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EDITED BY
Vineet Tiwari,
Indian Institute of Information Technology, Allahabad, India

REVIEWED BY
Farooq Ahmed Jam,
Global Illuminators, Malaysia
Winda Nur Cahyo,
Islamic University of Indonesia, Indonesia

*CORRESPONDENCE
Ahmed M. Attia
ahmed.attia@adu.ac.ae

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Smart supply chains: industry 4.0 and resilience in the UAE food and beverage sector

Ahmed M. Attia*

Military Programs, Abu Dhabi University, Alain, United Arab Emirates

Introduction: The United Arab Emirates (UAE) food and beverage (F&B) sector is structurally import-dependent and critical to national industrial diversification, food security, and circular economy goals, making supply chain resilience a strategic priority. This study investigates how the adoption of Industry 4.0 technologies (Internet of Things, artificial intelligence, big data analytics, blockchain, cyber-physical systems, and cloud computing) enhances supply chain resilience. Drawing upon the Resource-Based View, Dynamic Capabilities Theory, the Dynamic Resource-Based View, and Supply Chain Resilience Theory, the research posits that Industry 4.0 adoption impacts resilience directly and indirectly via supply chain and dynamic capabilities as mediators, with digital organizational culture acting as a moderator.

Methods: A quantitative, cross-sectional research design was utilized, gathering data via a structured survey administered to 395 senior supply chain and operations managers within UAE F&B manufacturing companies. The collected dataset was analyzed using partial least squares structural equation modeling (PLS-SEM) via SmartPLS with 5,000 resamples to evaluate measurement validity, structural paths, and moderation effects.

Results: The structural equation modeling results support all six hypothesized paths. Industry 4.0 technology adoption exerts a significant positive effect on supply chain capabilities ($\beta = 0.849$, $P < 0.01$\$) and dynamic capabilities ($\beta = 0.869$, $P < 0.01$\$). Both supply chain capabilities ($\beta = 0.735$, $P < 0.01$\$) and dynamic capabilities ($\beta = 0.769$, $P < 0.01$\$) positively influence supply chain resilience. Furthermore, Industry 4.0 adoption has a direct positive impact on resilience ($\beta = 0.856$, $P < 0.01$\$), and digital organizational culture positively moderates the technology-resilience relationship ($\beta = 0.729$, $P < 0.01$\$).

Discussion: The findings demonstrate that modernizing F&B supply chains requires more than standalone technological investments; digital tools must be combined with internal capability building and a supportive digital organizational culture. For UAE producers, leveraging solutions like IoT traceability and AI forecasting—underpinned by a data-driven culture—strengthens overall network adaptability and recovery. These insights align with national strategic frameworks such as the UAE Circular Economy Policy 2021–2031 and Operation 300bn.

KEYWORDS
digital organizational culture, industry 4.0, PLS-SEM, smart supply chains, supply chain resilience, UAE food and beverage manufacturing

1 Introduction

The Industrial Revolution 4.0, which manifests as a fusion of every area of industrial processes, encompasses dedicated technologies collectively referred to as the Internet of Things, cyber and physical technologies, big data analytics, and artificial intelligence, among many others. This approach ultimately implies front-to-back information flow accuracy across partners in a company by defining and ensuring end-to-end visibility and operational flexibility using these digital tools (Ng et al., 2021). It also implies storage and method flexibility, which is the ability to quickly reconfigure and redeploy source and supply processes to cope with the ever-changing consumption trends in the market (Kumar et al., 2024). The supply chain's ability to adjust quickly to changes in objectives or operations is called supply chain response, which refers to the performance of a supply chain under abnormal conditions, including recovery performance and response time performance (Spiegler et al., 2012).

Despite growing scholarly interest in Industry 4.0 technologies such as artificial intelligence, the Internet of Things, big data analytics, blockchain, cyber-physical systems, and cloud computing, the mechanism by which firms transform digital technology stock into resilience capital remains understated. Moreover, comprehensive empirical studies on the impact of this transformation of digital technology capabilities on the food and beverage industry in the UAE are few, according to the insights given in the empirical literature (Abu-Siam et al., 2026; Malik and Pasha, 2022). The study is informed by three key concerns. The first is theoretical: more attention to the literature is needed to bridge the gap, as it has been evidenced that information systems and digital infrastructure contribute to supply chain effectiveness as a whole (Abu-Siam et al., 2026) and that the pandemic upsurge enhanced the adoption of Industry 4.0; however, cross-stream application between the RBV, dynamic capabilities, supply chain resilience, and digital organizational culture conditioning is weak (Huang et al., 2023).

The second concerns empirical gaps: although the country's food and manufacturing industry has been used as a specific example in which "supply chain 4.0", "supply chain risk", and "organizational performance" are discussed (Kurdi et al., 2022), and warehouse-receipt and food-security instruments have been formalized as part of how the country will build its resilience owing to the ongoing industrial transformation (Brookbanks and Parry, 2024), how this process actually occurs has not yet been touched upon in this field.

The third concern is the emergence of the sustainability-nexus agenda: pioneering works demonstrate that including digital capabilities fosters societal development in economic terms through another concept of development called digital resilience, which is supported by specific institutional structures, and stakeholders enhance the relationship between adopting digital technology and engaging in eco-cooperation. However, stakeholder value seems to intervene in the organic relationship between these components. In this regard, an industrial organization in the UAE specifically (and Egypt within the region's geographic boundary) is an attractive empirical setting for studying how improved supply chain resilience driven by Industry 4.0 can help improve key digital and food-system sustainability issues such as reducing waste, improving demand forecasting accuracy, and producer-to-consumer traceability.

The food and beverage industry in the United Arab Emirates emerges as a fitting sector for the study of the food supply chain of the CCCA because of the food import-dependent nature of the country, the food security policies in its constitution, and the national policy of industry diversification. The study is significant in two ways. First, it integrates four theoretical constructs – the Resource-Based View, Dynamic Capabilities Theory, the Dynamic Resource-Based View, and Supply Chain Resilience Theory – within a single structural model based on PLS-SEM, which has not been attempted in this specific sector. Second, it advances the involvement of digital organizational culture as a moderating mechanism that needs quantification in real life, and it relates to technology adoption strategies by managers and the economic sector goals in the UAE, in particular the Circular Economy Policy 2021–2031 and industrial growth strategies such as Operation 300bn, explaining the mechanism involved in the operation of the strategy under study.

Consequently, this investigation aimed to analyze related studies and literature gaps, focusing on the mechanisms for the effective implementation of these tools in economic systems. It is in this light that this study responds to the literature gap by proposing a direct causal relationship between the introduction of digital platforms and the construction of dynamic capabilities. More specifically, the focal point of this work is the effect of digital capabilities and the extent to which these provide organizations with the means to cope with instability in an efficient manner (Hu et al., 2025; Warner and Wäger, 2018).

An analysis is helpful in conveying a more detailed view of how firms can leverage digital organizational culture and absorptive capacity to provide greater flexibility, given the growing uncertainty in the environment, by integrating these variables. Moreover, the current study argues that advanced technological changes and development offer more prospects than mere operational improvements built into organizational strategies, where sophisticated data science and prudent decisions of such advanced models promote risk and strategic management (Ghobakhloo et al., 2021). The study also addresses a gap in literature that has ignored the importance of digital tools in the development of an organization's dynamic capacities. In summary, this study introduces the idea of digital competency consolidation and structural organizational flexibility, which addresses some of the gaps identified in the literature (Agostini et al., 2023; Al-Faouri et al., 2024; Elia et al., 2021). An additional contribution of this study is the investigation of digital-enabling sensing, learning, and coordinating mechanisms to enhance organizations in such environmental contexts (Marchese et al., 2023). Consequently, this study is based on the dynamic capabilities framework perspective and determines how companies adapt to technological equipment to turn liabilities of competence into sources of strategic advantage (Leyva-Tapia et al., 2024). The study is guided by fundamental research questions that address the existing research gaps in the analysis of digital transformation and supply chain resilience.

RQ1: What are the technical dimensions favored by advancements in Industry 4.0, for its full implementation in the context of research on EPS in organizations? (Ghobakhloo et al., 2021; Mubarik et al., 2021; Ng et al., 2021).

RQ2: Will the 4.0 dimensions of networked manufacturing suffice in ensuring the success of the approach in organizations and supply chains (Gobbo et al., 2018)?

RQ3: How can organizations avoid developing a myopic focus on disruptive shock and instead look into the medium- and long-term effects of the shock on their operations and, more importantly, their preparedness embedded in adjusted risk management strategies (Aslam et al., 2025)?

2 Theoretical background and literature review

2.1 Theoretical background

This study is anchored in four interrelated theoretical lenses that, taken together, frame how Industry 4.0 technologies are converted into supply chain capability and resilience in volatile environments.

2.2 The resource-based view

In the RBV, a firm gains a sustained competitive advantage if it acquires and deploys bundles of resources that are simultaneously valuable, rare, imperfectly imitable, and non-substitutable (Alfaqiyah et al., 2025; Barney, 1991). From this perspective, competitive advantage does not come from one resource but from how resources are organized and utilized; therefore, resource heterogeneity and immobility are the two pillars on which long-run performance is built (Dixit et al., 2026). The RBV forms the basis of the "stock" logic for the current study, viewing Industry 4.0 technologies such as cyber-physical systems, the Industrial Internet of Things, artificial intelligence, and big data analytics as firm-level resources that can provide a sustained advantage (Bag et al., 2020; Fatorachian and Kazemi, 2018; Kumar and Aithal, 2023; Nisa and Chhipa, 2025).

