Advances in Consumer Research
https://acr-journal.com/
Volume-3 | Issue-1 | Jan 2026

Original Researcher Article

Technology-Enabled Supply Chain Capabilities and their Impact on Manufacturing Firm Performance: NCA and fsQCA Approach

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ABSTRACT
The high rate of adoption of digital technologies has radically changed the supply chain structure and practices in manufacturing companies. This paper analyzes the impact of technology-enabled supply chain capabilities (TESCCs) on the performance of the manufacturing firms based on the digitalization, servitization, risk management, collaborative innovation, and new technology. Based on the Resource-Based View, Dynamic Capabilities Theory, Technology Acceptance Model (TAM) and the configurational approaches, the study conceptualizes TESCCs as a multidimensional construct that includes digital visibility, integration, agility, collaboration, traceability, and human-technology interaction. In the study, the impact of advanced technologies, including artificial intelligence, blockchain-traceability system, analytics-driven forecasting, redistributed manufacturing, and digital servitization are mentioned as components in improving the resilience of the supply chain, collaborative new product development, and risk management.

The framework also lends credence to human-based adoption and acceptance of technologies as defined using TAM, in the conversion of technological investments into high-quality operational results. Teamwork structures such as sharing resources and collaborative forecasting can reinforce the performance of innovation and responsiveness, whereas the transparency provided by blockchains and the use of AI to support the decision-making process can increase trust, traceability, and mitigate risk. Altogether, these capabilities will lead to sustained competitive advantage, better financial performance, and greater innovation performance in manufacturing companies.

The study takes into consideration the nature of causal complexity and equifinality in producing high performance outcomes because it uses a holistic and a configurational approach which indicates that more than one combination of TESCCs can result in high-performing firms. The suggested conceptualization holds significant theoretical value in that it unites various lenses and comes up with practical implications to manufacturing managers who are interested in the strategic use of digital technologies in order to create resilient, nimble, and performance-based supply chains..

Keywords: Technology-Enabled Supply Chain Capabilities; Manufacturing Firm Performance; Supply Chain Digitalization; Dynamic Capabilities; Risk Management; Artificial Intelligence in Logistics; Blockchain-Based Traceability; Supply Chain Resilience.

1. INTRODUCTION:

The manufacturing companies are increasingly using the enhanced digital tools over the past few years with the aim of increasing the capacity of the supply chains and maintaining the competitive advantage in the dynamic and unpredictable business environments. The development of technologies, such as big data analytics, cloud computing, artificial intelligence, Internet of Things (IoT) and enterprise information systems, has transformed the way of planning, coordination, and execution of the process of supply chains radically (Dubey et al, 2021). Supply chain capabilities that are facilitated by technology, including visibility, integration, agility, responsiveness, and resilience, have become decisive factors on the operational and financial performances in manufacturing companies (Ivanov et al, 2019). Digital technologies allow sharing information in real-time and making decisions that can predict the future, as well as coordination across sectors, which increases the accuracy of demand forecasting, inventory management, and reliability in deliveries (Wamba et al, 2020). Consequently, companies that are able to develop and implement these functions are in a better place to react to market instabilities, supply-related shocks, and fluctuating customer demands.

Although the topic of performance implications of technology-enabled supply chain capabilities for firm improvement is becoming more popular among scholars, the empirical data is still incomplete and inconclusive. Although some studies find positive linear correlations between digital technologies and manufacturing firm performance (Bag et al, 2021), other researchers are of the opinion that technology investments are not sufficient to ensure high-level results alone, they need to be complemented by other organizational and relationship capabilities (Zhu et al, 2018; Gunasekaran et al, 2017). This implies that supply chain capabilities can act complex, non-linear and configurational, but not through disjointed net effects. These methods including those that assume that various combinations of technology-enabled supply chain capabilities can lead to similar degrees of high firm performance as well as the fact that the lack of some capabilities might not actually result in the reverse can be used (Fiss, 2011).

In order to fill these gaps, this paper uses a configurational approach that combines Necessary Condition Analysis (NCA) and fuzzy-set Qualitative Comparative Analysis (FsQCA) NCA allows finding the presence of technology-enabled supply chain capabilities to improve manufacturing firm performance to reach high firm performance at a minimum level (Dul, 2016), whereas FsQCA reveals the existence of various settings of capabilities to attain high outcomes (Ragin, 2008) Through these two complementary methods, the research addresses the recent demands of methodological pluralism and more in-depth causal explanations of the research in the field of supply chain management (Khan et al, 2022) In order to detect these elements, there is a need to utilize methodological frameworks that are able to detect the necessary technologies as well as combinations of supply chain capabilities known as adequate configurations Necessary Condition Analysis and Fuzzy-set Qualitative Comparative Analysis and, give more insights.

