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Can smart supply chain bring agility and resilience for enhanced sustainable business performance?

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Abstract

Purpose – Supply chains need to be made viable in this volatile and competitive market, which could be possible through digitalization. This study is an attempt to explore the role of Industry 4.0, smart supply chain, supply chain agility and supply chain resilience on sustainable business performance from the lens of natural resource-based view.

Design/methodology/approach – The study tests the proposed model using a covariance-based structural equation modelling and further investigates the ranking of each construct using the artificial neural networks approach in AMOS and SPSS respectively. A total of 234 respondents selected using purposive sampling aided in capturing the industry practices across supply chains in the UK. The full collinearity test was carried out to study the common method bias and the content validity was carried out using the item content validity index and scale content validity index. The convergent and discriminant validity of the constructs and mediation study was carried out in SPSS and AMOS V.23.

Findings – The results are overtly inferring the significant impact of Industry 4.0 practices on creating smart and ultimately sustainable supply chains. A partial relationship is established between Industry 4.0 and supply chain agility through a smart supply chain. This work empirically reinstates the combined significance of green practices, Industry 4.0, smart supply chain, supply chain agility and supply chain resilience on sustainable business value. The study also uses the ANN approach to determine the relative importance of each significant variable found in SEM analysis. ANN determines the ranking among the significant variables, i.e. supply chain resilience > green practices > Industry 4.0> smart supply chain > supply chain agility presented in descending order.

Originality/value – This study is a novel attempt to establish the role of digitalization in SCs for attaining sustainable business value, providing empirical support to the mediating role of supply chain agility, supply chain resilience and smart supply chain and manifests a significant integrated framework. This work reinforces the integrated model that combines all the constructs dealt with in silos so far in prior literature.

Keywords Green practices (GP), Industry 4.0 (I4.0), Smart supply chains (SmSC), Intelligent supply chain (ISC), Interconnected supply chain (ICSC), Supply chain agility (SCA), Supply chain resilience (SCR), Sustainable business performance (SBP), Natural resource-based view (NRBV), Artificial neural network (ANN)

Paper type Research paper

1. Introduction

Industry 4.0 (I4.0) has been gaining momentum across the globe as it promises to boost efficiency, reduce costs and improve productivity and sustainability (Tortorella *et al.*, 2022; Patidar *et al.*, 2023; Marinagi *et al.*, 2023). To increase competitiveness in its global market,

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economies are launching initiatives such as "Made in China 2025" focused on being the world's largest market for I4.0 technologies. I4.0 technologies are revolutionizing manufacturing and construction supply chain (SC), especially in developed economies like the UK (Newman *et al.*, 2021). In 2020, Germany had the highest score in the industrial Internet of Things (IIoT) readiness index. However, natural calamities and the recent pandemic significantly hampered all global SCs. The disruptions have indicated the extent of preparedness of SCs globally and their focus towards sustainability. This has prompted industry and academia to design sustainable SCs while ensuring they are competitive and leveraging the benefits of I4.0.

Industry 4.0 market is anticipated to grow from $130.90bn in 2022 to an estimated $377.30bn by 2029 [1]. Even in developing economies such as India, it has been projected that 75% of Indian manufacturing companies have adopted I4.0 technology, and around 55% of them plan to invest more in these technologies. On one hand, countries across the globe are taking initiatives on the digital front and making them future-ready to stay competitive, while businesses are also compelled to use I4.0 technologies to manage crises like COVID-19. For, SCs to be resilient and to ensure a sustainable business performance (SBP), disruptive technologies are the need of the hour (Sarkis, 2020; Dias *et al.*, 2021). In the context of I4.0, prior studies (Rao and Holt, 2005; Oztemel and Gursev, 2020; Hosseini and Ivanov, 2019; Sharma *et al.*, 2021) have analyzed the building blocks for making SCs future-ready.

I4.0 aids in improving sustainability in procurement (Kluczek, 2019), manufacturing and distribution (Liu *et al.*, 2017; De Sousa Jabbour *et al.*, 2018). Lepore *et al.* (2021) established the relationship between I4.0 technologies and SBP, along with its economic and environmental implications. Ghobakhloo (2018) put forth the "Digital Manufacturing", "Smart Manufacturing" and "Intelligent Manufacturing" as common synonyms for I4.0. I4.0 technologies, including augmented reality (AR), Internet of Things (IoT), robots, artificial intelligence (AI), virtual reality (VR), cloud and sensors, significantly impact supply chain performance (SCP). These include SC integration, collaboration, responsiveness and transparency, making SC resilient and sustainable (Frederico *et al.*, 2021). Practices of I4.0 have enabled digital transformations (Nujoom *et al.*, 2019; Shashi *et al.*, 2020) of value chains, encompassing products, services and business models (Kang *et al.*, 2016; Reinhard *et al.*, 2016) spanning several industry disciplines. I4.0 helps achieve the ultimate goal of excellent customer orientation and inclusion in value creation.

It has been evident that through I4.0 practices, economies are focusing on sustainable business development (Sharma *et al.*, 2021). Additionally amalgamated with green practices, firms can utilize I4.0 technologies for building up smart and sustainable SCs enabling agile and resilient operations. Green SCs minimize negative impacts on the environment by implementing measures that can reduce emissions and implement better waste disposal systems (Zhu and Sarkis, 2004; Li *et al.*, 2020a, b). The relationships between I4.0 and its influence on operations accuracy, system flexibility and quality have been thoroughly examined in the manufacturing context (Parhi *et al.*, 2022; Qureshi *et al.*, 2023; Sharma *et al.*, 2023b). Studying agility (Chen *et al.*, 2017) alongside resilience (Dubey *et al.*, 2021) in supply chains offers a broader insight into how businesses can adeptly manoeuvre through uncertainties, disruptions and rapid changes in their environments, ultimately fostering sustained success and growth (Albert, 2011). Interestingly, Gupta *et al.* (2019) studied the relationship between smart and agile for information processing in organizations, and Milošević *et al.* (2022) and Haseeb *et al.* (2019) attempted to explore the relationship between I4.0 and sustainability. Studying the relationship between all these variables like smart, green, agile and resilient together will unwind the complex relationships for better management of these decision variables in the SC context. There is also a dearth of a unified review of the technology implementation that can orient SCs toward sustainability while becoming smart. Further, despite the significance of I4.0 (I), no study has examined Green (G), Resilience (R), Agile (A), Smart (S) practices (now onwards termed as IGRASS in the rest of the paper) for designing a sustainable SC. However, there has been no work to date that has conceptualized the framework (Raut *et al.*, 2021) providing an integrated view of all the practices presenting empirical evidence for the phenomenon under question. The proposed study is motivated by the absence of an integrated framework in the literature. Also, the natural resource-based view (NRBV) aids in identifying the resources that are responsible for building internal capabilities for organizational success considering the sustainability pillars. The NRBV is an important concept that considers the ecological footprint of a company's resources and their environmental impact. This approach takes into account the effects resulting from the utilization of those resources and emphasizes the importance of sustainable practices to ensure the long-term viability of businesses. Hence, the study considers the theoretical lens of NRBV for identifying the relevant variables for each construct in the proposed framework. Table 1 presents some of the IGRASS variables studied in several combinations under different contexts and reports the significant relationships established so far. The analysis infers that the six important variables of IGRASS have not been studied in an integrated manner and neither empirically tested. Hence, the studies still need to holistically investigate all the building blocks of the proposed IGRASS framework.

Several industries especially manufacturing units across the globe are finding it difficult to strategically manage both internal and external SC-related challenges and are actively looking for activities and processes that can make their business process environmentally conscious, socially responsible and profitable (Sharma *et al.*, 2023b). The situation calls for identifying the missing links between I4.0 and sustainability issues like data transparency and traceability (Perano *et al.*, 2023), the flow of information (Hofmann *et al.*, 2019), managing risk (Liu *et al.*, 2022) and having an integrated perspective on sustainability (Chen *et al.*, 2017). Therefore, this demands an urgent need to have a unified approach (Ayuso *et al.*, 2014; Nujoom *et al.*, 2019; Sharma *et al.*, 2021; Ivanov, 2022; Tripathi *et al.*, 2022) that can bridge the gap and help present as well as future generations to judiciously utilize the resources and have a more effective and sustainable supply chain. Hence, the present study proposes an integrated framework that includes all the six dimensions of IGRASS. The author has not found any prior studies that have attempted to study all six dimensions together under the purview of NRBV that encompass tangible resources, intangible resources and capabilities (Barney, 1996) in the context of I4.0 for SBP. NRBV strongly considers internal resources and capabilities for achieving a competitive edge (Andersen, 2021). It focuses on the organizations' internal resources for organizational success. This internal focus allows companies to harness their strengths. As the research focuses on building internal resources and capabilities considering I4.0, green and SmSC practices for SBP, the theoretical foundation of NRBV has been adopted.

There is also a dearth of a unified review of the technology implementation that can orient SCs toward sustainability. To bridge this gap, the present research aims to contextualize NRBV to examine the proposed IGRASS framework. Hence, the study seeks the following questions:

RQ1. Can Industry 4.0 (I4.0) and green practices (GP) transform a traditional supply chain into a smart supply chain (SmSC)?

RQ2. Can Industry 4.0 (I4.0) and green practices (GP) help a supply chain be agile and resilient to achieve sustainable business performance (SBP)?

To answer the RQs authors propose a research framework based on NRBV tested using structural equational modelling (SEM) with 234 respondents from Prolific qualifying the selection criterion of a minimum 2 years of experience in I4.0 and activities in UK SCs.

This research work tests the relationship between different concept-specific variables and gains a thorough understanding using a mixed-method approach to the contributions of I4.0 in

Table 1.
Sectoral studies in Industry 4.0

Sr. No.	Industry	Variable	Significant relationship	Research method	Authors (Yr.)	Theory	Research gap (IGRASS constructs covered in the study)
1	Manufacturing	Operational Accuracy (OA), System Flexibility (SF), Software Infrastructure (SI) and Technical Capabilities (TC)	WE→I4.0, TC→I4.0 SF→I4.0, SI→I4.0 OA→I4.0, SR→I4.0	SEM-ANN	Parhi *et al.* (2022)	Technology, organizational and environmental (TOE)	Only the pillars of I4.0 are studied. The study is limited to the manufacturing industry .(I of IGRASS studied)
2	All Industries-Domestic and International	Resource Management, Performance Management, Leadership, Process Management, Improvement Learning and innovation	L→ ILI, PM→ILI RM→ILI, PM→ILI	SEM-ANN	Milošević *et al.* (2022)	Resource Based View (RBV)	Variables like resource management and innovation are studied in a general context (I and Sustainability of IGRASS)
3	SMEs	Big Data, IoT, Smart factory, IT implementation, Sustainable Business performance, Structure and Processes	BD→ITI, IoT→ITI SF→ITI, ITI→SBP,SP as Moderator	PLS-SEM	Haseeb *et al.* (2019)	Resource Based View (RBV)	Smart factories and Sustainable Business Performance are studied for SMEs (Smart and Sustainability of IGRASS studied)
4	Manufacturing SMEs	Employee training and learning (ETL), statistical process control (SPC), advanced manufacturing Top management leadership (TML), operational readiness (OR), customer focus (CF), Lean 4.0 practices, total productive maintenance (TPM), Advanced Manufacturing Technologies (AMT), technological readiness (TR)	TML → L4.0 practices TML → TPM, TML → SPC, TML → AMT, CF → L4.0 practices, CF – TPM CF → SPC, CF – AMT ETL → L4.0 practices ETL – TPM, ETL – SPC ETL → AMT	PLS-SEM, ANN	Qureshi *et al.* (2023)	Unified theory of acceptance and use of technology	All variables studied of I4.0 with a focus on the use of technology. The orientation of paper is around quality for manufacturing and SMEs (I of IGRASS is studied)
5	General	Information system agility, Supply chain flexibility, Smart supply chain, Information processing	ISC →ASD, APM →SCF ASD → SCF SR → A	SEM	Gupta *et al.* (2019)	Organization Information Processing Theory (OIPT)	Smart and Agility are studied. (S and A of IGRASS are studied)

Note(s): Software Infrastructure: SI, System Flexibility: SF, Agile Project Management: APM, Improvement Learning and innovation: ILI, Operational Accuracy: OA, Employee Training and Learning: ETL, Total Productive Maintenance: TPM, Technical Capabilities: TC, Workforce Empowerment: WE, Industry 4.0:I4.0, Supplier Relationship: SR, Stakeholder Relations: SR, Leadership: L, Process Management: PM, Resource Management: RM, Performance Management: PerM, Big Data: BD, Smart Factory: SF, Advanced Manufacturing Technologies: AMT, IT implementation: ITI, Sustainable Business Performance: SBP, Structure and Processes: SP, Top Management Leadership: TML, Customer Focus: CF, Lean 4.0:L4.0, Statistical Process Control: SPC, Supply Chain Flexibility: SCF, Intelligent Supply Chain: ISC, Agile Software Development: ASD, Agility: A, Artificial Neural Network: ANN, Structural Equation Modelling: SEM, Partial Least Square: PLS
Source(s): Authors' own work

making UK SCs sustainable (Schumacher *et al.*, 2016). The study has examined the moderating role of green practices (GP) with supply chain resilience (SCR), supply chain agility (SCA) and SBP. Based on the framework the study tests the two independent variables viz., I4.0 and GP, and three mediators in the study namely SmSC, SCA and SCR. The captured data, collected from 234 respondents, are cross-sectional and span from October 2022 to January 2023.

The study contributes immensely to the theory. The study incorporates various standardized scales to examine the proposed framework. The findings emphasize that SBP can be achieved with green initiatives and digital transformation that can make agile and resilient SC. All the direct relationships and the mediating relationships are found significant, except for the direct relationship between GP and SmSC. The elaborate framework of IGRASS serves as a building block for designing a sustainable SC.