2.3 Dynamic capabilities theory

Because the RBV alone cannot explain how firms renew their resource bases in environments characterized by rapid technological change, this study also draws on the dynamic capabilities' framework. Dynamic capabilities are defined as 'the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments' (Dixit et al., 2026; Svare and Gausdal, 2017). These capabilities have been further elaborated along three subroutines: sensing (scanning the environment to identify threats and opportunities), seizing (mobilizing resources to capture value), and transforming/reconfiguring (continuously realigning the asset base) (Teece et al., 1997). In fast-moving digital environments, firms can accumulate substantial stocks of valuable technologies and fail commercially if they lack the dynamic capabilities required to redeploy them. This foregrounds capability investment and deployment as the second theoretical pillar of this study.

2.4 The dynamic resource-based view

The Dynamic Resource-Based View represents the integration of the RBV and Dynamic Capabilities perspectives and provides a unifying lens for this study. Whereas the RBV explains how heterogeneous resources generate a competitive advantage at a given point in time, dynamic capabilities explain how firms reconfigure resource bundles as the environment changes (Helfat and Peteraf, 2003). The DRBV foregrounds the lifecycle of capabilities, recognizing that capabilities must be created, developed, and refreshed to remain valuable (Helfat and Peteraf, 2003). The use of the DRBV as a foundation for this study has shifted the outlook of industrial firms' engagement with Industry 4.0. The utilization of Industry 4.0 is viewed not as part of a digital productivity drive but as a series of endless efforts towards identifying, seizing, and reshaping technology requirements and modifying competitive advantages.

2.5 Supply chain resilience theory

Additionally, within the same context as the previous theoretical integrations, another theoretical position is taken up in this study. To begin with, it is presumed, within the constraints of the dynamic resource-based point of view, that Industry 4.0 technologies are not mere individual investment decisions but materialize into a digital resource stock, and only by deploying their dynamic capabilities do firms find value in this reserve that emerges from their considerate inherent resources through effective sensing, capturing, and transformation activities (Helfat and Peteraf, 2003; Huang et al., 2023). Thirdly, the technology–resilience relationship is also expected to play out through the adoption of advances in capabilities, mainly supply chain ability and dynamic capabilities, and also directly through technologies such as sensor-based data collection and predictive techniques for identifying immediate improvements in resilience (Huang et al., 2023). The transformation of these abilities due to technology is, however, fickle, especially given suggestions that the organizational culture of the firm based on new technologies comes before resilience. In particular, the literature on digital organizational culture as it affects supply chain management broadly has highlighted that resilience did not emerge as an issue in the relationship dynamics. As a result, we embed digital organizational culture as a contingency on technologies' ability to enhance resilience, which also means we apply the logic of this study more on contingency grounds and not on the lines of dominant models of technology acceptance. This approach – the combination of the DRBV capability lifecycle with a cultural contingency – sets the current study apart from existing research that looks at digitalization as a direct cause of resilience or as a process that is mediated by capabilities alone (Zouari et al., 2020). This is explained in the development of the hypotheses that follow.

2.6 Integration of the four lenses

Taken together, these four lenses form an integrated theoretical chain: Industry 4.0 technologies are introduced into firms that possess, or must develop, the dynamic capabilities to sense, seize, and reconfigure them. Over the lifecycle of a firm, this combination produces digital supply chain capabilities (visibility, agility, and modularity) that, in turn, generate supply chain resilience in the face of complex disruptions (Agrawal et al., 2023; Modgil et al., 2021). This integration is consistent with the broader notion of Industry 4.0, which requires a strategic roadmap rather than a one-time technology purchase (Ghobakhloo, 2018). Whether and how firms successfully execute this roadmap and sustain it over time is the empirical question this study pursues through the research questions stated in the Introduction (Dixit et al., 2026; Ng et al., 2021; Pirola et al., 2019).

3 Literature review and development of research hypotheses

The digital transformation driven by Industry 4.0 significantly enhances digital reactivity, operational efficiency, and predictive capabilities, as well as overall organizational resilience (Kumar and Aithal,

2023). Digital enablers are increasingly recognized as essential mechanisms for overcoming traditional operational constraints, with key variables ensuring meaningful and resilient performance levels. Modern academic and industrial debates frequently focus on eliminating digital–physical gaps through cyber-physical systems and the Industrial Internet of Things, effectively streamlining process chains while incorporating advanced solutions such as cloud computing and predictive analytics (Alfaqiyah et al., 2025). These tools offer vital real-time access to information, enabling rapid, well-informed decision-making when identifying, assessing, and managing supply chain risks (Calatayud et al., 2018; Odimarha et al., 2024). Furthermore, artificial intelligence empowers organizational employees to better forecast and optimize complex systems, infrastructure, and resources across the value chain, shifting supply chains away from conventional linear relationships towards web-like data-driven connections (Attah et al., 2024).

Historically, conventional supervision models, frequently observed in sectors such as banking, rely heavily on reactive, short-term problem-solving rather than anticipating future risks, making it difficult for firms to align logistics with long-term business plans, strategic objectives, and budgets (Rodríguez-Espíndola et al., 2022). Unforeseen global disruptions have repeatedly altered supply chains, demonstrating that when a single localized risk cascades into a systemic failure, it can trigger catastrophic consequences. Adopting a proactive approach to evaluate exposure across all cross-sectional vulnerabilities is essential for mitigating such risks before they escalate (Rodríguez-Espíndola et al., 2022). Cyber-physical systems actively counteract these uncertainties by providing real-time surveillance in logistics, dynamically optimizing freight and transportation, and delivering the comprehensive visibility necessary for corporate sustainability in volatile environments (Adama et al., 2024; Taras, 2025).

Despite these clear advantages, deploying highly mechanized processes presents notable implementation challenges, including high installation costs, demand for highly qualified human resources, and the constant threat of cyberattacks, theft, and economic sabotage (Adewumi et al., 2024). Moreover, fully exploiting these digital tools requires optimizing existing or developing new organizational cultures, along with deeply integrating data analytics frameworks, to protect established commercial competitive advantages (Soori et al., 2024). To address these concerns, decentralized technologies such as blockchain, artificial intelligence, and big data analytics provide a modular architecture that fosters decentralized trust, accelerates processing speeds, and satisfies stringent privacy requirements within the modern supply chain (Karanam et al., 2024; Reddy et al., 2025).

Ultimately, converging technological solutions enable businesses to fundamentally transform traditional closed-form logistics into highly adaptable, high-value operations capable of thriving in volatile and unpredictable market conditions (Irfan et al., 2025; Karanam et al., 2024; Tiwari et al., 2024). Although implementing these advancements is inherently complex, organizations can effectively navigate these hurdles by utilizing structured decision-making approaches such as the analytic hierarchy process and the technique for order of preference by similarity to ideal solution, tailored to specific operational contexts (Alam et al., 2025). Empirical and predictive evidence further demonstrates that combining AI predictive analytics with integrated blockchain applications achieves significant operational milestones such as a 42% decrease in recovery (Sen, 2025). This performance leap stems from a broader paradigm shift in supply chain management, which moves away from narrow "cost-effectiveness" models towards robust recovery planning (Sen, 2025). Advanced deep network architectures, including recurrent neural networks and complex machine learning algorithms, continuously monitor normal parameters, adjust product movements, and accurately redefine fluctuating industry demands (Hondoma, 2024; Torres et al., 2025). These advanced analytics consistently outperform preprogrammed risk metrics by predicting disruptions and executing strategic pivots only when economically feasible (Attah et al., 2024). Rather than replacing system-wide predictions, these new processes augment forecasting accuracy, ensuring that real-time data drives infrastructure adjustments for operational recovery and continuity (Attah et al., 2024). Finally, the overarching benefits of these sustainable tools remain fully accessible to firms of any type or size when supported by lean talent and adaptable systemic network structures (Ebirim et al., 2024).

According to the Resource-Based View, competitive advantage is obtained through the acquisition and use of resources that are valuable, rare, imperfectly imitable, and non-substitutable. In this context, Industry 4.0 technologies (e.g., IoT, AI, big data analytics, blockchain, cyber-physical systems, and cloud computing) are considered a bundle of digital resources that allow for an extension of the firm's operational reach in four potential directions: more efficiency, more flexibility, better quality, and more sustainability (Cuong et al., 2025; Ng et al., 2021). The Dynamic Resource-Based View further explains that the heterogeneous resources need to be reconfigured through dynamic capabilities to produce capability outcomes (Helfat and Peteraf, 2003); with respect to Industry 4.0 technologies, Ng et al. (2021) describe the six core design principles through which Industry 4.0 technologies enhance the firm's real-time responsiveness and information transparency, such as decentralization, interoperability, modularity, virtualization, real-time capability, and service orientation (Ghobakhloo, 2018).