This paper combines the two approaches to determine the elements that should be in place Technology-Enabled Supply Chain Capabilities and their Effect on the performance of manufacturing firms. This dual perspective can offer useful insights, which policymakers, managers, and stakeholders in the manufacturing industry in India can use to get a clear idea of Supply Chain Capabilities to improve manufacturing firm performance.

2. LITERATURE REVIEW

2.1 Theoretical background

Resource-Based View (RBV), Dynamic Capabilities Theory (DCT), and Configurational Theory can be applied to understand the influence of this technology-enabled supply chain capabilities on the manufacturing performance of firms According to RBV, the digital technologies that can be considered valuable strategic resources to improve information processing and coordination among the supply chain partners are enterprise systems, big data analytics, cloud computing, and Internet of Things (IoT) infrastructures (Wamba et al, 2020). Unless integrated into firm-specific capabilities of supply chain visibility, integration, agility, and responsiveness, these technologies do not necessarily result in better performance, which transform digital resources into operational and financial performance (Srinivasan and Swink, 2018). Supply chain capabilities based on technological means serve as dynamic features to share data in real-time, make predictive decisions, and collaborate to react to demand variability and supply shock and improve the stability and sustainability of company operations (Dubey et al, 2021). The Configurational Theory also hypothesizes that the performances of firms come as complex combinations of mutually dependent conditions, and not as net effects (Fiss, 2011). Similar high-performance can be obtained by different forms of technology-enabled supply chain capabilities for manufacturing firm performance, and lack of some capabilities does not necessarily imply bad performance, which is a sign of causal asymmetry (Khan et al, 2022). This theoretical orientation favors the use of configurational approaches including the Necessary Condition Analysis and fuzzy-set Qualitative Comparative Analysis that are useful in the description of causal complexity to the connection between technology-enabled supply chain capabilities and firm performance (Dul, 2016).

2.2 Organizational Factors

The organizational factors are very important in allowing firms to make good use and exploit the capabilities of technology-enabled supply chains. Top management support, organizational culture, skills of employees, and cross-functional coordination are the factors that determine the adoption, integration, and transformation of digital technologies into the performance-enhancing abilities (Gunasekaran et al, 2017). Strong commitment to leadership offers strategic guidance and resources allocation on digital supply chain efforts, whereas the welcoming organizational culture encourages receptivity to changes, trial and error, and the alternative basis of decision-making (Wamba et al, 2020). The other major organizational contributor within the effectiveness of technology-based supply chains is human capital. The digital capabilities, analytical ability, and supply chain of the employees determine the capability of a firm to derive value out of advanced technological tools like big data analytics and enterprise systems (Akter et al, 2016). Organizational factors assist with continuous sensing, learning, and reconfiguring processes necessitated by turbulent supply chain environments basing on dynamic capabilities perspective (Teece, 2007). Organizational structures that are flexible and closely aligned are more likely to adapt to the digital strategies of supply chains in response to the change in the environment and achieve better operational efficiency and firm performance (Queiroz et al, 2020).

2.3 Technological Factors

The focus of the technological factors is the technological-enabled supply chain capabilities and their impacts on the firm performance. The availability and compatibility of digital infrastructure, quality of data, system integration and complexity of technology are some of the key technological factors The innovative technologies used to enable real-time sharing of information, predictive decision-making, and coordination with their supply chain partners include advanced technologies like enterprise resource planning systems, big data analytics, cloud computing, artificial intelligence, and Internet of Things (IoT) platforms (Queiroz et al, 2020). The extent of integration of the technologies defines its effectiveness in improving supply chain visibility, agility, manufacturing firm performance and responsiveness. The interoperability and technology preparedness play a major role in determining the success of firms in deriving benefit out of the digital investments. On the other hand, high technological complexity and inadequate data quality may prevent adoption and limit performance gains, especially in manufacturing contexts where the legacy systems and fragmented IT infrastructure are common (Dubey et al, 2019). Regarding the dynamics capabilities, technological aspects are favorable to enable ongoing sensing and reconfiguring of supply chain processes via providing analytical-driven insights and real-time monitoring (Ivanov et al, 2019). Companies that have developed digital infrastructure are in a better place to react on unstable markets, supply, and emerging customer demands, thus enhancing resilience and firm performance (Wamba et al, 2020). In general, the technological aspects are the ones that dictate not only the use of digital tools but also the level of how much the technology-enabled supply chain capabilities are converted into lasting manufacturing performance benefits.