Our findings yield varied practical insights, guiding supply chain partners in pursuing the path toward achieving SBP. Throughout this journey, managers understand the importance of prioritizing agile and resilient practices to attain higher sustainability. Clear, precise directives are provided to practitioners concerning resource management, fostering innovation and promoting social responsibility for a sustainable supply chain. SmSCs will undoubtedly bring real-time data, intelligent devices and systems across all operations. However, to make the SCs future-ready, structural redesign and performance planning, through huge investments are pertinent, which is un-doubtfully in an ever more environmentally aware market, aiming for prolonged economic growth and sustainability.

The paper's structure is outlined as follows: Section 2 delves into the study's theoretical foundation, offering an in-depth exploration of its theoretical basis and a critical analysis of relevant literature. It elaborates on the proposed framework, detailing all the constructs incorporated within. Section 3 expounds on the proposed hypotheses. Section 4 elucidates the research methods employed for the investigation. Section 5 showcases the analysis of the results. Following this, Section 6 initiates a discussion. Finally, Section 7 concludes the study and presents implications as well as avenues for impending research.

2. Theoretical background

Relevant theoretical underpinning concerning digitalization and building blocks of IGRASS have been discussed in this section. Studies by Rodríguez-Espíndola *et al.* (2022) examined RBV in the adoption of I4.0 activities, including AI, big data, blockchain and cloud computing, in SCs. It aids in revealing the necessary resources to be considered during the digitalization of supply chains. NRBV and its relevance in the present context are explained next, followed by the role of the six building blocks under focus.

2.1 Natural resource-based view (NRBV)

RBV, as asserted by Wernerfelt (1984) and Barney (1996), considers tangible and intangible capabilities to function as strategic resources for organizations. Dubey *et al.* (2020) strongly emphasize that there is a dearth of studies within the realm of SC discipline that delve into the bundling of resources and capabilities. Notably, Darcy *et al.* (2014) asserted that the firm's resources and capabilities have a direct influence on SCP (Nandi *et al.*, 2020). SCP could be improved through the digitalization of SC, which enables seamless access and sharing of real-time information (Cheng and Lu, 2017; Martinez-Sanchez and Lahoz-Leo, 2018). As elucidated by Sehnem (2019), strategically managing resource consumption and ensuring sustainability emerge as focal points for organizations aiming to attain profitability (Singh, 2018). The resources, as highlighted by Kozlenkova *et al.* (2014), Bromiley and Rau (2016) and Nandi *et al.* (2020), play a pivotal role in exploiting opportunities, mitigating threats and ultimately gaining a competitive advantage.

NRBV also recognizes the significance of resources that are shared with other organizations. The literature on innovation acknowledges the prominence of suppliers (Andersen, 2021). Several studies have also emphasized the importance of green suppliers for overall sustainable performance and differentiation advantage (Andersen, 2021). Given these considerations, the present study positions the NRBV theory as an apt theoretical framework for comprehending the interplay of different building blocks of I4.0 and GP to achieve sustainable competitive advantage (Sharma *et al.*, 2022).

2.2 Conceptualization of the IGRASS framework

The term "IGRASS" focuses on the six important elements of the SC and the way it impact its performance. The IGRASS, I stands for I4.0, G stands for Green, R stands for Resilience, A stands for Agility, while the two S stands for Smart and Sustainability. Currently, the organizations' perspectives on these factors have become necessary for business transformation from a product and organizational point of view. With increasing environmental concerns among SC players, a green focus is required in the entire SC gamete for sustainable growth of the organization. SmSC comprises three critical aspects namely instrumented, interconnected and intelligent as asserted by Zhang *et al.* (2023). Agility is a techno-centric approach with a focus on customer sense and response strategy (Shashi *et al.*, 2020). A resilient organization's SC can cope with refining changes and provide quick responses brought by the SC disruption. Organizations for SBP should balance institutional (regulatory, community and competitive) constraints with their environmental, social and economic dimensions. The identified factors for each construct with its definition are mentioned in Table A1 (Annexure).

2.2.1 Industry 4.0 (I4.0). The concept of I4.0 has been investigated from two primary dimensions: a product-focused perspective and an organizational perspective, as expounded by Schumacher *et al.* (2016). To comprehensively analyze I4.0, the dimensions of technology, products, operations and customers were developed. The dimensions of people, governance, strategy, leadership and culture, encompass the organizational factors in the evaluation. Notably, prior research has delved into the intricate interplay between I4.0 key technologies (IT-related and operations-related technologies), organizational resilience (in terms of internal and external aspects) and overall performance in companies (Marcucci *et al.*, 2021; Raji *et al.*, 2021).

Addressing the requisites of digital technology readiness, Chonsawat and Sopadang (2020) delineated subthemes such as big data analytics, information systems, cybersecurity, tracking systems and predictive maintenance (Nujoom *et al.*, 2019). Furthermore, in the realm of I4.0, blockchain-based platforms play an instrumental role in enhancing accuracy (Zwitter and Boisse-Despiaux, 2018), security, real-time controllability (Lopes *et al.*, 2018) and labour cost reductions, as specified by Budak *et al.* (2018).

Some key applications of I4.0 also include the customization of products, production and services, which Gabriel and Pessl (2016) asserted is a fundamental paradigm shift. Cartier *et al.* (2018) and Lim *et al.* (2013) argued the utility of I4.0 in facilitating traceability and inventory tracking. I4.0 is the cornerstone for interactive manufacturing, where cyber-physical processes address the constraints, enabling SCs to achieve smart and interactive handling (Stark *et al.*, 2022). Acknowledging the technological landscape, Brewer *et al.* (2005) and Costin and Teizer (2015) proclaimed that the salient technological challenges originate from the cost-intensive nature of maintaining the technology. However, a dearth of technical expertise among professionals, and low investment in training and research does exist (Hosseini *et al.*, 2016).

As per the NRBV theory, a company possesses tangible and intangible assets, such as financial capital, physical infrastructure, human resources and technology (Barney, 1991; Barney, 1996) for sustainable performance (Andersen, 2021). The items for I4.0 are chosen from the NRBV resources which are support-related (like government support, financial support and research institute) and technology-related (like Internet, cyber-physical systems, cloud computing and IoT (Gupta *et al.*, 2019). Aligned with the human resource premise of NRBV the human capital items like training of employees and employment legislation are also included in the constructs. NRBV also focuses on resources like green image, reuse, eco-friendly products, wastage and energy consumption that improve the performance of supply chains (Dubey *et al.*, 2017), therefore GP is included as an important construct for SBP. Despite the prolific body of research on I4.0 concepts, a plethora of research addresses that amid the benefits of I4.0 lie intricate technological challenges to achieve sustainable outcomes. Next, we discuss the GP and its role in the present context.

2.2.2 Green practices (GP). A key tenet in realizing green SC practices is the active engagement of all partners within the SC network, as elucidated by Belhadi *et al.* (2020), Li *et al.* (2020a, b) and Yang and Liu (2023). The performance of a green SC encompasses a multifaceted spectrum of practices, including customer participation, internal environmental management, investment recovery, green purchasing and eco-design. Research focuses on diverse dimensions like internal corporate social responsibility (Mory *et al.*, 2016), the implementation of green information systems (Chuang and Huang, 2018), the adoption of environmental responsibility practices (Green *et al.*, 2012) and internal environmental management (Passetti *et al.*, 2018).

Green SC has dual objectives of mitigating the ecological impact while enhancing economic performance (Albert, 2011; Chen and Ho, 2019). A pivotal facet of green is ensuring SC sustainability (Rao and Holt, 2005). Notably, green procurement and logistics significantly contribute to organizational performance, a sentiment supported by Holt and Ghobadian (2009). The adoption of GP in SC contributes to business performance and helps organizations increase productivity (Kumar *et al.*, 2022; Sharma *et al.*, 2023a), improve profitability (Lee *et al.*, 2012) and gain a competitive position (Fierro and Benitez, 2011). The confluence of GP and innovative paradigms such as I4.0 has been advocated by Luthra *et al.* (2019). This study claims that such synergy of green and technology fosters scalability, flexibility, heightened productivity and sustainable growth (Kumar *et al.*, 2022; Sharma *et al.*, 2023a).

2.2.3 Supply chain resilience (SCR). Resilience is a company's ability to plan for, respond to and recover from unforeseen occurrences in a timely and cost-effective manner, returning to its original and improved state (Hosseini and Ivanov, 2019; Xu *et al.*, 2020). Companies with resilience are more resistant to disruptions in the supply chain and are more competent while handling such events whenever they do occur. Further resilient SCs continue to deliver their products and services to the customer by managing risks or promptly recovering from disruptions (Ambulkar *et al.*, 2015).

The imperative of compatibility within SCs stems from the intricate interlinkages among diverse businesses that can be managed by information sharing (IS). IS a pivotal in shaping SCR (Appiah *et al.*, 2020; Duchek *et al.*, 2020). An intriguing exploration undertaken by Dubey *et al.* (2021) and Behl (2020) delves into the influence of organizational culture on SCR by fostering trust and facilitating coordination among remote partners in SC. Chatterjee *et al.* (2022) have empirically manifested the impact of adopting I4.0 technologies and SCR on firm performance, with leadership support playing a moderating role. Scholarly insights consistently highlight the significance of top management's financial aid as a driver of sustainability and resiliency (Dubey *et al.*, 2021). The organization's s SC demonstrates the ability to cope with dynamic changes and provide quick responses brought by the disruptions (Golgeci and Ponomarov, 2013; Ambulkar *et al.*, 2015; Gu *et al.*, 2020; El Baz and Ruel, 2021). Brandon-Jones *et al.* (2014) discuss that a resilient organization's SC can restore material flow swiftly and navigate disruption in the SC. Marcucci *et al.* (2021) explained that I4.0 technologies influence organizational resilience and performance of organizations.

Hosseini and Ivanov (2019) emphasize the significance of SCR, which holds a pivotal role in not only ensuring economic viability (Albert, 2011) but also in environmental preservation, contributing to waste reduction and lowering energy consumption (Green *et al.*, 2012). The concept of resilience carries numerous definitions across different disciplines (Bhamra *et al.*, 2011; Burnard and Bhamra, 2011; Gunasekaran *et al.*, 2015). SCR can be defined as the property of a supply chain that enables the disrupted supply chain to recover its normal operating performance within an acceptable period after the disrupting forces are withdrawn or disappear (Dubey *et al.*, 2021).

2.2.4 Supply chain agility (SCA). Agility in the context of I4.0 refers to an organization's ability to swiftly and effectively adapt to changes, disruptions and opportunities that arise because of the shifting market demands, technological advancements and dynamic business environments (Essa *et al.*, 2020). Agility also embraces SCs to yield benefits (Abrahamson *et al.*, 2010) and competitive advantage (Albert, 2011) in a turbulent business environment. While closely entwined, agility and flexibility are distinctively recognized as the SC's reactive and response abilities (Hyun *et al.*, 2020). Scholars like Hobbs (2021) and Chenarides *et al.* (2021) asserted that flexibility is essential for creating a resilient SC. Notably, Shashi *et al.* (2020) have revealed that there exists a consistent and positive relationship between investments in technology and agility. Agility builds multiple capabilities in SC like customer sensing capabilities, customer responding capabilities, customer service, market knowledge, market experience, differentiation, ambiguity tolerance, learning, information sharing capabilities and knowledge for resolving problems and sensible decision making (Shashi *et al.*, 2020).

Digital SC is pivotal to real-time planning and control, allowing companies to attain flexibility and agility in a swiftly changing environment. This encompasses quick responses to demand, supply and price changes, thereby mitigating prolonged planning cycles and inflexible periods (Oztemel and Gursev, 2020). The relationship between agility and sustainability involves finding a balance between quickly adapting to changes and ensuring responsible practices that preserve resources and contribute to a more sustainable performance (Chen *et al.*, 2017).

The dynamic capabilities aspect of NRBV involves a firm's ability to adapt, evolve and innovate its resources and capabilities over time, i.e. adapt to services, products, markets and supply-demand changes (Lee *et al.*, 2009). To also stay relevant in changing markets and environments like SC disruption, quick response, restoration and recovery (Kozlenkova *et al.*, 2014; Chowdhury and Quaddus, 2017). Agility and resilience complement each other wherein, agility denotes how quickly an organization can adjust, transform and react to evolving circumstances, while resilience is about an organization's ability to recover and bounce back from adverse events or disruptions. Both are crucial in today's unpredictable business landscape (Oztemel and Gursev, 2020). Therefore, agility and resilience are the two important constructs of our model proposed in the research. Nevertheless, a deeper foray into scholarly literature is required to assess the interplay between agility and SBP holistically which has been hardly studied.

2.2.5 Smart supply chain (SmSC). 2.2.5.1 Instrumented supply chains (INSSC). Numerous I4.0 technologies have garnered substantial attention within the scholarly discourse. Prominent among these are machine learning, big data analytics, industrial IoT (Wu *et al.*, 2016; Spieske and Birkel, 2021), AR, cloud computing and collaborative robot applications (Salunkhea and Berglunda, 2022; Sindhwani *et al.*, 2022; Lee *et al.*, 2022). Also, advanced manufacturing solutions, simulation, mobile computing and AR are considered the I4.0 enabler technologies as aptly posited by Sharma *et al.* (2023b), Oesterreich and Teuteberg (2016) and Lepore *et al.* (2021).

Further, the key data-supported activities delineated by Almada-Lobo (2016) under the data transformation dimension's category are cloud manufacturing, data acquisition, data connection and real-time data. Data transformation technologies play an instrumental role in making raw data of SCs more accessible, useful and meaningful for analysis and gathering valuable insights for decision-making (Liu *et al.*, 2022).