Research surveys conducted in the Malaysian electrical and electronics industry confirm that supply chain mapping and visibility, operationalized through sensors, mobility, geographic information systems, and supply chain control towers, drive cleaner production and resilience outcomes in Industry 4.0 implementations (Huang et al., 2023; Mubarik et al., 2021). Recent bibliometric work provides additional confirmation that the "sustainability value drivers" of Industry 4.0 technologies are most visible when technologies are combined with adaptive operations, real-time optimization, and decentralized decision-making. Based on the above discussion, the first hypothesis of this study is as follows.

> *H1*: Higher levels of Industry 4.0 technology adoption are positively associated with higher levels of supply chain capability.

Supply chain resilience theory defines resilience not as an individual measurable entity but as a collective and adaptive capability of networks to maintain a dynamic equilibrium against disruption (Zouari et al., 2020). From this perspective, three dimensions of capabilities have repeatedly been identified as antecedents of resilience: agility (the ability to adjust material flows and procurement strategies to changing demand), modularity (the reconfigurability of value chains through dynamic material flow systems), and visibility (information transparency throughout the network in real time) (Kwak et al., 2017; Statsenko et al., 2024). The Risk and Resilience-Driven Capability framework suggests that the resilience of a supply chain is a function of these three capabilities and three corresponding risk management objectives (Zouari et al., 2020): agility supports control

risks, modularity supports disruption risks, and visibility supports supply risks.

A survey of 264 UK manufacturing plants found that supply chain connectivity and information-sharing resources lead to visibility capability, which in turn enhances resilience and robustness (Brandon-Jones et al., 2014). Information sharing is defined as "the glue that holds supply chain organizations together in a crisis" (Scholten and Schilder, 2015), and collaboration is a formative element of resilient supply chains. Furthermore, recent empirical evidence confirms that digital transformation facilitates supply chain resilience through the serial mediation of adaptability and innovation (Abu-Siam et al., 2026; Aslam et al., 2025). Information integration over a network is a key enabler of this process (Luca et al., 2025). The above discussion leads to the following hypothesis:

> *H2*: Higher levels of supply chain capability are positively associated with higher levels of supply chain resilience.

Dynamic capabilities theory defines "dynamic capabilities" as "the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments" (Teece et al., 1997). In Industry 4.0, technologies are the primary means by which the firm can sense signals from the environment (via data collected by IoT and analytics driven by AI), seize opportunities (via coordination enabled by platforms and modular systems of production), and transform the resource base (via continuous digital feedback loops) within the sensing–seizing–reconfiguring framework (Teece et al., 1997). Miozza et al. (2024) explicitly posit that dynamic capabilities are especially critical in environments of rapid technological change, where firms may hold valuable digital resources but still fail commercially if they lack the dynamic capabilities to redeploy them. Teece et al. (1997) stressed that capabilities suffer from a limited lifespan and, thus, need to be updated constantly. Digital capabilities are not excluded from this, as they must be built, grown, and rejuvenated to continue having relevance (Abu-Siam et al., 2026; Helfat and Peteraf, 2003).

In the pharmaceutical industry, empirical evidence indicates that digital transformation is achieved through the routine activities of sensing, learning, and coordinating, and that these activities help translate digital inputs into strategic outcomes (Miozza et al., 2024). Empirical studies further find that digital platform activities operate through routines based on learning and coordination (Chari et al., 2023). Some of the latest research suggests that companies introducing blockchain-enabled dynamic capabilities affect both the scope and speed of the supply chain's exploration–exploitation ambidexterity through competence and flexibility, thereby demonstrating that digital devices can be transformed and improved over time as strategic assets rather than remaining purely functional tools in their existing state (Sharma et al., 2026). Based on the above discussion, the third hypothesis is as follows:

> *H3*: Higher levels of Industry 4.0 technology adoption are positively associated with higher levels of dynamic capabilities.

Using the Dynamic Capabilities View, resilience is less a fixed condition and more an ongoing ability—something firms continually enact rather than a static state. This means that real operational routines are needed to help organizations anticipate, absorb, adapt, and recover when disruptions are present (Zouari et al., 2020). In environments that change quickly, dynamic capabilities allow firms to rearrange their resources so that survival is not merely hoped for but actually supported (Dixit et al., 2026; Wu et al., 2010). In particular, the reconfiguration phase within the capability lifecycle pushes resilience forward when turbulence occurs (Helfat and Peteraf, 2003). In addition, technological progress and digital transformation often strengthen supply chain resilience because they encourage both adaptability and innovation, which is a type of sensing–seizing configuration. Similarly, blockchain technology can help manufacturing firms establish dynamic capabilities that balance exploration and exploitation, thus enabling dynamic structural adaptation across the supply chain (Sharma et al., 2026). In addition, absorptive capacity can be treated as a sensing routine, and its link with supply chain improvement is indirectly influenced by digital organizational culture as a mediator (Rodríguez-González et al., 2023). Ultimately, innovation and firm resilience are tightly entwined; they remain essential for organizations navigating environments that are not stagnant but competitive at all times (Garrido-Moreno et al., 2024). Thus, from the earlier discussion, the fourth hypothesis is expected to be tested:

> *H4*: Higher levels of dynamic capabilities are positively associated with higher levels of supply chain resilience.

The theoretical model positions supply chain capability and dynamic capabilities as mediators through which Industry 4.0 technologies influence resilience, while also allowing for a direct impact of Industry 4.0 technology adoption on resilience outcomes. There are three theoretical reasons for this. First, the RBV does not limit the effect of valuable resources to a single causal channel; valuable resources can simultaneously have direct and indirect effects (Barney, 1991; Dixit et al., 2026). Second, some Industry 4.0 technology resources (e.g., cyber-physical safety systems and IoT-enabled monitoring) can generate immediate resilience gains irrespective of their translation into capabilities (Huang et al., 2023). Third, prior empirical studies found that the effect of digital supply chain adoption on supply chain resilience is direct and only partially mediated by capability variables (Huang et al., 2023).

Zouari et al., (2020) argue that resilience is inseparable from digital infrastructure: "the lack of a clear understanding of these elements has contributed to ambiguity in clarifying the interplay between DSCs and SCR." They explicitly tested a direct path from digital supply chain tools to resilience outcomes alongside mediated paths (Zouari et al., 2020). Studies of Industry 4.0 applications for sustainable manufacturing document a number of direct mechanisms—predictive equipment maintenance, real-time risk analytics, and sensor-based contamination detection—by which Industry 4.0 technology adoption supports resilience without requiring the intermediate formation of a named capability construct (Ng et al., 2021). Global reviews of supply chain resilience to geopolitical disruptions have also recently identified information-sharing IT applications as direct contributors to resilience in their own right (Huang et al., 2023). The fifth hypothesis of the study, based on the previous discussion, is as follows:

> *H5*: Higher levels of Industry 4.0 technology adoption are positively associated with higher levels of supply chain resilience.

While technological advancement is imperative for business, this strategic shift does not have a uniform impact across firms. This is because a firm's ability to change is augmented not only by technology, but also by the work environment and the beliefs held

by its members. Cabrera et al. stress that an organization's HR management culture and information system promote employee attitudes, practices, and beliefs towards digitization (Cabrera et al., 2001). This aspect of culture plays a significant role in understanding the relationship between digital transformation and resilience. In the context of human resource management and digital transformations, Industry 4.0 technologies and resilience initiatives serve as box-type solutions. However, technology integration and business development lead to better and faster economic growth, which can only be understood within this wider perspective. Reyes-Sánchez et al. (2025) verified that digital organizational culture and absorptive capacity serve as antecedents of supply chain resilience and sustainable performance (Rodríguez-González et al., 2023). Above all, Rodríguez-González et al. (2023) stated that technology trends promote the use of data for decision-making and foster new working practices, and that when these innovative practices are implemented, sustainability performance can subsequently be achieved as well (Chaudhuri et al., 2023). These findings are reinforced by evidence that innovation and organizational resilience together improve business performance (Garrido-Moreno et al., 2024). Resilience is maintained in balance and is not degraded by the implemented technology; an impregnable organizational shield arises only when all tools and human capital are sharpened. In contrast, the ductility achieved through digitalization is a function of personnel, as pointed out by Luca et al. (2025). This study therefore proposes the following hypothesis:

> *H6*: Digital organizational culture positively moderates the relationship between Industry 4.0 technology adoption and supply chain resilience.

Figure 1 presents the conceptual research model based on the previously developed hypotheses.

4 Methodology

4.1 Why the UAE food and beverage manufacturing sector?

The empirical setting of this study was the food and beverage manufacturing industry in the United Arab Emirates, which was selected for four key reasons that make it an ideal real-world laboratory. First, this sector is a strategic pillar of national industrial policy, directly supporting the UAE Circular Economy Policy 2021–2031 and the Operation 300bn strategy, so studying Industry 4.0 adoption is highly relevant for evidence-based policy work (Alshurideh et al., 2022). Second, the UAE food system is structurally fragile, mostly because of heavy import reliance and high per capita food loss, which makes supply chain resilience significant. There are clear vulnerabilities that can be reduced using digital instruments such as IoT traceability and AI forecasting, or similar methods that facilitate foresight. Third, this sector has demonstrated a relatively high level of post-COVID-19 digital maturity, making the environment practical for observation; this is supported by comparative survey results showing that Supply Chain 4.0 adoption connects strongly with performance (Kurdi et al., 2022). Finally, bringing this model to the UAE helps close a documented contextual gap, since most prior evidence comes from Western or Chinese manufacturing samples, while the UAE offers a uniquely high-stakes and rewarding context for investing in digital resilience.

