 2022; Golgeci and Ponomarov, 2013). We place particular emphasis on firms in developing economies, where uncertain environments create a unique context for examining the interplay of digitalisation, innovation, adaptability, and resilience.

The existing literature identifies SCD as a driver of SCI, yet findings on its effectiveness have been mixed (Hassan et al., 2024). Some studies indicate that SCD can stimulate innovation (Nambisan et al., 2019), while others suggest its impact is limited without complementary factors such as organisational readiness, supportive infrastructure, and adaptability. Adaptability provides firms with the necessary flexibility to adjust processes in response to changing conditions, making innovation efforts more effective (Benitez et al., 2022; Usai et al., 2021). Importantly, adaptability enhances a firm's absorptive capacity by facilitating rapid reconfiguration of supply chain processes in response to environmental changes (Stentoft et al., 2023). Drawing on the sensing-seizing-reconfiguring framework from DCV (Teece, 2007), adaptable firms are better positioned to sense emerging opportunities, seize them through innovation, and reconfigure their resources accordingly. This dynamic capability enables innovation to be not only reactive but also proactive, strengthening resilience in uncertain environments (Eckstein et al., 2015; Benitez et al., 2022). The role of adaptability, however, has often been overlooked, limiting our understanding of how SCD can effectively drive both innovation and resilience. Our study clarifies this by exploring how SAD acts as a critical enabler that allows SCD to translate into tangible innovation outcomes, thereby enhancing SCR. By incorporating SAD, we demonstrate that adaptability directly supports innovation, creating a feedback loop that bolsters resilience and ensures digital investments yield tangible benefits in volatile environments (Dubey et al., 2023; Usai et al., 2021).

In examining the dynamic relationships between these variables, we aim to uncover the mechanisms through which SCD translates into meaningful resilience outcomes, particularly for firms in developing economies. Our findings show that while SCI and SAD individually did not mediate the relationship between SCD and SCR, the sequential pathway from SAD to SCI was significant. This suggests that adaptability acts as a necessary foundation upon which innovation can successfully contribute to resilience. Without first establishing adaptability, the innovation triggered by digitalisation may not align effectively with the challenges inherent in the supply chain environment, thus weakening its impact on resilience outcomes. By focusing on SCI and SAD as mediating factors, we contribute to a more nuanced understanding of how SCD can strengthen resilience in complex and uncertain supply chain environments. In the sections that follow, we discuss the key theoretical and practical contributions our study offers for managers seeking to exploit digitalisation for enhanced SCR.

6.1 Theoretical implications

This study advances IPT by illustrating how digital supply chains not only improve information flow but also enhance the firm's capacity for dynamic problem-solving through adaptability. In doing so, we extend IPT from a static view of information exchange to a dynamic perspective where information drives continuous reconfiguration. Similarly, our study contributes to the DCV by empirically validating the sequential pathway through which adaptability develops innovation, reinforcing resilience. Unlike prior studies that treated capabilities as isolated constructs, we show that dynamic capabilities operate synergistically and sequentially to shape resilience outcomes in volatile environments.

Our theoretical contributions centre on how the integration of IPT and DCV provides a comprehensive framework for understanding the complex relationship between SCD, SCI, SAD, and SCR. By applying IPT, we offer insights into how digital supply chains enhance information processing capabilities, leading to improved adaptability and innovation. Conversely, the application of DCV helps explain how these enhanced capabilities can be reconfigured to improve resilience. Our findings deepen the understanding of how these elements interact synergistically to enhance resilience, particularly in developing economies, where uncertainty and resource constraints present unique challenges and opportunities.

Using IPT, we analyse the pathways from digital supply chains to both innovation and adaptability. In ***Study 1***, our results indicate that SCD significantly enhances SCI, which in turn contributes to SCR. This finding aligns with existing literature positing that SCD is a driver of SCI, highlighting that the effective processing and utilisation of information can lead to innovative supply chain practices (Li et al., 2024; Nambisan et al., 2019). However, despite the positive outcomes from ***Study 1***, there remains an ongoing discussion regarding the limitations of relying solely on innovation to achieve resilience, particularly in uncertain environments (Benitez et al., 2022; Hassan et al., 2024; Sabahi & Parast, 2020).