At the outset, initiating smart implementation necessitates significant investment in creating and sustaining a suitable organizational infrastructure. This could be possible through the top management's financial support, which significantly bolsters the impetus for technology implementation (Kamble *et al.*, 2018). Kim *et al.* (2021) and Agolla (2018) described that for such smart initiatives, human capital formation and assessment, comprising education, knowledge, experience and skills, are the core constituents. The inflow of technologies and various government policies during the infancy stages of technological revolutions also provide the environment for firms' smart pursuits (Popkova and Zmiyak, 2019).

INSSC enables mass customization and intelligent coordination to align demand and supply (Kagermann *et al.*, 2013; Lu, 2017). It also reduces lead times, and yields cost benefits as asserted by Budak *et al.* (2018) for overall performance. Furthermore, real-time tracking helps to maintain the optimal stock level by tracking the inventory (Malek *et al.*, 2019; Kamble *et al.*, 2019) and also helps in the execution of corrective actions (Hong *et al.*, 2019; Leng *et al.*, 2020). The present research intends to study the entire gamut of INSSC factors like transformative technology, investment, management support, human capital and strategic government policies and pathways to customization, coordination, agility and performance enhancements.

2.2.5.2 Interconnected supply chains (ICSC). Ras *et al.* (2017) primarily address the collaborative dimension of sustainability, focusing on aspects such as shared services and resource utilization. This collaborative approach is also reflected in advancements in human-machine interaction (Liao *et al.*, 2016; Zhong *et al.*, 2017; Xu *et al.*, 2018) as well as direct engagement with customers (Li *et al.*, 2017; Ralston and Blackhurst, 2020). I4.0 includes the three dimensions of interconnectedness: horizontal value chain integration (Shrouf *et al.*, 2014; Oesterreich and Teuteberg, 2016), end-to-end digital integration and vertical value chain integration (Kagermann *et al.*, 2013; Prause and Weigand, 2016).

In light of a proposed framework addressing many technological and societal issues: connectivity, resilience and human integration are among the most critical for bringing resilience to systems (Orji *et al.*, 2019). Also, improving interoperability, data acquisition, transmission and processing while enabling hierarchical levels among agents emerge as pivotal. Moreover, facilitating system acceptance among human agents and fostering human integration within the system are vital components of this framework (Valette *et al.*, 2021).

The scholarly research underscores the significance of collaboration in the context of sustainability, manifested through diverse forms of resource sharing and interactions. However, the I4.0 concept introduces ICSCs, while a comprehensive framework emphasizes connectivity, resilience and human integration as critical elements. However, the present research will propose an exhaustive framework encompassing all possible factors related to technological and societal aspects.

2.2.5.3 Intelligent supply chain (ISC). An ISC involves the integration of various digital technologies for managing the flow of goods, information and processes within a SC network (Schuh *et al.*, 2015). It is designed to bring greater efficiency, collaboration, flexibility and visibility to SC operations (Ras *et al.*, 2017). By harnessing the power of digital technologies, organizations can optimize their processes, reduce costs, improve customer satisfaction and gain a competitive advantage in the rapidly evolving business landscape (Salam, 2019).

The third critical element of SmSC requires intelligent systems that can build capabilities continuously to create innovations (Bonekamp and Sure, 2015) and develop improvements (Shamim *et al.*, 2016). The I4.0 landscape requires a comprehensive approach to employee qualifications, job descriptions and competencies (Gabriel and Pessl, 2016). The holistic method for managing human resources in the I4.0 realm requires four employee competencies viz., technical, methodological, social and personal. The dynamic nature of I4.0, due to the constant evolution of technologies and the rapid pace of innovation, necessitates continuously developing knowledge and capabilities among the workforce (Sciutti *et al.*, 2018).

An organization's capabilities are often the result of how resources are combined, integrated and managed within the organization (Majeed and Rupasinghe, 2017). This is aligned with NRBV to allocate resources, build capabilities and improve performance. In the construct, SmSC has intelligent (like intelligent systems, intelligent devices, human resource training), interconnected (like monitoring, track and trace, communication protocol, visibility) and instrumented (like AI, IoT, RFID) aspects that will help efficiently allocate resources to develop the organization's supply chain capabilities (Butner, 2010; Nandi *et al.*, 2020). The paradigm shift introduced by I4.0 for SmSC underscores the necessity for establishing a clear framework for defining sustainable business performance.

2.2.6 Sustainable business performance (SBP). Organizations are increasingly challenged to balance institutional (regulatory, community and competitive) constraints while also prioritizing their environmental (Dalenogare *et al.*, 2018), social and economic performance to attain sustainable outcomes (Ayuso *et al.*, 2014). Ramirez-Peña *et al.* (2020) and Sindhwani *et al.* (2022) advocate a strategic two-phase approach for organizations aiming to implement I4.0 technologies to enhance their performance (Rossit *et al.*, 2019). The initial phase focuses on sustainability, augmenting economic, energy and environmental performance indices. Subsequently, the final phase aims to elevate functional and social dimensions of performance. Technical and collaborative advancement enhance the competencies and positively impact the overall productivity of SC (Wilhelm *et al.*, 2016).

The convergence of big data and digitalization is expected to fuel sustainable development in the context of I4.0 applications, particularly concerning the fulfilment of sustainable development goals (SDG) (Nujoom *et al.*, 2019). The pivotal role of management support is vital to adopting sustainability practices in the current environment (Kluczek, 2019; Yadav *et al.*, 2020). Organizations through the lens of I4.0, can raise environmental awareness by enabling virtualization, digitization and integration, reducing waste and creating more efficient use of natural resources, raw materials and energy (Lepore *et al.*, 2021).

NRBV asserts that resources and capabilities must add value to the firm and enable it to achieve performance like better asset utilization, improved profitability and stronger competitive position (Bromiley and Rau, 2016) and overall sustainable performance (Andersen, 2021). Not all resources and capabilities are equally important or valuable to achieve performance (Lee *et al.*, 2012). NRBV suggests that firms should identify and focus on those resources and capabilities that offer unique value and competitive advantage to achieve sustainable performance. Therefore, the focus of this research is to examine those factors which contribute to SBP.

The impact of SC disruptions can be mitigated by technology with a synergy between institutional, environmental and socio-economic considerations. Hence, the present study proposes the strategic value of technological interventions, which help enhance SCR to catalyze SBP.

2.3 Research gaps

Yadav *et al.* (2020) conducted a comprehensive examination of sustainability employing I4.0 within manufacturing organizations in developing economies. Also, Schumacher *et al.* (2016) delved into the intricacies of I4.0 factors of digitalization across various industries. These factors, of paramount significance, were also the subjects of scrutiny in studies of Green *et al.* (2012), Shashi *et al.* (2020), Dubey *et al.* (2021), Aheleroff *et al.* (2022) and Sindhwani *et al.* (2022), each shedding light on their implications for various facets of green, resiliency, agility and overarching sustainability. Prior research provides a comprehensive perspective on I4.0

enablers that have a pivotal role in enhancing sustainability while acknowledging the challenges of adopting it. Nujoom *et al.* (2019) distilled that digitalization is expected to fuel sustainability in the context of I4.0 applications and create SmSCs. Kamble *et al.* (2018) highlighted an analysis of barriers to adopting I4.0, while Chen *et al.* (2017) presented the SC framework associated with IT-enabled SC.

Many authors have timely argued and emphasized the need for I4.0, but very few studies have been found studying the convergence of I4.0 with GP, which is expected to fuel sustainable development. The works of Haseeb *et al.* (2019) have focused almost on an integrated theme but on the SME sector where SCs deal and function in a degenerate manner. Though Gupta *et al.* (2019) and Haseeb *et al.* (2019) have discussed various variables and their relationships, a holistic theoretical model and the path to achieving SBP remains void. While SCA and SCR are often discussed separately, there is a paucity of research exploring the intricate association between these two concepts. Hence, the product-focused and organizational dimensions addressed in this research could provide a structured approach for analyzing the impact of I4.0 on SBP. There is a dearth of literature studying the impact of SC disruptions that can be mitigated with a synergy between technology and GP under the purview of institutional, environmental and socio-economic considerations.

Only a handful of research has studied IGRASS variables piecemeal, such as I4.0 with SCA, I4.0 with sustainability, green with sustainability and I4.0 with SCR, etc. The authors could not find any inclusive approaches capturing all the building blocks of sustainable systems. Extant literature has not studied SmSC with Green and Agile practices. Sharma *et al.* (2023a) studied the GRAS variables ignoring the smart systems that can reshape supply chains. The different types of smart variables like Instrumented, Intelligent and Interconnected are scarcely studied in the literature. The underpinning theory of NRBV highlights the potential for a company's human resources to constitute a sustainable competitive advantage. Similarly, this research has also stated that for SmSC, skilled human capital is instrumental for performance. In this context, employees' knowledge, skills and adaptability are instrumental in handling advanced technologies and digital tools to manage critical resources (Lee *et al.*, 2022).

Further, NRBV's theoretical foundation highlights the importance of resources that can translate into the technological infrastructure a company possesses. Therefore, building a smart system-specific combination of IoT devices, AI algorithms, big data analytics and INSSC systems can form a source of competitive advantage (Ras *et al.*, 2017). Also, NRBV emphasizes innovation and green practices as a key driver of SBP (Andersen, 2021). For Smart and Intelligent SCs, continuously innovating, adapting and integrating new technologies into existing processes becomes a critical capability for companies to maintain their competitive edge (Shamim *et al.*, 2016). Henceforth, there is a necessity to study the impact of these intelligent systems to create SmSC and also assess its impact on SBP.

The authors believe that the studies have not empirically tested the IGRASS variables holistically. Very few studies, such as those of Parhi *et al.* (2022), adopted SEM-ANN with variables such as software infrastructure, operational accuracy and technical capabilities in the manufacturing industry. Qureshi *et al.* (2023) also used SEM-ANN with variables such as leadership support, quality, lean and training to achieve readiness in manufacturing SMEs. Empirical evidence of the linkages between the various building blocks of IGRASS in SC has been missing for a long. Accordingly, the present study explores the plethora of factors towards achieving SBP in SC under the theoretical lens of NRBV. The studies still need to be holistically investigated capturing all the building blocks to design a sustainable system. Table 1 presents the seminal and most cited papers highlighting the significant relationships established so far.

3. Development of constructs and hypothesis

3.1 Direct relationships

3.1.1 Industry 4.0, smart supply chain and supply chain agility. The existing body of literature has extensively explored that with new technologies, traditional SCs transform and evolve into intelligent and smart SCs (Kamble *et al.*, 2018; Lepore *et al.*, 2021). The literature also emphasized the interconnectedness of the SC process and its efficiency (Ras *et al.*, 2017; Valette *et al.*, 2021), which profoundly impacts sustainability and performance outcomes (Dallasega *et al.*, 2018). There is a plethora of literature on I4.0 which has delved into the impact on SC processes through the integration of standardization and customization (Frank *et al.*, 2019; Weking *et al.*, 2020) and moving from mass production to mass customization for business performance (Kagermann *et al.*, 2013; Lu, 2017).

SCA is an excellent techno-centric strategy, heavily reliant on digitalization (Shashi *et al.*, 2020). Aligned with tenets of I4.0 (Schumacher *et al.*, 2016), SCA is also made up of five key components, i.e. leadership, governance, people, culture and strategy, which influence how the organization operates and adapts in response to evolving customer needs and market dynamics (Essa *et al.*, 2020). In light of the prior literature, researchers have mainly studied the relationship between technological facets and pivotal dimensions of agility for smart SCs. However, there is a need for a comprehensive evaluation that integrates the full spectrum of I4.0 nine dimensions (Schumacher *et al.*, 2016) and five similar dimensions of agility (Essa *et al.*, 2020), which the researchers have investigated in this study.

Supply chain digitalization enables efficient planning and control (Cenamor *et al.*, 2017), fostering flexibility (Prause and Weigand, 2016) and agility to effectively respond to vulnerabilities (Oztemel and Gursev, 2020; Pfaff, 2023). Shashi *et al.* (2020) argue that a consistent and positive relationship exists between investment in technology and agility. Technology provides the capabilities that enable organizations to respond rapidly to changing circumstances, optimize processes and enhance decision-making which collectively contribute to achieving agility in the supply chain (Pfaff, 2023).

I4.0 is increasingly gaining traction as a contemporary paradigm in the SC, it faces multifaceted organizational, legal, strategic and technological challenges, which can be mitigated by improving SCA (Saengchai and Jermsittiparsert, 2019). Dubey and Gunasekaran (2016) affirm that agility, including adaptability and alignment, has an affirmative and substantial influence on the sustainability of the SCs. Alhyari (2015) highlighted that agility contributes to cost savings and economic growth, underpins enhanced customer responsiveness and leads to business performance. Researchers have studied business performance with variables like cost, customer satisfaction, sustainability and economic growth (Pfaff, 2023). The resource-based view suggests that Industry 4.0 technologies and green practices integration serve as valuable resources and capabilities that, when integrated effectively into a smart supply chain, can provide firms with sustainable business performance (Darcy *et al.*, 2014). The business performance variable demands attention to study a culminated assessment of SBP as a key business performance metric through the lens of technology and agility. Therefore, we postulate

H1. Industry 4.0 has a significant and positive relationship with the Smart Supply Chain.

H2. Industry 4.0 has a significant and positive relationship with Supply Chain Agility.

3.1.2 Industry 4.0, green practices and smart supply chain. The pivotal role of I4.0 in designing accurate and controllable manufacturing processes that could help reduce errors was comprehensively elucidated by Umar *et al.* (2022). With the help of I4.0 technologies like IoT, the processes have become more robust and accurate (Kouhizadeh and Sarkis, 2020). Environmental footprints have also become more traceable through the integration of IoT (Auramo *et al.*, 2005).

The process design is effectively operationalized by synergizing technologies such as cloud computing and AI, thus unveiling greenhouse gas (GHG) emissions and enabling pre-emptive control measures (Auramo *et al.*, 2005).