2.4 External Factors

There is a major impact by the external factors on the adoptability and effectiveness of the technology-enabled supply chain capabilities and their effect on the firm performance. The market turbulence, the competitiveness, the regulatory pressure, supplier relations and customer relations are key among the external factors. The rising market volatility and competitive pressures are forcing manufacturing companies to use digital technologies to improve their supply chain agility, responsiveness, and cost-efficiency (Dubey et al, 2021). Companies in very competitive contexts have higher chances of investing in the innovative supply chain technologies to enhance their services and deliver better performance results. Digital adoption can be accelerated through industry standards that help in lessening the uncertainty and some degree of legitimacy to technology-enabled practices of supply chain especially in the emerging economies. The digital technologies also have performance moderating effects that are further mediated by inter-organizational relations with suppliers and customers Intense relationship-based networks and partnering make it much easier to share information and integrate technology and collaborate in solving problems across the supply chains networks (Wieland and Wallenburg, 2013). This kind of partnership allows companies to match the digital efforts with the capabilities of partners, which enhances the visibility of the supply chain, its resilience, and the overall manufacturing performance of the company (Ivanov et al, 2019). Together, these exogenous forces influence the environment within which technology-based supply chain capabilities are created and establish their usefulness in creating long-term performance benefits.

2.5 Financial Performance

Financial performance is a measure of how a firm can effectively use its resources in order to realize profitability, growth as well as long term economic sustainability. Financial performance (ROA, ROI, sales growth, cost reduction, and profitability margins) are used as indicators to measure financial performance in supply chain research (Richard et al, 2009). The supply chain capabilities provided by technology are instrumental in the financial performance due to their ability to increase the cost efficiency, asset utilization, and revenue through the increased coordination and decision-making within the supply chain (Wamba et al, 2020). Big data analytics, enterprise systems, and real-time information platforms are digital technologies that help firms to optimize stocks, minimize operational waste, and enhance the accuracy of demand forecasting, which results in lower operational and profit margins (Dubey et al, 2019). Moreover, digital technologies provide improved supply chain visibility and responsiveness that enable companies to match the supply with demand in the market more effectively, which in turn positively influences the sales growth and retaining customers, which positively impacts the financial performance (Gunasekaran et al, 2017).

Companies that invest in supply chain capabilities facilitated by technology can better alleviate the losses associated with disruption and maintain the revenue streams during uncertain conditions and ensure stable and higher financial performance over time (Khan et al, 2022). Financial performance is an important outcome variable which measures the value of technology-based supply chain initiatives in manufacturing companies in economic terms.

2.6 Innovation Performance

Innovation performance indicates how a firm is able to create and adopt new or better products, processes and technologies that improve competitiveness and future growth In the manufacturing and supply chain, innovation performance is often gauged by indicators such as product innovation, process innovation, speed of innovation and successful commercialization of the new idea (Crossan and Apaydin, 2010) The supply chain capabilities that become possible with the help of technology are instrumental in improving performance in terms of innovation because they have the power to share knowledge, collaborate, and learn at the organizational and inter-organizational levels (Chen et al, 2019).

Big data analytics, cloud technologies, and integrated information systems are the digital technologies that allow firms to have real-time information regarding the market and operations and make decisions in relation to experimental and data-driven innovation (Wamba et al, 2020). A better supply chain visibility and integration enable firms to work closely with suppliers and customers in developing new products, and making the production more efficient. A dynamic capabilities approach shows that the performance of innovation is tied to how well a firm is able to perceive the technological opportunities, capture new market demands as well as reconstruct the resources to help it continue innovating (Teece, 2007). The capabilities of the supply chain, facilitated by technology, enhance these dynamic processes by facilitating the swift flow of information, highly flexible coordination, and the ability to reconfigure the supply chain on the fly, which are prerequisites of innovation maintenance in uncertain and competitive environments (Khan et al, 2022).