The literature suggests that innovation outcomes often require additional complementary capabilities, such as adaptability, to translate effectively into resilience (Acar et al., 2019; Dubey et al., 2023; Eckstein et al., 2015). This insight motivated the development of ***Study 2***, which builds upon the initial findings by incorporating SAD as an additional mediating factor. The inclusion of SAD addresses a key gap identified in prior studies that often overlooked the role of adaptability in facilitating the translation of digital capabilities into resilience outcomes. Interestingly, our findings from ***Study 2*** reveal that the direct mediation of SCI and SAD between SCD and SCR, as standalone mediators, is insignificant. However, the sequential mediation from SAD to SCI is significant. This finding highlights the critical role of adaptability in laying the groundwork for innovation to effectively contribute to resilience. This sequential mechanism demonstrates that SAD establishes a stable environment where innovation can thrive, enhancing firms' responsiveness to environmental challenges and ensuring the successful operationalisation of resilience strategies. Our findings align with the emerging evidence suggesting that, particularly in highly uncertain environments, the sequential relationship of dynamic capabilities may offer a more robust pathway to resilience than relying solely on individual capabilities (Iftikhar et al., 2025).

The application of DCV provides a deeper understanding of the sequential pathways involving SAD and SCI. DCV suggests that dynamic capabilities, such as adaptability, allow organisations to respond to changing environments by restructuring their resources (Teece, 2007). In our extended model ***(Study 2)***, the path from SCD to SCR is most effective when it traverses through SAD and then SCI. Adaptability serves as the dynamic capability enabling firms to adjust to environmental disruptions, subsequently allowing innovation to drive resilience effectively. This sequence suggests that firms are not only generating novel ideas but are also prepared to implement these innovations in ways that contribute directly to resilience. By unpacking this sequential capability interaction, our study extends the DCV framework, where adaptability is not merely an outcome but a capability that supports ongoing innovation and ensures resilience in volatile environments. Furthermore, our combined use of IPT and DCV offers a unique perspective on the mediating roles of SAD and SCI. While IPT explains how digitalisation enhances information flows that enable both innovation and adaptability (Fan et al., 2017), DCV highlights how these capabilities interact dynamically to strengthen resilience (Aslam et al., 2020; Teece, 2007). The sequential pathway uncovered in ***Study 2*** reveals that prioritising adaptability as the initial response mechanism allows firms to establish the necessary foundation for impactful innovation. This suggests that pursuing innovation in isolation may be insufficient for achieving resilience; rather, adaptability must be prioritised to enable innovation to contribute effectively to resilience, especially in the face of disruptions. This perspective highlights the value of adaptability in enhancing the transformative potential of digital supply chains.

Our study also makes important contributions to the literature on supply chain management in developing economies. In these contexts, resilience is particularly critical due to high levels of environmental uncertainty. By incorporating both SCI and SAD as mediating factors, our research reveals how firms can exploit digitalisation more effectively to manage the prevalent uncertainty in these regions. The sequential approach from SAD to SCI to SCR provides a richer understanding of how digital investments can be structured to build both adaptability and resilience, ensuring that innovations are not only developed but also sustained under challenging conditions.

6.2 Practical implications

This study provides valuable insights for managers seeking to enhance supply chain resilience in complex and uncertain environments, particularly in developing economies. Our findings emphasise that SCD, when supported by SAD, enables innovation and ultimately strengthens resilience. This dynamic was explained in practice during the COVID-19 pandemic, when Unilever effectively utilised digital technologies to rapidly adjust its supply chains in response to the increased demand for hygiene products like hand sanitisers. The company demonstrated adaptability by repurposing existing production lines and innovating new product formulations and packaging solutions, enabling them to meet market needs more effectively and swiftly (Unilever, 2020). This case illustrates how the integration of digital capabilities with adaptability can drive innovation and enhance resilience during disruptive events.