The extant literature suggests that organizations managing SC demand collaboration across the partners from sourcing to distribution while concurrently enhancing green in the whole SC gamete (Dora, 2019; Sharma *et al.*, 2021). Hence, there is a profound influence of I4.0 on eco-friendly practices which remains an underexplored domain within the broader context of SCs and is worth investigating.

Digitalization within the SC has been examined to understand its contribution to overall performance (Zhu *et al.*, 2013; Karttunen *et al.*, 2023). The present study advocates for a holistic research approach amalgamating internal (economic) and external (environmental) facets. A holistic approach entails scrutinizing the involvement of internal personnel and systems (Dev *et al.*, 2021) alongside the myriad of external stakeholders (Green *et al.*, 2012) while also encompassing both strategic and operational (technical) dimensions. Such an integrated investigation can potentially unravel significant insights into sustainable environmental and economic (SEE) performance determinants within green SC practices. NRBV suggests that resources like I4.0 technologies and GP can together serve as valuable resources and enhance capabilities. When integrated effectively into a smart SC, it can provide firms with SBP (Darcy *et al.*, 2014). Therefore, the present research attempts to study the relationship of I4.0 with GP for designing SmSC. I4.0 and GP is less discussed in prior literature. So, it is crucial to analyze the impact of I4.0 and GP implementation in organizations in a highly developed social market economy like the UK. Thus, we hypothesize.

H3. Industry 4.0 has a significant and positive relationship with Green Practices.

H4. Green practices have a significant and positive relationship with the Smart Supply Chain.

3.1.3 Smart supply chain and supply chain agility. Previous scholarly works have suggested that a smart SC leads to a fundamental business transformation toward managing dynamic demand and data-driven evaluation of performance (Davis *et al.*, 2012). Furthermore, integrating demand-driven SC services and innovation also improves the efficiency of SCs (Schwab, 2016; Ghobakhloo, 2018). In this context, the overarching objective of harnessing big data is to help transform the enormous amount of raw data into actionable insights in real time, thereby technically supporting automation (Lee *et al.*, 2014; Almada-Lobo, 2016). Extant research predominantly examines how organizations build big data capability to improve SCA and attain competitive advantage (Nujoom *et al.*, 2019). There needs to be more research on alleviating SCA through transformational factors like human capital, product innovation, customer centricity and operational procedures.

In essence, an I4.0-based ICSC is a holistic cross-functional collaboration system of information technologies (Ras *et al.*, 2017), people (Schwab, 2016), machines and tools (Xu *et al.*, 2018). The extant literature has suggested that the primary goal of a SC that seeks support from all stakeholders is to strengthen and expand the firm's long-term competitiveness by increasing production efficiency, agility and flexibility through information (Lee *et al.*, 2014) and intelligence (Gabriel and Pessl, 2016).

Through collaboration, there is regulated movement of goods, services and data across the value chain. It enhances end-to-end visibility (Miragliotta *et al.*, 2018) and enables catalyses decision-making processes (Saucedo-Martínez *et al.*, 2017). Intelligent systems are pivotal in monitoring demand and supply variability and tracking and tracing inventory in real-time (Ras *et al.*, 2017). Given the dearth of empirical research on the synergies between SC agility, collaboration and performance, the present research posits a positive relation between interconnected SCs and SCA.

The seminal work of Roblek *et al.* (2016) presented I4.0's intelligent fundamental components: intelligent factories, new systems in developing products (Keller *et al.*, 2014), services (Gabriel and Pessl, 2016), distribution (De Sousa Jabbour *et al.*, 2018) and procurement (Roblek *et al.*, 2016). Lee *et al.* (2014) contend that self-organization, smart products, quality, variety and speed of delivery can be achieved through techniques like AI, RFID, Cloud and IoT. The prior studies examined the comprehensive integration of facets within the ISC, which necessitates adaptation to human needs (Agolla, 2018) and incorporates Cyber-Physical Systems for agility and sustainability. From an NRBV dynamism perspective, a smart supply chain provides the technological infrastructure and capabilities that enable agility. The present research has in-depth studied all the elements like interconnected, intelligent and instrumental as an important resource for a SmSC. It empowers businesses to make informed decisions, respond promptly to changes and maintain operational efficiency, even in the face of uncertainties or disruptions in the SC (Ras *et al.*, 2017). Hence, the present research posits a relationship between smart systems which enable agility and resiliency in supply chains. The above-mentioned studies did not adopt all the dimensions of instrumented, interconnected and intelligent supply chain, so they could not establish the contribution of each of these dimensions to SCA.

H5a. Instrumented supply chain has a significant and positive relationship with supply chain agility.

H5b. Interconnected supply chain has a significant and positive relationship with supply chain agility.

H5c. Intelligent supply chain has a significant and positive relationship with supply chain agility.

3.1.4 Green practices, supply chain agility and supply chain resilience. Luthra *et al.* (2019) argued that the convergence of I4.0 and environmental practices yields enhanced scalability, agility and performance in SC processes. This, in turn, culminates in the attainment of sustainable outcomes, as corroborated by the studies of Kumar *et al.* (2022) and Sharma *et al.* (2023a). The agile SC intends to have the ability to respond rapidly and cost-effectively adapting to unpredictable changes in markets in terms of both volume and variety (Christopher, 2000). This adaptability to changes is realized through a keen responsiveness to environmental factors (Agarwal *et al.*, 2007).

Considering these arguments in tandem with the contributions of GP like reuse, recycling, waste management, energy consumption and eco-friendly products (Green *et al.*, 2012), it becomes imperative to investigate the nature of GP's relationship to SCA. A green strategy serves as a conduit for achieving key elements of organizational resilience for the company and this study aims to bridge the gap in examining this relationship.

As GP extends across production (Budak *et al.*, 2018), distribution (De Sousa Jabbour *et al.*, 2018) and procurement (Roblek *et al.*, 2016) it enhances the organization's resilience and stability (Hyun *et al.*, 2020). While the two key outcomes of organizational resilience are reducing volatility and fostering performance (Nandi *et al.*, 2020; Ivanov *et al.*, 2021) and growth (Kueffner *et al.*, 2022; Sharma *et al.*, 2023b). Integrating the I4.0 technologies and SmSCs empowers firms to adapt swiftly, respond effectively to changes, differentiate strategically and efficiently manage operations in dynamic and unpredictable environments, thereby enhancing SCA (Martinez-Sanchez and Lahoz-Leo, 2018). From an NRBV perspective, integrating GP into SCA efforts represents a strategic alignment of green resources and capabilities for long-term sustainability, thus creating a competitive advantage in a market valuing eco-friendly practices (Singh, 2018). Since I4.0 contributes significantly to SCA, the present study has also looked into the impact of I4.0 and GP in designing an agile and resilient supply chain.

While prior research predominantly centres on the construction (Newman *et al.*, 2021), retail and manufacturing industries (Liu *et al.*, 2017; De Sousa Jabbour *et al.*, 2018), we propose the following hypothesis for the broader context of SCs. Investigating the nexus between GP and SCA can offer valuable insights for a more resilient SC. In a nutshell, this study uncovers those critical factors which can be helpful for GPs in developed countries in general.

H6. Green practices have a significant and positive relationship with supply chain agility (SCA).

H7. Green practices have a significant and positive relationship with supply chain resilience (SCR).

3.1.5 Green practices and sustainable business performance. In a study by Khan and Qianli (2017), financial performance positively correlates with the adoption of GP in SCs. Cost reduction can be achieved through designing ecologically friendly products, identifying non-value-added activities using value stream mapping (VSM) and encouraging biofuels in logistics (Khan *et al.*, 2019). Contributing to this discourse, Govindan *et al.* (2015) and Baines *et al.* (2012) emphasize the negative impact of production activities with minor waste across the manufacturing chain. Furthermore, the adoption of green product designs was found to improve both economic and environmental performance. However, more work must be done to determine if GP directly impacts agility, resilience and SBP.

According to NRBV, integrating an important resource GP for SCR enables companies to enhance their ability to withstand disruptions while remaining committed to environmental responsibility and driving SBP (Nandi *et al.*, 2020). The relationship between GP and SBP has received limited attention within academic research. Existing studies primarily adopt a practice-oriented approach and lack robust theoretical underpinning. Furthermore, the majority of research in this field tends to concentrate on GP within the confines of a single company, overlooking its broader implications for the entire supply chain. The predominant focus of these studies has been on assessing the economic, social and environmental dimensions as outcome variables (Wahl *et al.*, 2014). Most articles focus on the modelling of carbon policies during the design phase of GP and do not focus on the implementation phase (Cynthia *et al.*, 2019). Very few articles address the interrelation and integration of the three pillars of sustainability: economic, social and environmental within the context of SBP. Consequently, there is a pressing need for research that emphasizes the incorporation of environmental thinking to be embedded throughout every stage of the supply chain. This holistic approach can help foster a more comprehensive elucidation of the role of GP and SBP in advancing sustainability. Hence, this research has tried to assess the factors of GP which contribute significantly to SBP. Based on the above arguments, we hypothesize as follows:

H8. Green practices have a significant and positive relationship with sustainable business performance

3.1.6 Supply chain agility, supply chain resilience and sustainable business performance. Prior literature has argued that the four fundamental SC principles that connect and intricately define the supply chain are lean, agile, resilient and green (Ramirez-Peña *et al.*, 2019; Ivanov, 2020; Sharma *et al.*, 2021; Sharma *et al.*, 2023a). The resilient organization's SC can cope with dynamic changes and provide quick response brought by SC disruption, as emphasized in the works of Golgeci and Ponomarov (2013), Ambulkar *et al.* (2015), Gu *et al.* (2020) and El Baz and Ruel (2021). The manufacturing agile systems comprise a service-oriented architecture fostering collaboration between production systems, machines, products, factories and people (Magruk, 2016; Budak *et al.*, 2018). Moreover, customizable, agile, flexible and reconfigurable services in real-time (Prause and Weigand, 2016) extend resiliency to end-users. This enables a highly integrated human-machine manufacturing system (Zhong *et al.*, 2017). Studies by Sharma *et al.* (2023a) claimed the relationship between agility and resilience using the multi-criteria decision-making (MCDM) method but has been not empirically established. So, a significant research gap is the absence of a comprehensive framework that incorporates agility, resilience and sustainability as interconnected dimensions. Existing studies often treat these concepts separately, missing the opportunity to explore how they complement or conflict with each other in practical settings. Hence, the work proposes to examine the direct relationship of agility with resiliency and the indirect relationship with SBP.

Studies of Marcucci *et al.* (2021) and Zouari *et al.* (2021) studied the impact of I4.0 on organizational resilience. However, existing resilience models do not adequately account for the unique challenges and opportunities presented by digitalization. Present research has identified key performance indicators (KPIs) that can effectively capture the influence of digital technologies on an organization's ability to withstand interruptions. The role of human factors in I4.0-driven resilience is an underexplored area. Research should delve into how employees and organizational culture influence the adoption and effectiveness of I4.0 technologies in building resilience.

Scholars contend that if SCs are made resilient they will contribute to sustainability and help organizations improve asset utilization and gain a competitive position (Fierro and Benitez, 2011), and also improve profitability (Lee *et al.*, 2012). Tang (2006) argues that resilient SCs may not be the lowest-cost, but they are more capable of coping with the uncertain business environment (Hosseini and Ivanov, 2019). accentuated the multifaceted significance of SC resilience in economic viability, i.e. asset utilization and profitability (Albert, 2011). Alongside, environmental protection, i.e. reducing waste and energy consumption (Green *et al.*, 2012) and social equity, i.e. training of workers and labor legislation is emphasized during resilient operations in SCs (Agolla, 2018). The studies need to define the role of resilience and agility in making sustainable SCs. Prior literature focuses on different industries and contexts and suggests unique approaches to achieving agility, resilience and SBP. Research should delve into the contextual factors that influence the SCs by integrating these concepts, and considering variations across sectors, regions and organizational sizes (Ivanov, 2020). Many studies also focus on short-term outcomes, but there is a need to assess the long-term effects of integrating agility, resilience and sustainability (Albert, 2011). Balancing supply chain agility and supply chain resilience allows an organization to navigate dynamic environments, respond to changes swiftly, withstand disruptions and maintain operational stability, thereby enhancing its overall supply chain performance (Cheng and Lu, 2017). Agility focuses on proactive adjustments and quick responses to changes, allowing organizations to stay relevant and competitive in evolving markets. Resilience, on the other hand, ensures that when unforeseen challenges occur, organizations can recover effectively without significant long-term damage (Hosseini and Ivanov, 2019). This research has tried to assess the complementarity of agility and resilience that contributes to sustainability.

It is crucial to study the impact of such practices on an organization's SBP over extended periods. We seek to fill this gap in the literature. Besides, no well-designed study examined the impact of each of these variables in a developed country like the UK. Consequently, the authors posit the aforementioned hypothesis.

H9. Supply Chain Agility (SCA) has a significant and positive relationship with Supply Chain Resilience (SCR).

H10. Supply Chain Resilience (SCR) has a significant and positive relationship with Sustainable Chain performance (SBP)

3.2 Mediation hypothesis

Smart manufacturing technologies have a stronger impact on the sustainability outcomes of SCs (Di Maria *et al.*, 2022). Shorter lead times in SCs could be achieved through I4.0

implementation making the production processes within and among SCs much smarter. Investments in I4.0 technology help businesses adapt and grow more agile than those that don't. In the agribusiness domain in Sub Sahara Africa (SSA), Kamewor (2022) identified ways to enhance the innovation drive in SCs through SC Analytics; however, there is no empirical investigation on the sustainability aspect. Sharma *et al.* (2023a) developed a relationship between agility and resilience using MCDM analysis in the fresh food context. Sustainability is enhanced when green purchasing, integration of lifecycle management and reverse logistics (Zhu *et al.*, 2008) set the ground for resilient SCs. As sustainability in SCs could not be attained without turning SCs into agile and resilient ones, this study proposes the mediation effect of SmSC, SCA and SCR on SBP. Hence, the following hypothesis has been postulated:

H11. Industry 4.0 has a significant and positive relationship with supply chain agility when smart supply chain mediates the relationship between them.