2.7 Re distributed manufacturing and Technology-Enabled Supply Chain Capabilities

Redistributed manufacturing is the process of decentralizing production processes to smaller and geographically spread facilities, usually with proximity (in end market, supplier, or customer) to them. With the help of such digital technologies as additive manufacturing, cloud-based production planning, Internet of Things (IoT), and cyber-physical systems, redistributed manufacturing disrupts the patterns of traditional centralized manufacturing, and enhances flexibility, responsiveness, and customization. The consequences of this paradigm shift on technology-enabled supply chain capabilities and firm performance are enormous. The redistributed manufacturing networks coordination and administration is essential due to the capabilities of the supply chain that can be realized with the help of technology. Digital technologies allow viewing the production process and logistics in real-time, integrating data and synchronizing it with distributed nodes (Ivanov et al, 2019). Increased supply chain visibility and integration enable companies to operate at an appropriate inventory management, lead-time minimization, and production responsiveness to localized demand, subsequently enhancing operational efficiency and service quality (Queiroz et al, 2020). Strategically, redistributed manufacturing enhances the performance of firms through greater supply chain agility and resiliency. Redistributed production enabled through the close integration of production and consumption aids in innovation and customization, which adds to better customer satisfaction and long-term competitive advantage (Khan et al, 2022). Coherence of the redistributed manufacturing to the technological supply chain competencies promotes the capability of firms to realize high operational, innovation, and financial performance within the dynamic environments.

H1: Redistributed manufacturing has a significant positive influence on the manufacturing firm performance.

2.8 Risk management & competitive advantage for Technology-Enabled Supply Chain Capabilities

The ability of supply chains brought about by technology is critical towards reinforcing risk management and creating competitive advantage which will improve performance of firms. The use of advanced digital technologies like analytics of big data, real-time information systems, and Internet of Things (IoT) platforms increase the supply chain visibility and allow forecasting possible disruptions early, which allows companies to respond to them proactively (Dubey et al, 2021). The supply chain capabilities due to technology allow predictive and responsive actions to uncertainty. Forecasting based on analytics, digital twins, and simulation technologies enable companies to evaluate disruption scenarios and real-time adjust the structure of the supply chain to increase the level of resilience and operational continuity (Ivanov et al, 2019). Digital supply chain capabilities therefore lead to effective risk management that is a strategic asset and not a defensive feature. In addition to risk mitigation, the capabilities of technology-based supply chains are also a source of competitive advantage because they allow better responsiveness, flexibility, and value creation. Companies that use digital technologies to connect supply chain participants and streamline information processes are able to react faster to changes in the market and the needs of customers as compared to those who use the traditional systems (Wamba et al, 2020).

H2: Risk management & competitive advantage has a significant positive influence on the manufacturing firm performance

2.9 Collaborative new product development with forecast & resource sharing for Technology-Enabled Supply Chain Capabilities

Collaborative new product development (NPD) entails collective activities between the internal departments and external partners, including suppliers and customers, to design, develop and launch new products at an optimal level. With the facilitation of technology-enabled supply chain, collaborative NPD is able to boost firm performance remarkably by combining forecasting, resource sharing, and information exchange throughout the supply chain (Dubey et al, 2019). Digital technologies, including cloud-based applications, enterprise solutions, big data analytics, and IoT, make it possible to share demand forecasts, production capacity and resource availability in real-time, which enhances coordination and development lead times are decreased (Queiroz et al, 2020). Collaborative NPD forecasting enables the companies to predict what is required in the market and the timing of product development reconciliation with product production and distribution. The sharing of resources also increases efficiency as it becomes possible to access partner capabilities, equipment, and knowledge and solve problems more quickly and in a cost-effective manner (Bag et al, 2021). This partnering model enhances the supply chain capabilities that are technology-enhanced through the development of agility, flexibility, and resilience in the product development process.

Regarding its performance, companies that use technology to facilitate collaborative NPD gain in terms of shorter time-to-market, better product quality, and customer satisfaction, which are all competitive advantages and financial outcomes (Khan et al, 2022; Ivanov et al, 2019). Furthermore, the combination of predicting and common assets gives rise to dynamic capabilities that enable companies to feel the market market, reorganize production and supply chain, and never stop innovating, which keeps the companies growing in the long term and still profitable (Teece, 2007). The example of collaborative NPD together with forecasting and sharing resources is the way to demonstrate how technology-enabled supply chain capabilities can be utilized to improve operational and strategic results in manufacturing setting.