4.2 Measurement of variables and survey instrument

The current study is an extension of previous empirical studies on related industries in the UAE and applies a quantitative cross-sectional methodology using a self-administered structured questionnaire circulated among senior supply chain and operations managers

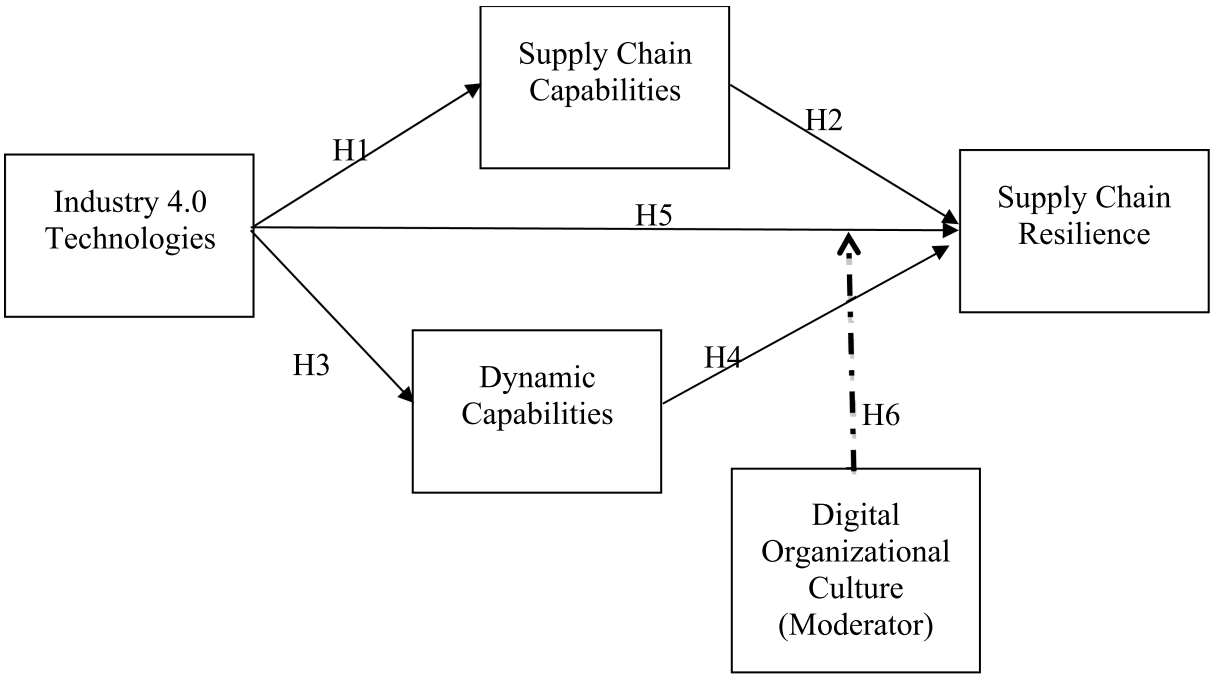

FIGURE 1
Research model.

(Alshurideh et al., 2022; Kurdi et al., 2022), as shown in Table 1. Responses were measured on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree), as used in previous research on the supply chain (Alshurideh et al., 2022), following the format of the survey tool used in previous research on food-processing supply chain resilience (Alshawabkeh et al., 2024). In studies measuring latent constructs adapted from established scales, the original wording of validated items was retained to ensure construct validity (Ali et al., 2021; Mubarik et al., 2021). The questionnaire comprised five latent constructs in accordance with the theoretical model: Industry 4.0 technologies; supply chain capability (mediator—agility, modularity, and visibility dimensions); dynamic capabilities (mediator—sensing, learning, and coordinating dimensions); digital organizational culture (moderator); and supply chain resilience.

TABLE 1 Operationalization of latent constructs.

Construct	Sub-dimensions	Number of Items
Industry 4.0 technologies	Adoption depth of IoT, AI, big data analytics, blockchain, cyber-physical systems, cloud computing	6
Supply chain capability	Agility, modularity, visibility	7
Dynamic capabilities	Sensing, learning, coordinating	6
Digital organizational culture	Data-driven culture, absorptive capacity, innovation orientation	5
Supply chain resilience	Adaptability, innovation, information integration, recovery	8

Alshurideh et al. (2022), Alshawabkeh et al. (2024), and Kurdi et al. (2022).

4.3 Sampling

This quantitative study examines supply chain resilience within Industry 4.0 for food and beverage manufacturing companies in the UAE (Darmaki and Jaafar, 2023). Because the sector is structurally heterogeneous, the sampling frame was set to include large organizations that have the process complexity, data infrastructure, and managerial autonomy needed to respond to Industry 4.0 adoption. The study employed a key informant approach (Alshurideh et al., 2022; Kurdi et al., 2022), defined the firm as the unit of analysis, and gathered data from senior supply chain managers via a quantitative survey. Following well-established methodologies, the study targeted at least 200 firms, a sample size considered statistically sufficient for partial least squares structural equation modeling (Alshawabkeh et al., 2024). A stratified random sample was selected so that it remained representative across firms with different sizes and technological readiness levels.

4.4 Non-response bias

In total, 395 responses were collected, reflecting a 49.4% overall response rate. To account for threats that response bias might pose, we examined the characteristics of early respondents (first round) and late respondents (who received three reminders and returned the questionnaire after the third reminder) (Lorentz et al., 2021). Independent-samples t-tests and chi-square tests revealed no significant variation between early and late respondents regarding firm size, firm age, ownership structure, managerial experience, or the purpose of the model (for all p-values > 0.05). Given the response rate of 49.4%, and in line with methodological perspectives on response rates and survey-based inference validity (Wilden and Gudergan, 2014), non-response bias does not appear to undermine the accuracy of the inferences.

5 Results

5.1 Measurement model assessment

Table 2 describes the demographic profile of the 395 respondents. The sample is mostly concentrated in mature, large-scale organizations: approximately 72.7% of the firms employed more than 250 people, and 75.7% had been operating in the UAE for 5–15 years. The data capture was grounded in key industrial functions, since 82% of the respondents worked in operations, production, supply chains, and logistics. At the same time, 77.7% of the participants reported professional experience of 5 to 10 years. In other words, there is a blend of mid-career staff working in well-established mid- to large-sized companies, which lends credibility and practical usefulness to the findings regarding adoption and circular value creation across the regional F&B industry.

According to the literature, a model is considered reliable when the value of Cronbach's alpha coefficient exceeds 0.7 (Cheung et al., 2023). As shown in Table 3, the model was deemed reliable. We then computed the factor loadings, average variance extracted, and composite reliability to assess the validity and discrimination of the measurement model. Convergent validity was examined based on factor loadings, AVE, and CR, where these are above 0.5 and 0.7, respectively. The constructs also had Cronbach's alpha values ranging from 0.879 to 0.956. A VIF value between 1 and 5 indicates a moderate correlation between variables, which is generally considered acceptable (Singh and Kumar, 2021). Table 3 reports the VIF values for the statements; all values were below 5. Harman's single-factor test was used to determine whether a single factor could account for more than 50% of the variance in the dataset. The analysis showed that all items loaded onto one factor and that this factor explained only 36.2% of the total variance, supporting the absence of common method bias in this study.

Table 4 displays the correlations among the research variables, indicating that all variables are strongly correlated with one another. The analysis's strong reliability and composite reliability scores served as the basis for estimating the CFI, NFI, and IFI values, as shown in Table 5. Table 6 reports the effect sizes and predictive relevance; the f^2 values represent the estimated effect sizes derived from the β coefficients and their influence on dependent variables, with values greater than 0.35 indicating large effects.

The analysis's strong reliability and composite reliability scores served as the basis for estimating the CFI, NFI, and IFI values, as shown in Table 5.

TABLE 2 Demographic characteristics of the sample.

Category	Sub-category	Frequency (n)	Percentage (%)
Firm size	Small (<50 employees)	41	10.4%
	Medium (50–250 employees)	67	16.9%
	Large (> 250 employees)	287	72.7%
Firm age	< 5 years	38	9.6%
	5–15 years	299	75.7%
	> 15 years	58	14.7%
Respondent job role	Supply chain/logistics	156	39.5%
	Operations/production	168	42.5%
	Sustainability/CSR	7	1.8%
	IT/digital transformation	59	14.9%
	Other	5	1.3%
Professional experience	< 5 years	30	7.6%
	5–10 years	307	77.7%
	> 10 years	53	13.4%

The f^2 values represent the estimated effect sizes derived from the β coefficients and their influence on dependent variables. Values greater than 0.35 indicate large effects, as mentioned in Table 6.