H12. Green practices have a significant and positive relationship with supply chain agility when smart supply chain mediates the relationship between them.

H13. Smart Supply Chain has a significant and positive relationship with supply chain resilience when supply chain agility mediates the relationship between them.

H14. Green practices have a significant and positive relationship with supply chain resilience when supply chain agility mediates the relationship between them.

H15. Green practices have a significant and positive relationship with sustainable business performance when supply chain resilience mediates the relationship between them.

4. Research method

4.1 Model development

A multitude of topical antecedents of SBP has been thoroughly and constructively screened and analyzed. The dearth of an integrated framework led authors to develop a model and test its reliability and validity. The study tests one dependent variable, i.e. SBP, two independent variables viz., I4.0 and GP, and three mediators in the study namely SmSC, SCA and SCR. Suitable scales of Butner (2010), Majeed and Rupasinghe (2017) for SmSC, Gupta *et al.* (2019) for I4.0 Lee *et al.* (2009) for SCA, Chowdhury and Quaddus (2017) for SCR, Lee *et al.* (2012) for SBP and Dubey *et al.* (2017) for GP have been used in the present study.

4.2 Measures

The face validity of the measures chosen for each factor was carried out, wherein six experts helped in refining and bringing clarity to each of the items to avoid any kind of conflict and ambiguity for respondents. The scales' content validity was checked using the item content validity index (ICVI) and scale content validity index (SCVI) during the pilot study. For the same, the same six experts were asked to rate the relevance of each item on a scale of four (Grant and Davis, 1997). As the number of experts increases the CVI decreases and it's difficult to attain agreement on the representativeness of the items (Grant and Davis, 1997). In concurrence with the experts' suggestions during the pilot study, the questionnaire was updated and the final version was shared among the users and managers conversant with I4.0 practices. The data collected from Prolific from 234 respondents were then subjected to understand the factor structure using Exploratory factor analysis (EFA) and confirmatory factor Analysis (CFA) to assess the validity of the measures. Authors also put efforts into ensuring the quality of the responses through a rigorous respondent selection. The professionals having a minimum experience of 3 years in the SC realm with a pertinent understanding of I4.0 practices are qualified to respond to the questionnaire. The questionnaire contained all the relevant information regarding the definition of the factors used in the study but did not provide any sequence while answering. This was done to avoid any common method bias.

4.3 Data collection and analysis

The questionnaire consisted of the items selected and modified from the existing scales and was measured using the Likert scale (1 = strongly disagree; 7 = strongly agree). The scale consists of 21 items in I4.0, 9 items in Green Practices, 14 items in SSC, 5 items in Agility, 6 items in Resilience, and 4 items in SBP. The form was created in the Google form and the data collection was spread over four months. Around 234 respondents were used for the final analysis out of a total of 242 responses received due to incomplete and duplicate responses. The study tests the proposed model by applying a covariance-based structural equation modelling (CB-SEM) and further investigates the ranking of each construct using the artificial neural networks approach. Confirmatory factor analysis (CFA) was carried out for the main study and the hypothesis was tested using SPSS AMOS V 23. The study carries the full collinearity test in SPSS to test the common method bias and the discriminant validity using the heterotrait-monotrait ratio of correlations (HTMT) analysis. The full collinearity test (Kock, 2015) tests the contamination of the data with the common method bias. In this method, random numbers are generated by creating a dummy dependent variable and regressing all the constructs. Kock (2015) suggests the VIF for the full collinearity test to be less than 3.3, above that common method bias exists. The measurement model and structural model in the AMOS V.23 software package required several iterations. In AMOS mediation was carried out using bootstrapping and for moderation multi-group analysis (MGA) feature was used. The study also further uses artificial neural networks (ANN) (plugin in AMOS) for carrying determine the underlying non-linear relationships and to prioritize the significant constructs in the study.

5. Results

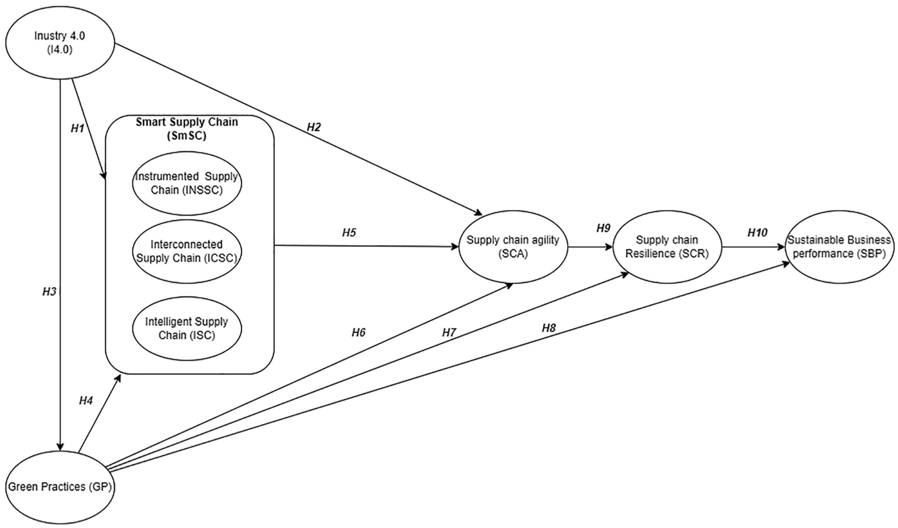
The study evaluates the impact of I4.0 and GP for achieving SBP among industries. We have studied GP, I4.0, SmSC, SCA, SCR and SBP (Refer to Figure 1). A hypothetical model has been empirically tested using 234 respondent data associated with various SCs in the UK. The results present a rich insight into the role of I4.0 and GP towards achieving a sustainable business through key constructs such as the agility and resilience of SC.

5.1 Demographics

The respondents in the study are majority female (70%) while males made up (30%). The highest percentage of respondents belonged to the lower management level. Around 84% worked in MNCs most of the respondents are bachelors (68%) and 25% did their master's and only 7% are Ph.D. holders. Among these respondents, the majority are working professionals. Only a handful of them are freelancers and government employees. The manufacturing, IT and education industry takes the largest percentage of respondents in this study. Table 2 presents the demographic details of the respondents.

5.2 Measurement model

The indices related to content such as the item content validity index (ICVI) and the scale content validity index (SCVI) revealed the error-free items in the scale. The ICVI was obtained as 0.996



Source(s): Authors' own work

Figure 1.
Smart sustainable supply chain model (SmSSC)

Categories	Sub-categories	Percentage (%)
Gender	Male	30
	Female	70
Management level	Top	13
	Middle	34
	Lower	53
MNC	Yes	84
	No	16
Qualifications	PhD	7
	Masters	25
	Bachelors	68
Occupation	Academician	4
	Working professional	40
	Government employee	2
	Entrepreneur	2
	Freelancer	1
	Student (with 2 years of working experience in Industry 4.0)	17
	Others	4
Industry	Manufacturing	15
	Construction	9
	Transportation and warehousing	2
	Service	5
	IT	13
	Healthcare sector	10
	Education	14
	Pharmaceutical	4
	Retail	5
	Agriculture	0
	Finance	5
	Government	4
	Others	11
	General Management	4

Source(s): Authors' own work

Table 2.
Demographic profiles of the respondents

while the SCVI was “1” confirming the content validity of the study. The construct reliability and validity were established after several rounds of analysis, using Exploratory Factor Analysis (EFA) followed by the CFA. In EFA, a variable that loaded less than 0.3 was not considered in the study. The data looked normal and free from any skewness. For CFA convergent and discriminant validity using maximum likelihood for all the identified items (Zu *et al.*, 2010) was verified. The goodness of fit indices $\left(\lambda^2/_{df} = 1.891, CFI = 0.913, NFI = 0.841, \ TLI = 0.908, RMSEA = 0.066\right)$ are also found to be quite satisfactory. The factor loadings presented in Table 3, were found to be well above 0.60 (Hair *et al.*, 2022) and hence the variables were retained in the study. The scores for the composite reliability were found to range from 0.93 to 0.97 satisfying the reliability for the measures (Fornell and Larcker, 1981). The average variance extracted (AVE) is found to be greater than 0.75 attaining the highest value of 0.868. The correlation among the constructs is lower than the suggested threshold value of 0.80 confirming the validity of discriminants. Table 4 presents the constructs' statistical measures. In addition to this, we also tested the discriminant validity of the items using the HTMT analysis. The HTMT has been carried out using the guidelines of Franke and Sarstedt (2019). Table A2 (Annexure) presents the correlation matrix used for the HTMT calculations for items of the two constructs namely green practices and Industry 4.0. The HTMT values for the study ranged from 0.6 to 0.75 for the various items between different constructs in the study.

5.3 Common method variance (CMV) and multicollinearity

A significant error in the measures can arise when researchers use the same survey channel for measuring the independent and the dependent variables (Eichhorn, 2014). Podsakoff *et al.* (2003) presented ways of tackling this issue related to biases arising from the data collected from the same source. The primary way of reducing the error is by giving the respondents the freedom to answer the specific questions with truth and honesty and not to tempt them to answer as the researcher wants. The constructs and the model under study were not revealed to the respondents and the responses were kept anonymous. Using Harmon's single-factor test on the entire collection of variables, the six factors were found. Out of a total of 75.45% of the variance explained by all the factors, the first factor accounted for 17.32% of the variation. This confirmed the absence of any single factor in the model and reduced the risk of concluding the model's relationships. The chances of multi-collinearity have been assessed using the variance inflation factor (VIF). The VIF has been observed as below 5 confirming the absence of multi-collinearity among the variables. The results of the full collinearity test show that the VIF is within 3.3 and implies the data is free from the common method bias in the study.

5.4 Structural model

The casual model is topical for the researchers and reveals interesting insights. The study valorizes the argument put forth in the studies of Sharma *et al.* (2023a) in their paper GRAS enablers for fresh food supply chains. The results confirm a significant influence of GP on SCA and also a direct effect on the SBP. The fit indices for the structural model are observed to be quite good $\left(\lambda^2/_{df} = 1.914, CFI = 0.920, NFI = 0.846, TLI = 0.915, RMSEA = 0.064\right)$. The hypothesis test results are briefed in Table 5. Nine out of ten direct hypotheses are supported. The results of the indirect effects are also summarized where H12 is non-significant.

5.5 Mediation results

To understand the mediating impact of constructs such as SmSC, SCA and SCR in the model, hypothesized relationships H11 to H15 were tested in IBM AMOS V 23 and the indirect effects were calculated. Table 6 infers the significant relationship between I4.0 and SCA through the

Table 3. Item factor loadings and measurement details

Constructs		Items	Measures	Source	Factor loadings
Instrumented supply chain (INSC)		INSC1	We have integrated technology such as artificial intelligence (AI) in our supply chain	Butner (2010), Majeed and Rupasinghe (2017)	0.63
		INSC2	We have integrated the Internet of Things (IoT) into our supply chain		0.67
		INSC3	Rapid technological changes are taken care of by updating software and supply chain systems regularly		0.73
		INSC4	We use radio frequency identification (RFID) to improve efficiency		0.66
Interconnected supply chain (ICSC)		ICSC1	We have real-time monitoring capabilities in our supply chain		0.61
		ICSC2	We use standardized communication protocols such as the Internet Protocol, the Hypertext Transfer Protocol (HTTP), etc		0.64
		ICSC3	We emphasize integration, coordination and management of key business processes across our supply chain		0.82
		ICSC4	Inventory levels are easily visible throughout the supply chain from procurement to end customer		0.79
		ICSC5	Demand levels are evident throughout the supply chain from the end customer at the downstream to the supplier in the upstream		0.82
Intelligent supply chain (ISC)		ISC1	We have adopted smart processes like intelligent systems/standard operating procedures (SOP) for planning, sourcing, making and delivering goods		0.86
		ISC2	We use intelligent devices to actively monitor the proper handling of systems/equipment in our supply chain		0.64
		ISC3	Our systems provide relevant and accurate information for effective decision-making		0.84
Industry 4.0	Support related factors	I4.support1	We get financial support from the government for driving Industry 4.0 for supply chain transformations	Gupta *et al.* (2019)	0.65
		I4.support2	We get support from the government or any other agencies for driving Industry 4.0 in our supply chain		0.61
		I4.support3	Our industry sector gets support from external agencies which help in converting local innovations into commercial products in our supply chain		0.65
		I4.support4	Collaboration with research institutes and universities to facilitate skills development, human resource training and transfer technology is upfront		0.65
	Technology related factors	I4.tecno1	Internet to access data from remote sensors and control physical objects in our supply chain		0.65

(*continued*)

Table 3.

Constructs	Items	Measures	Source	Factor loadings
	I4.tecno2	We use cyber-physical systems to manage big data and control the interconnectivity of machines for security in our supply chain		0.76
	I4.tecno3	We use cloud computing for data management and storage processes		0.8
	I4.tecno4	We have employed cyber security services in our systems		0.65
	I4.tecno5	We use trust-based security to authenticate IoT devices and ensure only trusted components communicate with each other in our supply chain		0.83
	I4.tecno6	We conduct annual security audits that include control systems, partner network access, maintenance network access and wireless links		0.74
	I4.tecno7	We have IoT based assistant for supply chain partners		0.86
	I4.tecno8	We have Virtual Reality, Augmented Reality, Artificial Intelligence and machine learning (also called Metaverse) in our supply chain that help interact among the supply chain partners well		0.76
Focus on Human Capital	I4.HC1	We invest a percentage of company income in the training and development of workers to upgrade skill sets of workers as per Industry 4.0 requirements and develop capability for specialised jobs		0.79
	I4.HC2	New Labour and employment legislation is required for job security in this era of robotics and automation		0.8
	I4.HC3	We have developed a policy to train and support the un-employed or lower-skilled employees towards usage of intelligent systems		0.79
Process Integration	I4.0_16	We have done internal expansion, mergers and acquisitions		0.74
	I4.0_17	We have integrated our systems with our suppliers and customers in the supply chain		0.79
Supply chain agility (SCA)	SCA1	We can adapt our services and/or products quickly to the new customer requirements	Lee *et al.* (2009)	0.88
	SCA2	We can adapt quickly to new market developments		0.85
	SCA3	We can adapt to the supply-demand changes as fast as required by the market		0.93
	SCA4	We are always able to adjust our product portfolio as fast as required by the market		0.89
	SCA5	We can react adequately fast to supply-side changes, e.g. compensate for spontaneous supplier outages, delivery failures, market shortage		0.82

(*continued*)

Table 3.