H3: Collaborative new product development with forecast & resource sharing has a significant positive influence on the manufacturing firm performance

2.10 Manufacturing servitization via TAM for Technology-Enabled Supply Chain Capabilities

Manufacturing servitization is the strategic shift toward manufacturing firms to focus on offering product-centric service and instead providing product-service systems with the support of digital technologies. The supply chain capabilities enabled by technology are the key to servitization, as it helps share information, integrate customers and provide services throughout the supply chain (Kohtamaki et al, 2019). Technology Acceptance Model (TAM) can be a helpful theoretical framework to understand how digital technologies that aid servitization, including the IoT-enabled monitoring, analytics service, and digital service portals, are adopted and used by employees, partners, and customers (Venkatesh and Basaez, 2008). In a manufacturing setting, digital service-related technologies, which can be perceived to add value to operational efficiency, predictive maintenance, and customer responsiveness, are adopted and utilized, which contributes to improving technology-enabled supply chain capabilities, manufacturing firm performance including visibility, coordination, and response. The ease of use also minimizes resistance to change among the supply chain participants so that service-oriented processes can be easily integrated in production, logistics, and after sales activities. Regarding performance, the manufacturing servitization with the high levels of technology acceptance help to achieve better performance of the firm due to the development of stable service revenues, customer satisfaction, and long-term relational value. (Raddats et al, 2019). The mediating factors are technology-enabled supply chain capabilities which can provide real-time service delivery, data-driven decision-making and co-create value with customers continuously. By including TAM in the servitizationperformance association, it is reasonable to indicate the significance of human and organizational approval of the digital technologies in transforming the servitization plans into sustainable competitive edge and high-quality firm performance

H4: *Manufacturing servitization via TAM* has a significant positive influence on the manufacturing firm performance

2.11 Human computer interaction framework for AI in logistics and adoption for Technology-Enabled Supply Chain Capabilities

The HCI models are vital in the incorporation of artificial intelligence (AI) in logistics processes and to increase the ability of technology-based supply chains and performance of firms. HCI is concerned with user-friendly systems that help to ensure the active communication between the human operator and AI-based systems, like predictive analytics, autonomous vehicles, and smart warehouse management systems. An efficient HCI makes AI outputs readable, practical, and consistent with human decision-making, which must be a priority in enhancing the efficiency of operations, minimizing mistakes, and providing ways to act in time. AI-enhanced decision-making in logistics must have smooth coordination between machines and human beings HCI frameworks cannot be avoided in designing interfaces, predictive insights visualization, and feedback to improve the quality of decisions, lower cognitive load, and resource use. AI uses in conjunction with human experience allow companies to improve forecasting, aircraft routes, and resources of the supply chain are reallocated dynamically, which contributes to the enhancement of technology-based capabilities (eg, agility, responsiveness, and resilience) (Queiroz et al, 2020). Regarding performance, HCI-based AI logistics systems have a positive effect on firm performance, that is, they allow making decisions quicker and based on data, decrease operational expenses, and enhance the quality of services (Wamba et al, 2020).

H5: *Human computer interaction framework for AI in logistics* has a significant positive influence on the manufacturing firm performance

2.12 Supply chain improvement in manufacturing sector

Globalization, digitalization and the need to be resilient and sustainable have led manufacturing industry to pay more attention to supply chain improvement. The strategies that should be used to improve the supply chain are cost efficiency, flexibility of operations, visibility, collaboration, and risk mitigation (Ivanov and Dolgui, 2021). The manufacturing sector has attained an amazing degree of enhancement in its supply networks by the ongoing advancement of novel innovations such as the Internet of Things (IoT), big data analysis, blockchain, and artificial intelligence. (AI) that can supply a real-time monitoring network, predictability, and automation (Queiroz et al, 2022) Supply chain is being enhanced in lieu of the digital transformation IoT and AI have the potential to enhance the accuracy of demand prediction, production planning and optimization of transportation, lower lead times, and become more receptive to the changes of the market environment (Li et al, 2023) By ensuring the security and impossibility of altering the transactions, blockchain enhances the levels of transparency and confidence within the network of the supply chains, which is particularly helpful in the industries with a high degree of quality (Saberi et al, 2019). In addition, the cloud-based systems allow partners to work together and share resources, which improves integration and agility (Kohtamaki et al, 2020). Research recommends that digital twins, multi-sourcing, and distributed manufacturing are digital and adaptive strategies that should be more resilient and provide a long-term competitive edge (Liu et al, 2022).