5.2 Structural model assessment

The research model was tested empirically using partial least squares structural equation modeling with SmartPLS software version 4.0 and 5,000 resamples. In this process, the direct and indirect influences of Industry 4.0 technology implementation were examined. Figure 2 and Table 7 show that digital technology implementation has a positive effect on supply chain capabilities ($\beta = 0.849$, $p < 0.01$), explaining 84.9% of the variance. Supply chain capabilities also exerted a significant positive effect on supply chain resilience ($\beta = 0.735$, $p < 0.01$), accounting for 73.5% of the variance. Digital technology implementation affects supply chain resilience significantly and positively ($\beta = 0.856$, $p < 0.01$), accounting for 85.6% of the variance. Digital technology implementation also has a positive effect on dynamic capabilities ($\beta = 0.869$, $p < 0.01$), and dynamic capabilities positively affect supply chain resilience ($\beta = 0.769$, $p < 0.01$). Furthermore, digital organizational culture moderates the link between digital technology implementation and supply chain resilience ($\beta = 0.729$, $p < 0.01$), representing 72.9% of the variance. Therefore, all hypotheses were supported.

Four control variables were identified and incorporated into the structural model as single-item constructs: firm size, firm age, firm type, and managerial experience of the respondent. None of the control variables had a significant effect on the endogenous variables. To validate the proposed moderating influence of digital organizational culture on the relationship between Industry 4.0 technology adoption and supply chain resilience, we used a two-stage moderation process within the PLS modeling. This approach was preferred because it provides reliable statistical results and limits discrepancies when considering non-observable components. The interaction term took the form of the product of the subfactors of Industry 4.0 Technologies and Digital Organizational Culture (the moderating variable).

TABLE 3 Demonstrations of FL, α, CR, AVE, and VIF.

Constructs	Items	FL	α	CR	AVE	VIF
Industry 4.0 technologies			0.956	0.925	0.783	
	I4T 1	0.875				1.180
	I4T 2	0.873				1.248
	I4T 3	0.912				1.081
	I4T 4	0.954				1.316
	I4T 5	0.935				1.263
	I4T 6	0.879				1.171
Supply chain capabilities			0.921	0.946	0.766	
	SCC 1	0.875				1.255
	SCC 2	0.987				1.299
	SCC 3	0.866				1.477
	SCC 4	0.896				1.572
	SCC 5	0.980				1.456
	SCC 6	0.935				1.657
	SCC 7	0.986				1.234
Dynamic capabilities			0.921	0.925	0.842	
	DC 1	0.922				1.345
	DC 2	0.813				1.336
	DC 3	0.823				1.247
	DC 4	0.915				1.451
	DC 5	0.987				1.391
	DC 6	0.865				1.287
Digital organizational culture			0.911	0.945	0.803	
	DOC 1	0.822				1.156
	DOC 2	0.932				1.367
	DOC 3	0.926				1.569
	DOC 4	0.918				1.558
	DOC 5	0.976				1.289
Supply chain resilience			0.879	0.921	0.774	
	SCR 1	0.819				1.263
	SCR 2	0.932				1.247
	SCR 3	0.884				1.341
	SCR 4	0.892				1.284
	SCR 5	0.845				1.376
	SCR 6	0.970				1.388
	SCR 7	0.968				1.284
	SCR 8	0.985				1.256

VIF, variance inflation factor; FL, factor loadings; AVE, average variance extracted; CR, composite reliability; α, Cronbach's alpha.

TABLE 4 Correlation matrix.

Variables	I4T	SCC	DC	DOC	SCR
I4T	1.000				
SCC	0.792**	1.000			
DC	0.756**	0.725**	1.000		
DOC	0.876**	0.834**	0.737**	1.000	
SCR	0.753**	0.849**	0.738**	0.821**	1.000

$N = 395$, **Correlation is significant at the 0.01 level (2-tailed).

TABLE 5 Model fit indices.

Scale	SRMR	CFI	NFI	IFI
I4T	0.077	0.91	0.92	0.94
SCC	0.069	0.93	0.90	0.90
DC	0.064	0.92	0.94	0.93
DOC	0.066	0.95	0.96	0.92
SCR	0.071	0.92	0.93	0.96

SRMR values are based on the Smart PLS results (SRMR values between 0.064 and 0.077 AND NFI ≥ 0.90 indicate a good model fit).

TABLE 6 Effect sizes and predictive relevance.

Scale	q^2 (predictive relevance)	f^2 (effect size)
I4T	0.50	0.38 (large effect)
SCC	0.53	0.39 (large effect)
DC	0.47	0.35 (large effect)
DOC	0.48	0.37 (large effect)
SCR	0.57	0.36 (large effect)

q^2 values are the estimated predictive relevance based on the R^2 values and the model structure.

6 Discussion and conclusion

6.1 Theoretical implications

According to the results of this study, the adoption of Industry 4.0 is the key element in this digital era that influences a company's capacity to identify, respond to, and reduce risk factors in a timely manner. This adoption provides a significant competitive advantage and supply chain resilience alongside organizational business agility. Many corporations roll out various technologies without realizing their full potential, while too many others refrain from investing, only to discover later that these technologies yield no economic returns. There are also many issues concerning organizational culture, in which rebranding an organization changes nothing except its outward image.

When information technologies are combined with attributes that are more pertinent to people, strategic assets are required for the success of the organization in volatile, uncertain, complex, and ambiguous environments (Martín-Rojas et al., 2023). Management's innovation-led ambidexterity is critical to firm agility, together with the robustness of digital architectures (Alamsjah and Yunus, 2022). Furthermore, digitally adept organizations tailor their methods to supply chain risk management and coping with system shocks (Taghikhah et al., 2025). This phenomenon is not a consequence of intricate technological advancements, but rather the organic result of contingencies with regard to factors such as technical progress, self-thinking processes, and the environment. There is some understanding of policy investment to ensure that no negative effects are associated with these developments; this phenomenon is related to SMEs that have, in many cases, developed the capability to contribute to global production as they rely not only on local chains (Troise et al., 2021).

The verification of all six hypotheses, with the participation of 395 firms producing food and beverages in the UAE, confirms that the use of Industry 4.0 technologies does not stop at improving the capabilities of a supply chain. Resilience is enhanced through both direct and indirect effects: dynamic capabilities, on the one hand, act as a mediator that transmits the effect of Industry 4.0 technologies onto supply chain resilience, while digital organizational culture, on the other hand, functions as a moderator that conditions the strength of the technology–resilience relationship (Rodríguez-González et al., 2023). The model clarifies the current confusion by drawing on several theoretical lenses, including the Resource-Based View, Dynamic Capabilities Theory, the Dynamic Resource-Based View, and Supply Chain Resilience Theory. It frames resilience as comprising adaptability, innovation, information integration, and recovery, as these are assimilated in the field (Ali et al., 2021).

The findings show that the rules of the game are different: organizational culture is not only a passive catalyst but also an active force. Combining the direct and indirect effect pathways brings together the seemingly distinct viewpoints or evidence produced by various authors, showing that human and other resources are enhanced side by side through capability building. Notable aspects, such as the presence of commendable companies in the sample and experienced managers developing the supply chain, are essential to the UAE. They help eliminate typical logistical gaps while applying the UAE Circular Economy Policy 2021–2031 and Operation 300bn (Dave and Shaikh, 2022).

6.2 Practical implications

These results will be of practical value to manufacturing administrators throughout the UAE. They demonstrate that administrators can indeed consider digital outlays—such as IoT mapping, predictive analytics, and blockchain implementations—as rational investments, provided they are part of a wider transformation agenda rather than disconnected solutions (Büchi et al., 2019; Elete et al., 2024). On the other hand, it has been observed that where technologies are designed to enhance flexibility of use, system modularity and clarity of information may be more prominent as drivers of supply chain integration (Loske and Klumpp, 2021). Furthermore, top executives should recognize that dynamic capabilities incorporate processes that are externally oriented—"processes that go beyond the organization." This confirms that aligning dynamic capabilities with human resource management requires changing the organizational structure so that capability building is given greater weight in incentive schemes.

The moderation results offer a compelling rationale for encouraging digital cultures. Such cultures are likely to enhance innovation achievements through data governance and experimentation when conclusions are effectively applied (Serafimova and Vasilev, 2024). Justifying this framework within the UAE F&B industry assists in substantiating policymaking through incentive structures and

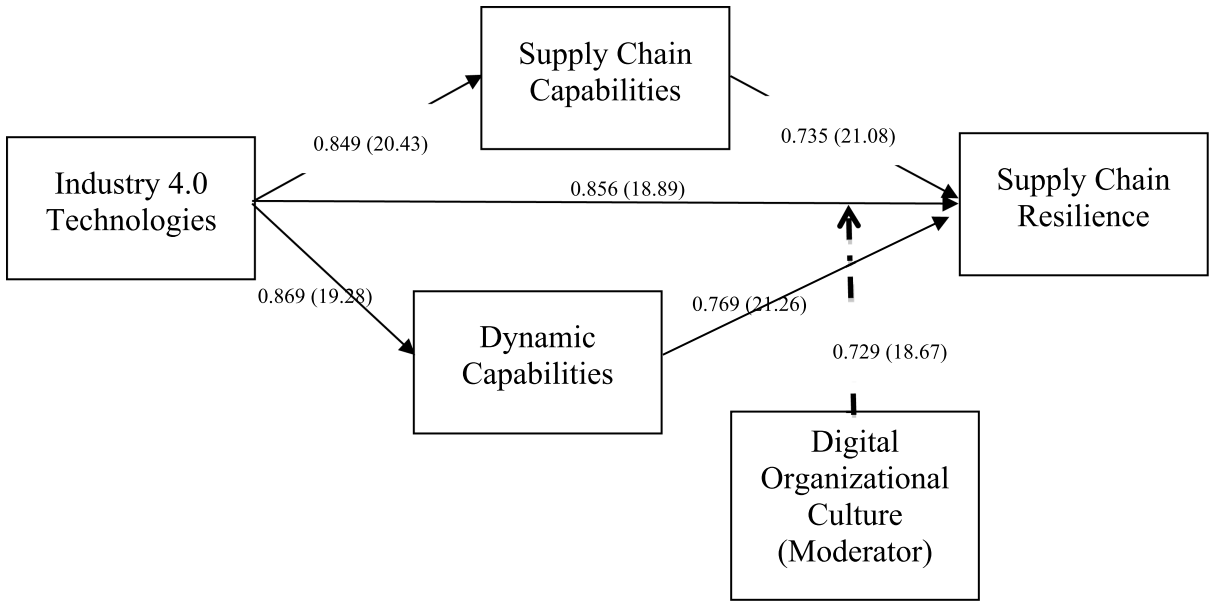

FIGURE 2
The structural equation modeling with standardized coefficients and *t*-values.