Constructs	Items	Measures	Source	Factor loadings
Supply chain resilience (SCR)	SCR1	The organization's supply chain can cope with variations brought by the supply chain disruption	Chowdhury and Quaddus (2017)	0.91
	SCR2	The organization's supply chain can provide a quick response to the supply chain disruption		0.93
	SCR3	The organization's supply chain can maintain high situational awareness at all times		0.95
	SCR4	The organization's supply chain can restore Material flow quickly		0.93
	SCR5	The organization can recover quickly post the supply chain disruption		0.92
	SCR6	The organization's supply chain would not take long to recover to normal operating performance		0.93
Sustainable business performance (SBP)	SBP1	Sustainable supply chain practices have aided in achieving overall improved performance in the organisation	Lee *et al.* (2012)	0.92
	SBP2	We have created a green image of our products		0.95
	SBP3	We have created a green image of our products		0.94
	SBP4	Sustainable supply chain practices have aided in achieving overall improved performance in the organization		0.96
Green practices (GP)	GP1	We have created a green image of our products	Dubey *et al.* (2017)	0.86
	GP2	Products are designed for reuse and recycling		0.88
	GP3	We are implementing green supply chain activities		0.87
	GP4	We purchase and promote the use of eco-friendly products		0.9
	GP5	We focus on reduced wastage in our supply chain		0.92
	GP6	We focus on reduced energy consumption		0.89
	GP7	We also emphasize the reduced use of Polyvinyl chloride (PVC) or any other non-recyclable raw materials		0.86
	GP8	Green supply chain activities of our supply chain include the reduction of waste discharge		0.92
	GP9	Solid waste management and wastewater treatment costs have significantly reduced compared to the last year's figures		0.95

Source(s): Authors' own work

mediating effect of SmSC ($\beta = 0.702, p = 0.000$) thereby supporting H11 and concluding the full mediation. The non-significant indirect effect of GP on SCA ($\beta = -0.032, p = 0.562$) through the mediating effect of SmSc infers no mediation and does not support H12. Partial mediation is observed for GP, SCA and SCR as the relationship between GP and SCR is significant ($\beta = 0.453, p = 0.05$) when SCA mediates the two supporting H13. H14 is also supported, as the mediating effect of SCA between GP and SCR is found significant ($\beta = 0.218, p = 0.000$). Similarly, the indirect effect between GP and SBP is found significant supporting H15, Byrne (2009) also suggests the study of indirect effects using the bootstrapping method. Using 2,000 resamples with a 95% confidence interval in IBM AMOS V.23, the authors conducted the bias-corrected bootstrapping to analyze the indirect effects on SCA, SCR and SBP.

Constructs	CR	AVE	MSV	SCA	I4.0	GP	SmSC	SBP	SCR
SCA	0.953	0.823	0.812	*0.895*					
I4.0	0.944	0.802	0.800	0.747	*0.866*				
GP	0.972	0.796	0.642	0.751	0.801	*0.892*			
SMARTSC	0.934	0.786	0.699	0.800	0.799	0.757	*0.800*		
SBP	0.963	0.868	0.743	0.800	0.824	0.783	0.794	*0.932*	
SCR	0.973	0.859	0.812	0.901	0.820	0.749	0.803	0.862	*0.927*

Note(s): Diagonal values depict the square root of AVE of individual latent constructs
Source(s): Authors' own work

Table 4.
Statistical measures for the constructs

Structural relationships/path	Hypothesis	β value (standardized regression weight)	*p*-value	Results
Direct effects				
I4.0→ SmSC	H1	0.792	***	Supported
I4.0→ SCA	H2	0.034	0.115	Not Supported
I4.0→ GP	H3	0.962	***	Supported
GP → SmSC	H4	0.074	0.106	Not Supported
SmSC → SCA	H5	0.849	***	Supported
GP → SCA	H6	0.246	***	Supported
SCA → SCR	H7	0.908	***	Supported
SCR → SBP	H8	0.598	***	Supported
GP → SCR	H9	0.160	***	Supported
GP → SBP	H10	0.287	***	Supported
Indirect effects				
I4.0→ SmSC → SCA	H11	0.702	0.000	Supported
GP→ SmSC →SCA	H12	−0.32	0.562	Not supported
SmSC → SCA → SCR	H13	0.243	***	Supported
GP → SCA → SCR	H14	0.218	***	Supported
GP → SCR → SBP	H15	0.702	***	Supported
SmSC $R^2 = 0.88$				
SCA $R^2 = 0.78$				
SCR $R^2 = 0.83$				
SBP $R^2 = 0.79$				

Note(s): *** level of significance: $p < 0.001$
Smart Supply Chain (SmSC), Supply Chain Resilience (SCR), Supply chain Agility (SCA)
Sustainable Business Performance (SBP), Green Practices (GP), Industry 4.0 (I4.0)
Source(s): Authors' own work

Table 5.
Path estimates for the proposed model

Hypothesis	Effect- direct	Effect- indirect	Result
I 4.0→ SmSC → SCA	0.034^{ns}	0.702***	Full mediation
GP→SmSC→SCA	0.19***	−0.32 ^{ns}	No Mediation
SmSC→ SCA → SCR	0.114***	0.453**	Partial mediation
GP → SCA → SCR	0.060***	0.218***	Partial mediation
GP → SCR → SBP	0.013***	0.702***	Partial mediation

Note(s): *** level of significance: $p < 0.001$
** level of significance: $p < 0.05$
Sustainable Business Performance: SBP, Green Practices: GP, Industry 4.0: I 4.0, Smart Supply Chain: SmSC, Supply Chain Agility: SCA, Supply Chain Resilience: SCR
Source(s): Authors' own work

Table 6. Summary of the mediation effect

5.6 Artificial neutral network (ANN)

Multiple linear regression (MRA) simplifies decision-making by detecting only linear relationships among the constructs while underestimating the non-linear relationships. Non-linear relationships present more accurate and robust prediction models (Shaker and Sureshbabu, 2020) presiding over the traditional MRA (Shahla *et al.*, 2019). But, the black box nature of ANN makes them unsuitable for carrying out hypothesis testing (Lee *et al.*, 2020), for that reason authors conducted a two-step approach viz., SEM followed by ANN, as adopted in studies of Shahla *et al.* (2019), Lee *et al.*, 2020, Akour *et al.* (2022) and Al-Sharafi *et al.* (2022).

The model accuracy is presented using the Root Mean Square of Error (RMSE) of training and testing data sets. This is accompanied by the standard deviations and averages for both data sets. The values obtained from RMSE and the normalized priority for the predictor variables are mentioned in Tables 7 and 8 respectively. Accuracy of prediction is observed

Neural networks	Training	Testing
Iteration 1	0.152	0.268
Iteration 2	0.173	0.039
Iteration 3	0.185	0.124
Iteration 4	0.162	0.06
Iteration 5	0.121	0.07
Iteration 6	0.151	0.077
Iteration 7	0.17	0.055
Iteration 8	0.154	0.075
Iteration 9	0.153	0.077
Iteration 10	0.14	0.072
Average	*0.156*	*0.092*
Standard deviation	*0.017*	*0.062*

Source(s): Authors' own work

Table 7. RMSE values for the study

Predictors	Normalized importance	Rank
SCR	1	1
I4.0	0.49	2
GP	0.48	3
SMSC	0.46	4
SCA	0.28	5

Source(s): Authors' own work

Table 8. Predictor variables with ranking

from values of the RMSE value that ranges from 0.140 to 0.173 for training data. For the testing data, the RMSE values are observed in the range of 0.039–0.268. Basis the ANN output, SCR is observed as the most important predictor for SBP followed by I4.0, GP, SmSC and SCA. The relative importance has been derived from the predictor variable importance that is run ten times. The calculation for relative importance is carried out by finding the ratio between the individual importance to the highest importance value.

6. Discussions

The popularity of I4.0 has plagued the SCs to go digital. The present research has mapped the findings and provided a comparative analysis with previous works in Table A3 (Annexure). The interaction between economic considerations with environmental (noise pollution, congestion and carbon dioxide emissions) and social issues in SC needs immediate attention (Linton *et al.*, 2007) which can be easily answered if SC utilizes I4.0 to improve overall efficiency (Sharma *et al.*, 2023a). It is seen in the literature that SC managers and stakeholders focus on profitability (Wu and Pagell, 2011) however, in the present scenario where resources are depleting at an accelerated rate, there is an urgent need for interventions that can fulfil present needs with judicious utilization of resources. Thus, a comprehensive understanding of the key dimensions for achieving sustainable business performance requires attention.

I4.0 practices are essential for devising strategies for achieving SmSc (H1) but insufficient for high SBP (Brettel *et al.*, 2014; Bag *et al.*, 2021). For high performance on sustainability, I4.0 could be leveraged only when SCA, GP, SmSc and SCR are practiced in SCs. Investing in I4.0 enhances not just inventory traceability and tracking, but also accuracy and security, as well as real-time manoeuvrability (Lopes *et al.*, 2018) and labor cost savings (Budak *et al.*, 2018). Pillar of I4.0 contributes towards forming an intelligent, integrated and interconnected SC as well. And, the foci of any SmSC are automation, reducing errors and achieving higher-level performance (Leng *et al.*, 2020; Hong *et al.*, 2019). Mass customization is what I4.0 practices will bring to the SCs as asserted in the studies of Kagermann *et al.* (2013) and Lu (2017).

The H3 found significant in the present study infers that in the industry, I4.0 has a great role in making effective and innovative green SCs in economies like the UK. De Giovanni and Cariola (2021) also very well established the innovative process strategies in green SCs using an I4.0 environment in the context of manufacturing in developed nations. Though, the significant relationship in the developing context has been partially studied, in the present context I4.0 is observed to transform the green SCs.

It is interesting to note that H4 is found to be non-significant, which tests the relationship between GP and SmSC leading to the understanding that the SCs are not smart if they go green, rather GP helps the firm to become more agile than smart. This contrasts with the studies of Vázquez-Bustelo and Avella (2006) conducted in Spain. Further, GP has a long-term implication for the sustainability of the SCs consistent with the studies of Kluczek (2019) and Yadav *et al.* (2020).

The present study also found that businesses significantly augment the SCs going smart to agile. This supports the H5. Agile SCs withstand competitive and dynamic markets (Sharma *et al.*, 2019). It enhances transparent decision-making that can accurately map or navigates market swings thereby ensuring responsive and flexible SCs. Hence, SmSCs gain expertise in better sensing the market needs, fulfilling them learning from decisions made every time and differentiating themselves from competitors. Abourokbah *et al.* (2023) studied an interesting model integrating SCA and SC responsiveness in building innovation performance in SCs. Supporting evidence for H5 also confirms the studies of Muafi and Sulistio (2022).

GP-assisted SCs transform to agile by increasing resource efficiency, strengthening cooperation, lowering risk and fostering innovation (Reynolds and Uygun, 2018). The same results have been found in the present study supporting H6. GP enables the elimination of waste thereby enabling agile SC for rapid reconfiguration. Further, agile strategies when operating in highly uncertain environments help in coping with sudden and unexpected changes in demand and supply in a cost-effective manner (Gligor *et al.*, 2015).

Significant relationships between GP and SCR (H7) bring substantial evidence towards GP such as buying raw materials from local suppliers or using renewable energy sources will help to lessen reliance on a single supplier or energy source (Sadma, 2021; Azevedo *et al.*, 2013). Resilience in SCs is constrained by material availability which demands agility that can make an SC comfortable with change (Cohen *et al.*, 2022). This diversification can assist in managing risks associated with SC interruptions such as natural catastrophes or geopolitical conflicts.

Umar *et al.* (2022) presented a thought-provoking relationship between I4.0 practices in SCs and the GP that eventually creates sustainable SCs in emerging economies. This aligns with the present study where H8 has been found significant. The considerable association between GP and SBP signifies the opportunity for firms to achieve SBP by adopting GP. As a result, SCs that adapt I4.0 are guided by data-driven decisions and can survive, prosper and fulfil environmentally sustainable goals (ESG). Integrating GP into SC management can help companies develop more resilient and sustainable SCs that can withstand disruptions and provide long-term value for all stakeholders (Sharma *et al.*, 2023a).

The path analysis (H9) also confirms the significant relationship between agility and resilience in SCs. This relationship ensures strategic flexibility and opportunity to innovate even in disruptions and unfavorable conditions. SCA influences SCR and sustainable advantage by keeping the production process functioning normally and controlling production capacity. SCR promotes long-term advantage by ensuring timely product delivery and consistent sales volumes in pandemic conditions (Tarigan *et al.*, 2021).

SCR and SBP are inextricably linked since both strive to maintain a company's long-term existence tested in H10. Significant relationships between SCR and SBP align with various studies (Ivanov, 2022; Aheleroff *et al.*, 2022) that have established the relationship between these, terming these as viable SCs. The robustness of a company's supply network is crucial to its long-term viability. A resilient SC may help a firm achieve long-term success and contribute to a more sustainable future by decreasing environmental impact, promoting social responsibility, assuring economic sustainability and stimulating innovation. A resilient SC also aids a company's economic sustainability by maintaining a regular supply of materials and goods, lowering prices and enhancing operational efficiency. Previous researchers have proposed that technological, societal and environmental uncertainties need to be answered to make a SC resilient to attain sustainability in the long run (Matos and Hall, 2007). The findings also direct to the contribution of Aheleroff *et al.* (2022) where the authors specifically put forth the growing importance of integrating Industry 5.0 while making SC resilient.