Managers should perceive adaptability not merely as a defensive mechanism but as a strategic enabler of innovation, allowing supply chains to thrive amid disruptions. Additionally, our results suggest that to fully exploit SCD, firms must develop organisational capabilities that facilitate flexibility and foster a culture of innovation. Specifically, our findings indicate that firms should not solely concentrate on enhancing resilience through innovation; rather, they should prioritise utilising SAD as a critical intermediary. By strengthening SAD, firms can establish a robust foundation that makes subsequent innovation efforts more effective and sustainable (Acar et al., 2019; Dubey et al., 2023). This sequential pathway from adaptability to innovation ensures that firms are well-equipped to tackle unforeseen challenges, creating a stable platform from which to drive innovation.

Building on these insights, managers can exploit structured adaptability frameworks to operationalise these pathways. For example, firms can adopt Intelligent Manufacturing Systems, which are prevalent in developed economies like Germany and Japan (Kusiak, 2018). Although these practices originated in advanced economies, they are increasingly being adapted to fit the constraints of developing economies through scalable and incremental adoption strategies (Castañeda-Navarrete, 2021). For instance, adopting Industry 4.0 solutions such as digital twins and flexible manufacturing cells, starting with low-cost digital applications, allows firms to dynamically adjust production based on real-time data. Small and medium-sized enterprises (SMEs) can implement affordable collaborative robotics (cobots) and additive manufacturing (3D printing) to enhance operational flexibility with lower capital investment (Rainer et al., 2025). Managers should strategically invest in digital infrastructure that supports not just efficiency but also dynamic adaptability, ensuring that innovation efforts are sustainable under fluctuating market conditions. By initially enhancing operational adaptability through these frameworks, firms can enable more dynamic innovation activities, which collectively build greater SCR against future disruptions

However, the extent to which firms can adopt these digital and adaptive solutions may vary significantly depending on firm size and their available resources. Smaller firms could benefit from strategic partnerships to overcome resource limitations, while larger firms should focus on the cross-functional integration of digital systems to bolster both adaptability and innovation. Ultimately, the adoption of SCD should be accompanied by intentional efforts to cultivate SAD, enabling supply chains to be both innovative and resilient in unpredictable environments. Regardless of firm size, an integrated approach combining digitalisation with adaptability is essential for building an innovative and resilient supply chain.

The integration of digitalisation and adaptability provides a comprehensive framework (see Fig. 4) for supply chain managers to not only mitigate risks but also lay the groundwork for effective innovation. By prioritising adaptability as a foundational step, firms can ensure a robust response mechanism that facilitates sustainable and market-aligned innovation.

6.3 Limitations and future research directions

While this study offers significant insights into the relationship between SCD, SCI, SCA, and SCR, it is not without limitations. *First*, the cross-sectional nature of the study restricted our ability to draw causal conclusions about the relationships among these constructs. Future researchers could adopt a longitudinal approach to capture how these relationships evolve over time and establish stronger causal inferences. *Second*, we employed two different models from distinct samples, which, while enhancing cross-validation and methodological robustness, may introduce variability that was not fully accounted for. To address this, future research could utilise a time-lagged approach or conduct repeated measurements across multiple time points to better control for variability and capture the temporal dynamics among these constructs more comprehensively. *Finally*, although we highlighted the crucial role of SCA in linking SCD with SCI and SCR, the specific mechanisms that facilitate adaptability remain underexplored. Future studies should investigate how SCA can be cultivated as a strategic enabler, focusing on aspects such as proactive risk management, adaptive leadership, and the integration of emerging technologies (Benitez et al., 2022; Dubey et al., 2023). Exploring these areas could yield deeper insights into how organisations can leverage SCAD to drive sustained innovation and build resilience in uncertain environments.

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