TABLE 7 Hypothesis testing.

Path	*β*-values	Mean	STDEV	*t*-values	*p*-values	Decision
Direct effects						
I4T → SCC	0.849	0.849	0.074	20.43	0.000	Endorsed
I4T → SCR	0.856	0.856	0.078	18.89	0.000	Endorsed
SCC → SCR	0.735	0.737	0.064	21.08	0.000	Endorsed
I4T → DC	0.869	0.870	0.078	19.28	0.000	Endorsed
DC → SCR	0.769	0.771	0.074	21.26	0.000	Endorsed
Indirect effects						
I4T → SCC → SCR						
I4T → DC → SCR						
Interaction effects						
I4T × DOC - > SCR	0.729	0.731	0.078	18.67	0.000	Endorsed

N = 395.

upgrading schemes aligned with the country's key economic priorities. Finally, the model suggests that IT providers should deliver bundled solutions supporting functions such as sensing, learning, and coordinating, rather than selling and installing single technologies, which would allow the central systems to function more effectively.

6.3 Study limitations

This study has several limitations that should be acknowledged when interpreting its findings. First, the cross-sectional survey design captures associations between constructs at a single point rather than longitudinal change processes. This limits the strength of causal inference, despite four control variables—firm size, firm age, ownership structure, and managerial experience—reducing between-firm heterogeneity (Cheung et al., 2023).

Second, multiple factors limit the interpretation of the data. The sample consists predominantly of large-scale corporations: firms with fewer than 50 employees account for just 10.4% of the sample, while businesses with 250 or more employees account for as many as 72.7%; the remaining firms fall between 50 and 249 employees. For these reasons, the findings may be specific to large producers of food and beverages within the UAE, and generalization of the results to the SME sector should be approached with caution. Research on firms subjected to external threats has shown that SMEs and large businesses build supply chain resilience differently due to their diverse resource bases and operating practices. Moreover, the business models for enabling Industry 4.0 can vary by firm age or organization size. In addition, the research deliberately overlooks micro-enterprises (fewer than 10 employees) and including them could change the level of the present phenomena.

Third, despite its advantages, the usefulness of this study is admittedly limited to one country and one sub-sector only, inasmuch as local practices and the processes of implementing Industry 4.0 can differ, even in sectors outside food manufacturing. It would be appropriate to apply the research approach across all types of businesses, industries, and nations to address these concerns.

Fourth, reliance on self-reported single-informant data is subject to common-method-variance concerns. These concerns are mitigated procedurally through Harman's single-factor test and full-collinearity VIFs, but they are not eliminated (Cheung et al., 2023). Furthermore, PLS-SEM is more permissive than covariance-based SEM in its treatment of measurement-model fit. The operationalization of the digital-organizational-culture moderator may also understate the UAE-specific cultural overlay documented in recent UAE-contextual digital-resilience work.

Finally, the alternative specification in which supply chain resilience acts as an antecedent of dynamic capabilities through feedback routines remains theoretically viable. This possibility should be tested in future work using cross-lagged panel designs grounded in the Dynamic Resource-Based View (Helfat and Peteraf, 2003). Future research along these lines would strengthen the external validity and temporal robustness of the conversion mechanism documented here.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

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References

Abu-Siam, Y., Alquqa, E. K., Shwedeh, F., Alzoubi, H. M., and Khatib, M. E. (2026). *Harnessing Fourth Industrial Revolution Technologies for Disruptive Innovation: The Mediating Power of Digital Transformation in the UAE Food Manufacturing Sector*, 199–208. Bingley, United Kingdom: Emerald Publishing Limited.

Adama, H. E., Popoola, O. A., Okeke, C. D., and Akinoso, A. E. (2024). Economic theory and practical impacts of digital transformation in supply chain optimization. *Int. J. Adv. Econ.* 6, 95–107. doi: 10.51594/ijae.v6i4.1072

Adewumi, G., Dada, S. A., Azai, J. S., and Oware, E. (2024). A systematic review of strategies for enhancing pharmaceutical supply chain resilience in the U.S. *Int. Med. Sci. Res. J.* 4, 961–972. doi: 10.51594/imsrj.v4i11.1711

Agostini, L., Nosella, A., Sarala, R. M., and Nkeng, C. (2023). Emerging trends around strategic flexibility: a systematic review supported by bibliometric techniques. *Manag. Decis.* 63, 1835–1881. doi: 10.1108/md-02-2023-0135

Agrawal, N., Sharma, M., Raut, R. D., Mangla, S. K., and Asian, S. (2023). Supply chain flexibility and post-pandemic resilience. *Glob. J. Flex. Syst. Manag.* 24, 119–138. doi: 10.1007/s40171-024-00375-2

Alamsjah, F., and Yunus, E. N. (2022). Achieving supply chain 4.0 and the importance of agility, ambidexterity, and organizational culture: a case of Indonesia. *J. Open Innov.: Technol. Mark. Complex.* 8, 83–83. doi: 10.3390/joitmc8020083

Alam, Z., Khan, K. U., Khan, A., and Atlas, F. (2025). Navigating the digital road: unveiling and prioritizing barriers to digital transformation in Pakistani courier supply chains. *Spectr. Decis. Mak. Appl.* 2, 297–313. doi: 10.31181/sdmap21202521

Al-Faouri, E. H., Huson, Y. A., and Aljawarneh, N. M. (2024). Smart strategies: bibliometric insights into technology applications and innovation performance in supply chain management. *Uncertain Supply Chain Manag.* 12, 2399–2412. doi: 10.5267/j.uscm.2024.5.027

Alfaqiyah, E., Alzubi, A., Aljuhmani, H. Y., and Öz, T. (2025). How industry 4.0 technologies enhance supply chain resilience: the interplay of agility, adaptability, and customer integration in manufacturing firms. *Sustainability* 17, 7922–7922. doi: 10.3390/su17177922

Ali, I., Arslan, A., Chowdhury, M. M. H., Khan, Z., and Tarba, S. Y. (2021). Reimagining global food value chains through effective resilience to COVID-19 shocks and similar future events: a dynamic capability perspective. *J. Bus. Res.* 141, 1–12. doi: 10.1016/j.jbusres.2021.12.006

Alshawabkeh, R., Rumman, A. A., and Al-Abbadi, L. (2024). The nexus between digital collaboration, analytics capability, and supply chain resilience of the food processing industry in Jordan. *Cogent Bus. Manag.* 11, 1–25. doi: 10.1080/23311975.2023.2296608

Alshurideh, M. T., Alquqa, E. K., Alzoubi, H. M., Kurdi, B. A., and AlHamad, A. (2022). The impact of cyber resilience and robustness on supply chain performance: evidence from the UAE chemical industry. *Uncertain Supply Chain Manag.* 11, 187–194. doi: 10.5267/j.uscm.2022.10.008

Aslam, H., Rehman, A. u., Iftikhar, A., Haq, M. Z. u., Akbar, U., and Kamal, M. M. (2025). Digital transformation: unlocking supply chain resilience through adaptability and innovation. *Technol. Forecast. Soc. Change* 219, 124234–124234. doi: 10.1016/j.techfore.2025.124234

Attah, R. U., Garba, B. M. P., Gil-Ozoudeh, I., and Iwuanyanwu, O. (2024). Enhancing supply chain resilience through artificial intelligence: analyzing problem-solving approaches in logistics management. *Int. J. Manag. Entrepreneurship Res.* 6, 3883–3901. doi: 10.51594/ijmer.v6i12.1745

Bag, S., Pretorius, J. H. C., Gupta, S., and Dwivedi, Y. K. (2020). Role of institutional pressures and resources in the adoption of big data analytics-powered artificial intelligence, sustainable manufacturing practices, and circular economy capabilities. *Technol. Forecast. Soc. Change* 163:120420. doi: 10.1016/j.techfore.2020.120420

Barney, J. B. (1991). Firm resources and sustained competitive advantage. *J. Manag.* 17, 99–120. doi: 10.1177/014920639101700108

Brandon-Jones, E., Squire, B., Autry, C. W., and Petersen, K. J. (2014). A contingent resource-based perspective of supply chain resilience and robustness. *J. Supply Chain Manag.* 50, 55–73. doi: 10.1111/jscm.12050