While exploring I4.0 practices, aided in interpreting the association between GP, I4.0, SmSC, SCA, SCR and SBP; the role of NRBV is very critical (Andersen, 2021). Organizational performance has been investigated under the purview of RBV by various researchers such as Deephouse (1996), El-Garaihy *et al.* (2022) and Dai *et al.* (2021) in the SC context. The relationships established in the study also present a consonance with the studies of Sharma *et al.* (2023a) that determined the indirect and direct relationships among the GRAS enablers in the FFSC using the MCDM approach. The study emphatically established the multiple relationships determined through an MCDM approach. But the present study demonstrates the importance of agility and resilience achieved through digitalization making SC smart and green for a general SC. The present study build up on the initial studies of Marinagi *et al.* (2023), Patidar *et al.* (2023), Aheleroff *et al.* (2022) and Sharma *et al.* (2023a), where none of the papers have integrated the six dimensions, that have been proposed and tested in the current study. The present study empirically tests the studies of Sharma *et al.* (2023a), using the SEM-ANN approach while adding important variables, i.e. I4.0 and SmSC. Also, though, the GRAS framework was carried out in an FFSC specifically, the current modified framework IGRASS builds on the previous papers' findings. The present study peculiarly put forth that smarter SCs emerge from the influence of digitalization. And, for translating a firm towards sustainability, SmSC alone cannot be the only resort. SmSC which is composed of ISC, ICSC and INSSC though influences the SCA, are insufficient in achieving SBP. This is emphasized by the mediating role of SCA and SCR for achieving SBP supporting H11, H13, and H14 and H15. Hence, in today's changing business scenario, SmSC will aid mass customization of the SCs (Lu, 2017) effectively and efficiently.

Green SC management methods assist firms in enhancing asset utilization, achieving a competitive position and boosting profitability (Fierro and Benitez, 2011; Lee *et al.*, 2012). The model also presents an interesting caption for SC that, while they compete with several SCs a real transformation of SCs needs to be in terms of making a SmSC by integrating several aspects of I4.0. As the SCs are now visualizing themselves to be sustainable, this needs to be done in phases. The first phase must focus on sustainability, and improving economic, energy and environmental performance indexes. The next phase should be bringing structural changes, integrating I4.0 practice and transforming the operations smart.

The articles present in the literature have previously had the selected dimensions, in isolation but not in integration. The results of the integrated framework, presented in the study, will expand the horizon of the decision-makers while bringing a bigger picture during the designing and planning the supply chain practices. Studying all dimensions of resilience, sustainability, green practices, agility, Industry 4.0 and Industry 5.0 is advantageous due to multiple reasons. Firstly it guarantees a thorough comprehension of the opportunities and problems that today's organizations and society must overcome. Secondly, it aids companies to have an edge over their competitors. They are better able to adapt to changes in the market, satisfy changing customer needs for sustainability, and make use of cutting-edge technologies to increase productivity and creativity. Thirdly, Organizations may anticipate and reduce risks associated with supply chain disruptions, environmental calamities, and economic downturns by having a better understanding of resilience. Businesses can reduce the risks connected to resource shortages and climate change by incorporating sustainability and green practices into their operations. Fourthly, it prepares people and organizations with the information and abilities they need to prosper in a world that is changing quickly due to globalization, climate change and technology disruption, which are changing entire sectors and communities. Fifthly, the integration of all these dimensions helps create a more environmentally friendly product and services which is smart enough to reduce carbon footprint and carry out work more efficiently. Supply chains will always be motivated to design a supply chain and its product and services having long-term viability.

7. Conclusions

UK SCs can take away several learnings from the present study. The overall SC performance in terms of accurate delivery and improved efficiency could be achieved through several I4.0 technologies such as artificial intelligence (Akturk *et al.*, 2022). The greentisation (combining green and digital) of the SCs creates a smart sustainable SC (SmSSC). Though the studies in SCR, SCA, GP, I4.0 and SCA have been in silos, there have been very few, such as those of Abourokbah *et al.* (2023), Tripathi *et al.* (2021), Grant and Clarke (2020) and Menhat *et al.* (2019) to mention a few, those have combined one or more variables. The overarching variables adopted in the present study are a novel contribution to the SC context. The scale's sufficient psychometric qualities were established using SPSS AMOS path modelling. Although the various scales have been integrated, examined and validated in the multisectoral SCs context in the UK, they should be very carefully applied to other industrial sectors in other countries with suitable contextualization via qualitative investigations. Green SC management methods assist firms in enhancing asset utilization, achieving a competitive position and boosting profitability (Fierro and Benitez, 2011; Lee *et al.*, 2012). The model also presents an interesting caption for SC that, while they compete with several SCs a real transformation of SCs needs to be in terms of making a SmSC by integrating several aspects of I4.0. As the SCs are now visualizing themselves to be sustainable need to do so in phases. The first phase focuses on sustainability, improving economic, energy and environmental performance indexes. The next phase should be bringing structural changes integrating I4.0 practice and transforming the operations smart.

7.1 Theoretical implications

The study contributes to the theory in different facets. The study integrates NRBV to contextualize the SmSC for UK SCs. The proposed comprehensive model investigates the effects of I4.0 and green practices on SBP. It also presents avenues for future research in the I4.0 and SBP context. In the extant SC studies similar to the present have not been found. The findings posit that the relationships of I4.0 and SBP are enhanced when variables such as SmSC, SCA and SCR mediate. Even though each has been utilized as an important independent variable in SCs in specific and in other countries in general (Kumar *et al.*, 2022; Sharma *et al.*, 2023a, b). This presents an important takeaway for researchers who want to explore a similar domain. The study carries a cross-section of SC managers on I4.0 practices and further integrates these with the SmSC, SCA, SCR and SBP to provide directions to the managers for realizing the importance of disruptive technologies and their role in achieving sustainability. Finally, the study attempts to unearth the proposed holistic model in UK SCs which has never been done before. It has tested the model among the UK SC managers and SC partners having relevant experience in the domain of I4.0 and SC activities.

7.2 Practical implications

SmSC has the potential to significantly improve sustainable business practices. Businesses may enhance efficiency, eliminate waste and minimize their environmental and social effect by incorporating technology and data analysis into the SC processes. The findings establish a link among the investigated constructs and propose the following implications for the managers:

(1) *Low carbon footprint in logistic operations:* Logistics activities being the most polluting and indispensable activity in the economy, require optimization in terms of the transportation routes, decrease in energy consumption and waste elimination. SmSc has a great role to play in reducing the burden on the environment through environment-friendly warehousing, transportation and distribution. Businesses, for example, may minimize their carbon footprint and lower transportation expenses by employing data analysis to discover the most effective transportation routes and warehousing practices. During the warehousing operations organizations should make all efforts to reuse and recycle the waste being generated in all the intermediate stages. Promotion and usage of energy-efficient systems and adoption of renewable energy sources are the ultimate resolutions for environmental concerns.

(2) *Waste management in SCs:* By being smart businesses will better manage their SC operations by avoiding waste and improving their environmental effect by checking inventory levels and utilizing predictive analytics. Predictive analytics will help provide the organizations with better solutions for managing waste in every SC stage. These smart tools can help limit the consumption of raw materials, decrease

packaging waste and promote recycling and reuse, SmSC will save huge amounts of resources.

(3) *Social responsibility:* SmSC may also encourage social responsibility by sourcing products from ethical and sustainable sources and encouraging fair labour standards across the SC. Businesses may guarantee that their goods are manufactured ethically and sustainably by monitoring suppliers and performing frequent audits.

(4) *Enhanced brand reputation:* Businesses that embrace GP and sustainability can improve their brand reputation, which can lead to higher consumer loyalty and financial success. This can assist in limiting the risks of SC interruptions while also providing a competitive edge in the market. Organizations that are 14,001 certified have a great future for building their brands and enhancing their portfolio.

(5) *Improved transparency and collaboration:* Smart systems allow for following green methods of working that also frequently include collaboration with suppliers, consumers and other stakeholders. This may help strengthen connections and promote openness throughout the SC, allowing risks to be identified and mitigated before they become severe disruptions.

(6) *Increased Innovation:* Adopting GP and smart practices frequently necessitates firms thinking imaginatively about ways to cut waste, enhance energy efficiency and lessen their environmental effect. This can lead to novel solutions that make supply networks more flexible and adaptive to changing market conditions. Firms using the proposed framework will bring in innovative solutions for enhancing the sustainability of their businesses through agile and resilient operations. The knowledge of industry smart practices and investing in these solutions through training programs leading to skill upgradations will lead to a problem-solving environment.

(7) *Innovation with mindfulness:* To enhance the value of the products and services, industries and supply chains need to integrate Industry 5.0 practices and methodologies. Under Industry 5.0, the human aspects are considered for designing the products. The mass customization of the products and services considering the human dimension plays a crucial role in enhancing the value for the customers. However, including the environmental aspects will help identify the recyclability and reuse of the products. This will create a breakthrough in technological advancements. That is, as the product becomes complex, complexity increases concerning its recyclability and the decomposition of the product. Thus, technological advancements need to take care of the reduction, reuse and recycling opportunities in the products designed. This will have a lot of opportunities for boosting circularity in supply chains. Such considerations will help achieve the sustainability development goals (SDG).

Ultimately, SmSC may assist organizations in meeting their sustainability objectives by decreasing environmental impact, preserving resources and encouraging social responsibility across the SC. Businesses may enhance their sustainability performance and gain a competitive edge in an increasingly environmentally concerned marketplace by using SmSC techniques. Decision makers can also consider the importance attained through the ANN approach among the independent constructs while considering the decision variables during the design and implementation of the practices in SCs. It is important to note that disruptive technologies will assist managers in transforming their companies into smart factories by understanding the nexus of embracing I4.0 for long-term company development, such as process innovation, technical applicability, infrastructure development and economic-ecological-social advantages. Furthermore, with the availability of real-time data, intelligent devices and intelligent systems, SC operations may be successfully planned and controlled (Sander, 2016), making the system flexible and efficient.

7.3 Study limitations and future directions

The study has four major limitations. First, it uses a cross-sectional approach to analyze the role of I4.0 on SBP at a certain moment for a generic SC, while, longitudinal studies would bring a better perspective of the underlying relationships. The same respondents could be involved in the longitudinal studies which are although challenging but not impossible. Longitudinal studies will aid in contextualizing the evolution of the phenomenon in UK SCs drawing inferences from the pre and post-studies. Secondly, although the study has been conducted in economies, here UK SCs, could not be generalized to other developed economies since the resources and constraints vary across geographies. There is an urgent need for studies for developing nations such as China Bangladesh, India and Indonesia since they are the nations that need to sustainably utilize their resources for better future-readiness. These studies will help in generalizing the findings as the maturity level in IT integration and I4.0 practices vary across the globe. Thirdly the study has been conducted for a generic SC. Future studies need to focus on the sector-specific study to create a sector-specific model of the IGRASS framework. Fourthly, the future research should emphasis on industry 5.0 and its dimensions while collecting data.

Note

1. https://www.fortunebusinessinsights.com/industry-4-0-market-102375

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Annexure

Table A1. Analysis of the literature review

Construct	Factors studied	Industry	No. of papers	Research method	Sample papers	Definition
Industry 4.0	New technologies like AI, blockchain, cloud, IoT, machine learning, big data, augmented reality, robotics, smart industry, transformation of workers, digital manufacturing, industrial IoT, customization, demand driven supply chain, operational technologies, resources, technology acceptance, leadership, governance, organization culture	Manufacturing, technology, e-commerce, financial, healthcare	56	Theoretical, empirical-primary data, case study/ research,_ mixed methods	Schwab (2016), Ghobakhloo (2018), Kagermann *et al.* (2013), Schumacher *et al.* (2016), Marcucci *et al.* (2021), Rodríguez-Espíndola *et al.* (2022), Cartier *et al.* (2018), Budak *et al.* (2018), Frank *et al.* (2019), Weking *et al.* (2020)	I4.0 is the term for the advanced digital transformation of business models, goods, and value chains
Green practices	Green information system, environmental practices, supplier as an enabler for green, ecological impact	E-commerce, manufacturing, healthcare	20	Theoretical, empirical-primary data, secondary data, experiment data, case study/ research, mixed methods	Chuang and Huang (2018), Green *et al.* (2012), Passetti *et al.* (2018), Dora (2019), Sharma *et al.* (2021), Belhadi *et al.* (2020), Li *et al.* (2020a, b), Luthra *et al.* (2019), Kumar *et al.* (2022), Sharma *et al.* (2023a), Li *et al.* (2020a, b), Yang and Liu (2023)	To lessen the influence on the environment, green supply chain methods include inter-organizational operations such as green procurement, green logistics and green distribution

(*continued*)

Construct	Factors studied	Industry	No. of papers	Research method	Sample papers	Definition
Instrumented smart SC	Infrastructure, human capital, top management support, government policies, technologies, cybersecurity, tracking systems, predictive maintenance, analytics	Financial, education, manufacturing, technology, e-commerce	14	Theoretical, empirical-primary data, secondary data	Spieske and Birkel (2021), Lee *et al.* (2022), Lepore *et al.* (2021), Chonsawat and Sopadang (2020), Kamble *et al.* (2019), Leng *et al.* (2020), Hong *et al.* (2019), Kim *et al.* (2021) Kim *et al.* (2021), Popkova and Zmiyak (2019)	Pervasive data collecting networks that enable real-time visibility will help assist supply chains
Interconnected smart SC	Cross-functional collaboration, digital twin, end-to-end digital integration, vertical value chain integration, horizontal value chain integration, collaborative communication, customer loyalty, wearable devices	Education, e-commerce, manufacturing, financial, healthcare	18	Theoretical, empirical-primary data, secondary data, mixed methods	Ras *et al.* (2017), Miragliotta *et al.* (2018), Saucedo-Martínez *et al.* (2017), Valette E. *et al.* (2021), Belhadi *et al.* (2020), Zhong *et al.* (2017), Xu *et al.* (2018), Zhong *et al.* (2017), Oesterreich and Teuteberg (2016), Li *et al.* (2017), Ralston and Blackhurst (2020), Budak *et al.* (2018)	Collaboration amongst SC partners through the efficient and effective application of IS
Intelligent smart SC	People, perceived usefulness for technology, ease of use of technology, training, consumer preference	Technology, manufacturing, e-commerce, financial, telecom	14	Theoretical, empirical-primary data, secondary data, case study/ research, mixed methods	Gabriel and Pessl (2016), Rodríguez-Espíndola *et al.* (2022), Chonsawat and Sopadang (2020), Sciutti *et al.* (2018)	Using cutting-edge analytics and tools for next-generation optimisation, make decisions about the supply chain

(*continued*)

Table A1.