Brookbanks, M., and Parry, G. (2024). The impact of industry 4.0 technologies on the resilience of established cross-border supply chains. *Supply Chain Manag. An Int. J.* 29, 731–754. doi: 10.1108/scm-07-2023-0333

Büchi, G., Cugno, M., and Castagnoli, R. (2019). Smart factory performance and industry 4.0. *Technol. Forecast. Soc. Change* 150, 119790–119790. doi: 10.1016/j.techfore.2019.119790

Cabrera, Á., Cabrera, E. F., and Barajas, S. (2001). The key role of organizational culture in a multi-system view of technology-driven change. *Int. J. Inf. Manag.* 21, 245–261. doi: 10.1016/s0268-4012(01)00013-5

Calatayud, A., Mangan, J., and Christopher, M. (2018). The self-thinking supply chain. *Supply Chain Manag. Int. J.* 24, 22–38. doi: 10.1108/scm-03-2018-0136

Chari, A., Stahre, J., Bärring, M., Despeisse, M., Li, D., Friis, M., et al. (2023). Analyzing the antecedents to digital platform implementation for resilient and sustainable manufacturing supply chains—an IDEF0 modeling approach. *J. Clean. Prod.* 429:139598. doi: 10.1016/j.jclepro.2023.139598

Chaudhuri, R., Chatterjee, S., Mariani, M. M., and Wamba, S. F. (2023). Assessing the influence of emerging technologies on organizational data-driven culture and innovation capabilities: a sustainability performance perspective. *Technol. Forecast. Soc. Change* 200:123165. doi: 10.1016/j.techfore.2023.123165

Cheung, G. W., Cooper–Thomas, H. D., Lau, R. S., and Wang, L. C. (2023). Reporting reliability, convergent and discriminant validity with structural equation modeling: a review and best-practice recommendations. *Asia Pac. J. Manag.* 41, 745–783. doi: 10.1007/s10490-023-09871-y

Cuong, N. K., Long, N. N., Dung, H. T., and Hai, T. V. (2025). Digital transformation, organizational agility, and firm performance in emerging markets: evidence from Vietnam's machinery sector. *Probl. Perspect. Manag.* 23, 342–357. doi: 10.21511/ppm.23(3).2025.25

Darmaki, N. A., and Jaafar, H. B. (2023). Small and medium enterprises' performance in Dubai: a critical role of technological factors and environmental factors. *Manag. Sci. Lett.* 13, 86–95. doi: 10.5267/j.msl.2023.2.002

Dave, S., and Shaikh, N. (2022). "Technological innovations in supply chain management towards a circular economy in the healthcare sector of the UAE," in *The Advances in Finance, Accounting, and Economics Book Series*, Ed. Pablos PO, Zhang X, and Almunawar, MA. (Hershey, Pennsylvania, USA: IGI Global), 142–155.

Dixit, C., Kumar, R., and Kumar, A. (2026). Developing a sustainable and resilient supply chain: industry 4.0 drivers, dynamic capabilities, and performance evaluation. *Prod. Plan. Control*, 1–15. doi: 10.1080/09537287.2025.2611895

Ebirim, W., Olu-lawal, K. A., Ninduwezuor-Ehiobu, N., Montero, D. J. P., Usman, F. O., and Ani, E. C. (2024). Leveraging project management tools for energy efficiency in HVAC operations: a path to climate resilience. *Eng. Sci. Technol. J.* 5, 653–661. doi: 10.51594/estj.v5i3.863

Elete, T. Y., Nwulu, E. O., Erhueh, O. V., Akano, O. A., and Aderamo, A. T. (2024). Digital transformation in the oil and gas industry: a comprehensive review of operational efficiencies and case studies. *Int. J. Appl. Res. Soc. Sci.* 6, 2611–2643. doi: 10.51594/ijarss.v6i11.1692

Elia, S., Giuffrida, M. G., Mariani, M. M., and Bresciani, S. (2021). Resources and digital export: an RBV perspective on the role of digital technologies and capabilities in cross-border e-commerce. *J. Bus. Res.* 132, 158–169. doi: 10.1016/j.jbusres.2021.04.010

Fatorachian, H., and Kazemi, H. (2018). A critical investigation of industry 4.0 in manufacturing: a theoretical operationalization framework. *Prod. Plan. Control* 29, 633–644. doi: 10.1080/09537287.2018.1424960

Garrido-Moreno, A., Martín-Rojas, R., and Morales, V. J. G. (2024). The key role of innovation and organizational resilience in improving business performance: a mixed-methods approach. *Int. J. Inf. Manag.* 77:102777. doi: 10.1016/j.ijinfomgt.2024.102777

Ghobakhloo, M. (2018). The future of the manufacturing industry: a strategic roadmap toward industry 4.0. *J. Manuf. Technol. Manag.* 29, 910–936. doi: 10.1108/jmtm-02-2018-0057

Ghobakhloo, M., Fathi, M., Iranmanesh, M., Maroufkhani, P., and Morales, M. (2021). Industry 4.0 ten years on: a bibliometric and systematic review of concepts, sustainability value drivers, and success determinants. *J. Clean. Prod.* 302:127052. doi: 10.1016/j.jclepro.2021.127052

Gobbo, J. A., Busso, C. M., Gobbo, S. C. d. O., and Carreão, H. (2018). Making the links among environmental protection, process safety, and industry 4.0. *Process. Saf. Environ. Prot.* 117, 372–382. doi: 10.1016/j.psep.2018.05.017

Hair, J. F., Hult, G. T. M., Ringle, C. M., Sarstedt, M., Danks, N. P., and Ray, S. (2021). "Partial least squares structural equation modeling (PLS-SEM) using R," in *Classroom Companion: Business*, (Springer International Publishing).

Helfat, C. E., and Peteraf, M. A. (2003). The dynamic resource-based view: capability lifecycles. *Strateg. Manag. J.* 24, 997–1010. doi: 10.1002/smj.332

Hondoma, T. (2024). "Forecasting demand using recurrent neural networks (RNN)," in *The Advances in Marketing, Customer Relationship Management, and e-Services Book Series*, Eds. Masengu R, Option Chiwaridzo OT, Dube M, and Ruzive B. (Hershey, PA: IGI Global), 197–215.

Huang, K., Wang, K., Lee, P. K. C., and Yeung, A. C. L. (2023). The impact of industry 4.0 on supply chain capability and supply chain resilience: a dynamic resource-based view. *Int. J. Prod. Econ.* 262:108913. doi: 10.1016/j.ijpe.2023.108913

Hu, Y., Chen, S., Yang, W., Ullah, M. R., and Zulfiqar, M. (2025). Innovate, connect and communicate to sustain: the digital harmony of technologies, capabilities and platforms. Humanities and Social Sciences Communications, 12. doi: 10.1057/s41599-025-05945-y

Irfan, M., Verma, J., Parameswaran, S., and Sheikh, I. A. (2025). "Integrating emerging technologies," in *The Advances in Logistics, Operations, and Management Science Book Series*, Ed. Khokhar M. (Hershey, PA: IGI Global Scientific Publishing), 199–220.

Karanam, R. K., Sachani, D. K., Natakam, V. M., Natakam, V. M., Yarlagadda, V. K., and Kothapalli, K. R. V. (2024). Resilient supply chains: strategies for managing disruptions in a globalized economy. *Am. J. Trade Policy* 11, 7–16. doi: 10.18034/ajtp.v11i1.719

Kumar, R., Samadhiya, A., Kumar, A., Luthra, S., Pandey, K. K., and Jaouhari, A. E. (2024). Nourish resilience in the digital food supply chain in the post-COVID landscape: literature review for past insights and future roadmap. *Int. J. Ind. Eng. Oper. Manag.* 7, 100–116. doi: 10.1108/ijieom-02-2024-0007

Kumar, S., and Aithal, P. S. (2023). Tech-business analytics in the secondary industry sector. *Int. J. Appl. Eng. Manag. Lett.* 7, 1–94. doi: 10.47992/ijaeml.2581.7000.0194

Kurdi, B. A., Alzoubi, H. M., Alshurideh, M. T., Alquqa, E. K., and Hamadneh, S. (2022). Impact of supply chain 4.0 and supply chain risk on organizational performance: empirical evidence from the UAE food manufacturing industry. *Uncertain Supply Chain Management* 11, 111–118. doi: 10.5267/j.uscm.2022.11.004

Kwak, D., Seo, Y., and Mason, R. (2017). Investigating the relationship between supply chain innovation, risk management capabilities and competitive advantage in global supply chains. Pure (Coventry University), 38, 2–21. doi: 10.1108/ijopm-06-2015-0390

Leyva-Tapia, L. E., Acuña-Cid, H. A., Reyes-Mendoza, A., Barragán-Quintero, R. V., and Ahumada-Tello, E. (2024) *Dynamic Capabilities in the Industry and their Impact on the Introduction of Technologies*. London, United Kingdom\Cham, Switzerland: Springer Nature / Palgrave Macmillan.

Lorentz, H., Laari, S., Meehan, J., Eßig, M., and Henke, M. (2021). An attention-based view of supply disruption risk management: balancing biased attentional processing for improved resilience in the COVID-19 context. *Int. J. Oper. Prod. Manag.* 41, 152–177. doi: 10.1108/ijopm-06-2021-0381

Loske, D., and Klumpp, M. (2021). Human-AI collaboration in route planning: an empirical efficiency-based analysis in retail logistics. *Int. J. Prod. Econ.* 241:108236. doi: 10.1016/j.ijpe.2021.108236

Luca, C., Carbonara, N., and Pellegrino, R. (2025). The effect of digital technologies and staff skill sets on hospital resilience: the role of supply chain information integration. *Technol. Forecast. Soc. Change* 215, 124075–124075. doi: 10.1016/j.techfore.2025.124075

Malik, Z., and Pasha, U. (2022). The role of data management and automation in the impact of industry 4.0 on supply chain performance: an empirical analysis. *Int. J. Bus. Econ. Aff.* 7, 1–20. doi: 10.24088/ijbea-2022-74001

Marchese, S., Gastaldi, L., and Corso, M. (2023). Thriving in turbulent environments through adaptive forms of organizing. *Manag. Decis.* 63, 2038–2060. doi: 10.1108/md-05-2022-0655

Martín-Rojas, R., Garrido-Moreno, A., and Morales, V. J. G. (2023). Social media use, corporate entrepreneurship, and organizational resilience: a recipe for SMEs' success in a post-Covid scenario. *Technol. Forecast. Soc. Change* 190:122421. doi: 10.1016/j.techfore.2023.122421

Miozza, M., Brunetta, F., and Appio, F. P. (2024). Digital transformation of the pharmaceutical industry: a future research agenda for management studies. *Technol. Forecast. Soc. Change* 207:123580. doi: 10.1016/j.techfore.2024.123580

Modgil, S., Singh, R. K., and Hannibal, C. (2021). Artificial intelligence for supply chain resilience: learning from Covid-19. *Int. J. Logist. Manag.* 33, 1246–1268. doi: 10.1108/ijlm-02-2021-0094

Mubarik, M. S., Naghavi, N., Mubarik, M., Kusi-Sarpong, S., Khan, S. A., Zaman, S. I., et al. (2021). Resilience and cleaner production in industry 4.0: role of supply chain mapping and visibility. *J. Clean. Prod.* 292:126058. doi: 10.1016/j.jclepro.2021.126058

Ng, T. C., Ghobakhloo, M., Iranmanesh, M., Maroufkhani, P., and Asadi, S. (2021). Industry 4.0 applications for sustainable manufacturing: a systematic literature review and a roadmap to sustainable development. *J. Clean. Prod.* 334:130133. doi: 10.1016/j.jclepro.2021.130133

Nisa, N. U., and Chhipa, M. K. (2025). Enhancing sustainable performance through innovation: the roles of tacit knowledge and affective trust in UAE industrial organizations. *J. Adm. Bus. Stud.* 11, 236–249. doi: 10.20474/jabs-11.4.4

Odimarha, A. C., Ayodeji, S. A., and Abaku, E. A. (2024). The role of technology in supply chain risk management: innovations and challenges in logistics. *Magna Scientia Adv. Res. Rev.* 10, 138–145. doi: 10.30574/msarr.2024.10.2.0052

Pirola, F, Cimini, C, and Pinto, R (2019), Digital readiness assessment of Italian SMEs: a case-study research. Journal of Manufacturing Technology Management, 31, 1045–1083, doi: 10.1108/JMTM-09-2018-0305

Reddy, K. M., Venu, M., Pandi, V. S., and Kumari, E. V. (2025). *Integrate Blockchain and AI Technologies: a Reliable, Accessible Structure for Self-Governing Data Exchanges in Intelligent Supply Chains*, 255–261. Lausanne, Switzerland: Frontiers Media SA.

Reyes-Sánchez, J. D. J., Alvarez, H. J., Davalos, J. P. R., Burgos, A. P. C., and Magallanes, H. M. (2025). *Economic Resilience and Digital Transformation in the Construction of Competitiveness*, 223–256. Vienna, Austria: International Union of Soil Sciences (IUSS).

Rodríguez-Espíndola, O., Chowdhury, S., Dey, P. K., Albores, P., and Emrouznejad, A. (2022). Analysis of the adoption of emergent technologies for risk management in the era of digital manufacturing. *Technol. Forecast. Soc. Change* 178:121562. doi: 10.1016/j.techfore.2022.121562

Rodríguez-González, R. M., Guijarro, A. M., and Guzmán, G. M. (2023). Digital organizational culture and absorptive capacity as precursors to supply chain resilience and sustainable performance. *J. Clean. Prod.* 420:138411. doi: 10.1016/j.jclepro.2023.138411

Scholten, K., and Schilder, S. (2015). The role of collaboration in supply chain resilience. *Supply Chain Manag. Int. J.* 20, 471–484. doi: 10.1108/scm-11-2014-0386

Sen, A. (2025). Strategic reshaping of global supply chain risk management: an integrated resilience-agility framework in the context of highly regulated international defense joint ventures. *Int. J. Innov. Sci. Res. Technol.* 2530, 2530–2533. doi: 10.38124/ijisrt/25nov1522

Serafimova, V., and Vasilev, V. (2024). Digital culture as a competitive advantage in the sustainable development of organizations. *AGORA Int. J. Econ. Sci.* 18, 210–222. doi: 10.15837/aijes.v18i1.6724

Sharma, M., AlNuaimi, B. K., Khan, M., Alghafes, R., and Pandey, R. (2026). Blockchain-enabled dynamic capabilities for supply chain ambidexterity: empirical evidence from manufacturing firms for enhanced competence and flexibility. *Technol. Forecast. Soc. Change* 226, 124467–124467. doi: 10.1016/j.techfore.2025.124467

Singh, S. G., and Kumar, S. V. (2021). Dealing with the multicollinearity problem in the analysis of side friction characteristics under urban heterogeneous traffic conditions. *Arab. J. Sci. Eng.* 46, 10739–10755. doi: 10.1007/s13369-020-05213-y

Soori, M., Jough, F. K. G., Dastres, R., and Arezoo, B. (2024). AI-based decision support systems in industry 4.0, a review. *J. Econ. Technol.* 4, 206–225. doi: 10.1016/j.ject.2024.08.005

Spiegler, V., Naim, M. M., and Wikner, J. (2012). A control engineering approach to the assessment of supply chain resilience. *Int. J. Prod. Res.* 50, 6162–6187. doi: 10.1080/00207543.2012.710764

Statsenko, L, Jayasinghe, RS, and Soosay, C (2024), Supply network resilience capabilities: a social–ecological perspective. Supply Chain Management: An International Journal, 29, 1–26, doi: 10.1108/SCM-11-2022-0438

Svare, H., and Gausdal, A. H. (2017). Dynamic capabilities and network benefits. *J. Entrepreneurship Manag. Innov.* 13, 117–146. doi: 10.7341/20171315

Taghikhah, F., Prior, D. D., Hafezi, R., Baker, D., and Matouš, P. (2025). Understanding digital capabilities and their impacts on Australian Agri-food supply chain resilience: engineering vs. socio-ecological thinking. *Technol. Forecast. Soc. Change* 218, 124191–124191. doi: 10.1016/j.techfore.2025.124191

Taras, M. (2025). Strategic implementation of SaaS-based tracking systems for sustainable logistics in a VUCA/BANI world. *Int. J. Res. Publ. Rev.* 6, 8978–8987. doi: 10.55248/gengpi.6.0625.2294

Teece, D. J., Pisano, G. P., and Shuen, A. (1997). Dynamic capabilities and strategic management. *Strateg. Manag. J.* 18, 509–533. doi: 10.1002/(sici)1097-0266(199708)18:7<>3.0.co;2-z

Tiwari, M. K., Bidanda, B., Geunes, J., Fernandes, K., and Dolgui, A. (2024). Supply chain digitization and management. *Int. J. Prod. Res.* 62, 2918–2926. doi: 10.1080/00207543.2024.2316476

Torres, J. A. O., Santiago, A. M., García-Martínez, J. R., López-Zapata, B. Y., López, J. A. M., Zapata, O. J. R., et al. (2025). A data-driven approach using recurrent neural networks for material demand forecasting in manufacturing. *Logistics* 9, 130–130. doi: 10.3390/logistics9030130

Troise, C., Corvello, V., Ghobadian, A., and O'Regan, N. (2021). How can SMEs successfully navigate a VUCA environment: the role of agility in the digital transformation era. *Technol. Forecast. Soc. Change* 174:121227. doi: 10.1016/j.techfore.2021.121227

Warner, K., and Wäger, M. (2018). Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal. Long Range Planning, 52, 326–349. doi: 10.1016/j.lrp.2018.12.001

Wilden, R., and Gudergan, S. P. (2014). The impact of dynamic capabilities on operational marketing and technological capabilities: investigating the role of environmental turbulence. *J. Acad. Mark. Sci.* 43, 181–199. doi: 10.1007/s11747-014-0380-y

Wu, S. J., Melnyk, S. A., and Flynn, B. B. (2010), Operational Capabilities: The Secret Ingredient. Decision Sciences, 41: 721–754. doi: 10.1111/j.1540-5915.2010.00294.x

Zouari, D., Ruel, S., and Viale, L. (2020). Does digitalizing the supply chain contribute to its resilience? *Int. J. Phys. Distrib. Logist. Manag.* 51, 149–180. doi: 10.1108/ijpdlm-01-2020-0038