Table A1.

Construct	Factors studied	Industry	No. of papers	Research method	Sample papers	Definition
Resilience	Technology, Top management support, flexibility, supply and demand management, real time communication, organization culture, information sharing	E-commerce, manufacturing, healthcare	12	Empirical-primary data, experiment data, case study/research, mixed methods	Ramirez-Peña *et al.* (2019), Frederico *et al.* (2021), Ambulkar *et al.* (2015), El Baz and Ruel (2021), Brandon-Jones *et al.* (2014), Hosseini and Ivanov (2019), Appiah *et al.* (2020),Duchek *et al.* (2020), Dubey *et al.* (2021),Behl (2020)	A collaborative strategy for controlling interruptions within a supply chain without affecting its essential operations is called supply chain resilience
Agility	Customer responding capabilities, customer sensing capabilities, market knowledge, customer service, market experience, differentiation, ambiguity tolerance, learning, information sharing capabilities, servitization	Manufacturing, e-commerce, service	8	Empirical-primary data, experiment data, case study/research, mixed methods	Shashi *et al.* (2020), Oztemel and Gursev (2020), Abrahamson *et al.* (2010), Albert (2011)	The idea of flexibility is expanded by agility, which gives flexibility a rapid component. Agility clarifies "how quickly things change"
Sustainable business performance	Technology, big data, supply chain cost, resource availability, resource consumption, green practices, energy saving, waste reduction, economic, environmental, functional, social aspects, organization culture	E-commerce, manufacturing, healthcare	30	Theoretical, empirical-primary data, secondary data, experiment data, case study/research, mixed methods	Lepore *et al.* (2021), Nujoom *et al.* (2019), De Sousa Jabbour *et al.* (2018), Kluczek (2019), Yadav *et al.* (2020), Ramirez-Peña *et al.* (2020), Sindhwani *et al.* (2022), Rossit *et al.* (2019), Ivanov (2020)	Sustainable performance is the harmonization of the environmental, social and financial goals that should be used in the delivery of essential company activities

Source(s): Authors' own work

	GP1	GP2	GP3	GP4	GP5	GP6	GP7	GP8	GP9	SCR1	SCR2	SCR3	SCR4	SCR5	SCR6
GP1															
GP2	0.837														
GP3	0.756	0.832													
GP4	0.756	0.756	0.858												
GP5	0.763	0.771	0.756	0.832											
GP6	0.732	0.77	0.767	0.756	0.844										
GP7	0.706	0.766	0.716	0.783	0.756	0.778									
GP8	0.756	0.756	0.763	0.759	0.602	0.759	0.861								
GP9	0.759	0.759	0.768	0.759	0.602	0.602	0.759	0.891							
SCR1	0.611	0.586	0.607	0.585	0.63	0.552	0.574	0.618	0.613						
SCR2	0.6	0.599	0.605	0.581	0.653	0.591	0.592	0.658	0.644	0.883					
SCR3	0.622	0.626	0.625	0.625	0.673	0.602	0.615	0.666	0.657	0.759	0.886				
SCR4	0.633	0.658	0.617	0.616	0.641	0.603	0.611	0.667	0.651	0.756	0.759	0.886			
SCR5	0.583	0.598	0.569	0.587	0.633	0.606	0.625	0.668	0.633	0.821	0.602	0.759	0.862		
SCR6	0.593	0.622	0.584	0.592	0.664	0.614	0.631	0.674	0.655	0.633	0.633	0.756	0.633	0.875	

Source(s): Authors' own work

Table A2.
Correlation matrix for items of the green practices and Industry 4.0

Table A3.
A comparison between present research and critical articles from literature

Parameters of comparison Year	Present study (P1)	Marinagi *et al.* (2023) (P2) *2023*	Patidar *et al.* (2022) (P3) *2022*	Aheleroff *et al.* (2022) (P4) *2022*	Sharma *et al.* (2023a, b) (P5) *2023*
Theme/title	Can Smart Supply Chain Bring Agility and Resilience for Enhanced Sustainable Business Performance	Resilient Supply Chain 4.0 and the impact of Industry 4.0 technologies on key performance indicators (KPIs) for creating a resilient supply chain	Supply chain resilience and its key performance indicators: an evaluation under Industry 4.0 and Sustainability perspective	Mass personalization in the context of Industry 4.0 and Industry 5.0, with a focus on sustainability and resilience	Green, resilient, agile and sustainable fresh food supply chain enablers: evidence from India
Primary variables studied	Industry 4.0, Green practices, resilience, Agility, Smart Supply chain, Sustainability (IGRASS)	Resilience and Industry 4.0	Resilience, Sustainability	Industry 4.0, Industry 5.0, Sustainability and Resilience	Green, Resilience, Agility, Sustainability
Secondary variables studied	Smart Supply Chain: Intelligent Supply Chain, Instrumented Supply Chain, Interconnected Supply Chain	Industry 4.0 technologies (IoT, CPS, AR, CC, IoS, BDA, AI, DT, BC, IR, AM, flexibility, redundancy, visibility, agility, collaboration, robustness, security, information sharing)	Time-oriented (TO) organizational (OR), Lead time, time to market and risk assessment frequency	Mass personalization Technology-driven approaches Sustainable collaboration between humans, machines and technologies, Industry growth Enabling technologies (e.g. Blockchain, Cobot) RAMI (Reference Architecture Model for Industry) Human Capital 5.0	NA
Context	General supply chains	General Supply chain	General Supply chain	Manufacturing Industry	Fresh food supply chains

(*continued*)

Parameters of comparison Year	Present study (P1)		Marinagi *et al.* (2023) (P2) *2023*	Patidar *et al.* (2022) (P3) *2022*	Aheleroff *et al.* (2022) (P4) *2022*	Sharma *et al.* (2023a, b) (P5) *2023*
Relationships tested	*Structural relationships/ path*	*Results*	NA	NA	NA	NA
	I4.0→ SmSC	Supported				
	I4.0→ → SCA	Not Supported				
	I4.0→ GP	Supported				
	GP → SmSC	Not Supported				
	SmSC → SCA	Supported				
	GP → SCA	Supported				
	SCA → SCR	Supported				
	SCR → SBP	Supported				
	GP → SCR	Supported				
	GP → SBP	Supported				
	I4.0→ SmSC → SCA	Supported				
	GP→ SmSC →SCA	Not supported				
	SmSC → SCA → SCR	Supported				
	GP → SCA → SCR	Supported				
	GP → SCR → SBP	Supported				
Methodology	Structural Equational Modelling (SEM)		Non-systematic literature review	FAHP with sensitivity analysis	Conceptual study	FAHP and ISM
Sample size	234 respondents		NA	NA	NA	18 experts from three fresh food retail companies in India

(continued)

Table A3.

Table A3.

Parameters of comparison Year	Present study (P1)	Marinagi *et al.* (2023) (P2) *2023*	Patidar *et al.* (2022) (P3) *2022*	Aheleroff *et al.* (2022) (P4) *2022*	Sharma *et al.* (2023a, b) (P5) *2023*
Research gap identified	1. Extant literature has not studied Smart Supply Chain with Green, Agility and Resilience for Sustainable Business Performance 2. Smart supply chain is not studied as Intelligent, Instrumented and Interconnected in prior research 3. The relationship between all these variables is not empirically tested earlier 4. Theoretical lens of NRBV is not used earlier to highlight the importance of resources for having a technological infrastructure 5. A holistic theoretical model and the path to achieve sustainable business performance remains void in previous researches	Impact of Industry 4.0 technologies on SCRes constituent elements and the relationship between KPIs and these constituent elements have not been studied	Industry 4.0 technologies and their affect on key performance indicators (KPIs) of a resilient SC on sustainability have not been studied	The study identifies a gap in existing research by emphasizing the need for considering human capabilities, machines and technologies as sustainable collaborators in the context of mass personalization	Paucity on the Conceptualization, mutual interactions and a methodological framework to evaluate the Fresh Food Supply Chains from the perspective of Green, Resilient, Agile and Sustainable enablers

(*continued*)

Parameters of comparison Year	Present study (P1)	Marinagi *et al.* (2023) (P2) *2023*	Patidar *et al.* (2022) (P3) *2022*	Aheleroff *et al.* (2022) (P4) *2022*	Sharma *et al.* (2023a, b) (P5) *2023*
Contribution	1. The variables adopted in the present study are a novel contribution to the SC context 2. Use of mixed-method approach to the contributions of I4.0 in making UK SCs sustainable 3 A holistic research approach amalgamating internal (economic) and external (environmental) facets 4 All the dimensions Instrumented, Interconnected and Intelligent of Smart Supply Chain were studied to establish the contribution of each of these dimensions to SCA.	The study aims to extend current research on how KPIs for creating a resilient supply chain are influenced by Industry 4.0 technologies, providing insights for academics and practitioners interested in Resilient Supply Chain 4.0	Importance of time-oriented criteria and the impact of Industry 4.0 technologies, such as block chain, big data and cyber-physical systems, on enhancing the value of KPIs and fostering economic, environmental and social sustainability	The research proposes a Reference Architecture Model (RAMI 5.0) and emphasizes the role of Human Capital 5.0 in achieving higher sustainability and resilience through mass personalization	Establish interrelationships among GRAS enablers and provides a hierarchical structure towards adopting sustainable practices in fresh food supply chain

(*continued*)

Table A3.

Table A3.

Parameters of comparison Year	Present study (P1)	Marinagi *et al.* (2023) (P2) *2023*	Patidar *et al.* (2022) (P3) *2022*	Aheleroff *et al.* (2022) (P4) *2022*	Sharma *et al.* (2023a, b) (P5) *2023*
Findings	The work empirically reinstates the combined significance of green practices, Industry 4.0, smart supply chain, supply chain agility and supply chain resilience on sustainable business performance The study also uses the ANN approach to determine the relative importance of each significant variable found in SEM analysis. ANN determines the ranking among the significant variables, i.e. supply chain resilience > green practices > Industry 4.0> smart supply chain > supply chain agility presented in descending order	Industry 4.0 technologies can improve KPIs for creating a Resilient Supply Chain 4.0 The paper summarizing the impact of each Industry 4.0 technology on selected KPIs for SCRes	Interplay of identification of the KPIs, the impact of Industry 4.0 technologies and the impact on sustainability	The study presents findings related to the shift from Industry 4.0 to Industry 5.0, and the importance of a human-centric approach in achieving sustainability and resilience	Empirical evidence on Green, Resilient, Agile and Sustainable enablers of Fresh Food Supply Chain and portraying the primary and secondary relations with the variables that make up the whole system
Framework	This work reinforces the integrated model investigating all the building blocks of the proposed IGRASS framework that combines all the constructs dealt with in silos so far in prior literature	The text introduces Resilient Supply Chain 4.0, emphasizing the interoperability of Industry 4.0 with supply chain resilience	Technologies that enhance KPI's value and, in turn, foster economic, environmental and social sustainability of the Supply Chain	The study proposes a Mass Personalization as a Service (MPaaS) model and discusses RAMI 5.0 as a framework for achieving mass personalization	The work provides a theoretical framework that will guide in integrating firms' resources to build capabilities that address sustainability issues and help deliver efficient values to the fresh food supply chain

(continued)

Parameters of comparison Year	Present study (P1)	Marinagi *et al.* (2023) (P2) *2023*	Patidar *et al.* (2022) (P3) *2022*	Aheleroff *et al.* (2022) (P4) *2022*	Sharma *et al.* (2023a, b) (P5) *2023*
Theories	Theoretical underpinning of Natural Resource based View (NRBV) was used as it is an apt theoretical framework for comprehending the interplay of different building blocks of Industry 4.0 and Green practices to achieve sustainable competitive advantage	Industry 4.0, Supply Chain Resilience and Supply Chain Management	NA	The text refers to Industry 4.0 and Industry 5.0 as theoretical frameworks guiding the discussion on mass personalization and sustainability	Resource-based view
Industry	General	General	General	Manufacturing	Fresh foods
Country	UK	Global	Global	Global	India
Citation		Marinagi *et al.* (2023). The Impact of Industry 4.0 Technologies on Key Performance Indicators for a Resilient Supply Chain 4.0. *Sustainability*, *15*(6), 5185	Patidar *et al.* (2022). Supply chain resilience and its key performance indicators: an evaluation under Industry 4.0 and sustainability perspective. *Management of Environmental Quality: An International Journal*, *34*(4), 962–980	Aheleroff *et al.* (2022). Toward sustainability and resilience with Industry 4.0 and Industry 5.0. *Frontiers in Manufacturing Technology*, *2*, 951,643	Sharma *et al.* (2023a). Green, resilient, agile and sustainable fresh food supply chain enablers: Evidence from India. *Annals of operations research*, 1–27

Source(s): Authors' own work

Table A3.