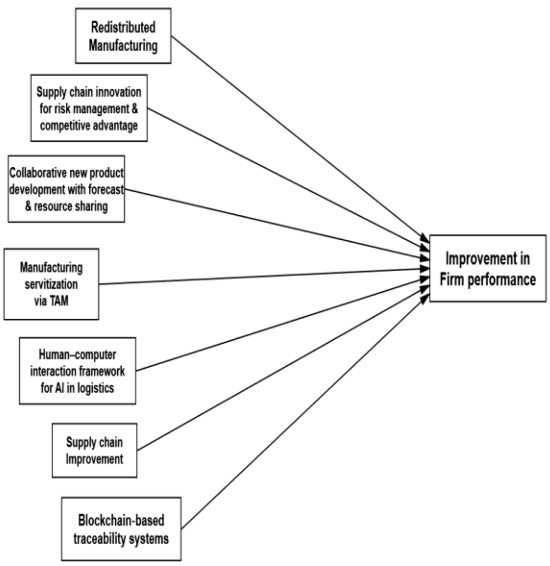
H6: *Supply chain improvement in manufacturing sector* has a significant positive influence on the manufacturing firm performance.

2.13 Blockchain based traceability system and adoption for Technology-Enabled Supply Chain Capabilities

Traceability systems that are based on blockchain have become one of the technology-enabled capabilities that have impacted supply chain transparency, security, and accountability. A blockchain can offer products, components, and transactions visibility in end to end supply chain, by offering a decentralized and immutable ledger that enables firms to monitor products, components, and transactions throughout the supply chain to the end-user. Further interoperability of blockchain and the current digital supply chain. technologies, including IoT sensors and enterprise resource planning systems, enhances the capabilities of technologies that are vital to enhancement of operational and strategic performance, including information sharing, coordination, and real-time decision-making (Dubey et al, 2021). Blockchain traceability systems help in the risk management of reducing the chances of fraud, counterfeiting and mistakes in operation of the logistics and procurement. Blockchain offers the supply chain partners transparency and security, which boosts trust and compliance with the rules and sustainability requirements, and these factors positively impact the reputation of firms and their competitive advantage In addition, companies using blockchain to track their products can streamline their inventory and minimize recall expenses and increase their responsiveness to market and demand changes, with better financial and operational results. The resourcefulness of blockchain-based traceability systems with the rest of the technology-facilitated supply chain competencies therefore enable a high level of performance of firms in terms of efficiency, agility, resilience, and sustainability throughout the supply network.

H7: Blockchain based traceability system has a significant positive influence on the manufacturing firm performance.

Figure 1: Conceptual model for improvement factor effecting Firm Performance



Methodology

3.1 Research objective

In this paper, the identified factors are explored in the light of needed and various factors of technology-based supply chain capabilities and how it affects the performance of manufacturing firms in India through manufacturing firms. It also attempted to determine the optimal settings of the chosen antecedents with the highest influence on adoption of technology-enabled supply chain capabilities of the firms. The research has five antecedents that are both obtained during the literature review and the discussions with the experts in the industry. The antecedents to focus on during the analysis include redistributed manufacturing, supply chain innovation to address risk management and competitive advantage, manufacturing servitization through TAM, human-computer interaction framework to use AI in the supply chain, supply chain enhancement and blockchain based traceability system The research trial on the chosen antecedents with reference to their relative significance on the basis of necessary and sufficient conditions to adopt the technology-enabled supply chain capabilities by the manufacturing companies in India. A conceptual structural framework was proposed and tested based on a SEM-PLS, NCA and FsQCA strategy with adoption of technology-enabled supply chain capabilities as the dependent variable and the chosen antecedents as the independent variables.

Data type and sampling technique

Data was gathered from 405 top executives in the manufacturing industry located in the NCR region of India. The sample of respondents was based on their exposure and experience regarding the technology-enabled supply chain capabilities that were implemented by the firms over the last several years. To gather the responses, the interview schedule approach was embraced. The researcher noted down the responses in the personal discussions with the chosen industry executives. To gather the responses, a judgmental sampling method, non-probability method, was used The process of selecting the respondents began with selection of the industries, the top performing companies in the chosen industry, information was sought out on the websites of the firms and requests were sent to the HR managers through email where short discussions could be made with the research purpose Inquiries were initiated to commence the discussion regarding the respondents' awareness of the diverse technology-enabled supply chain capabilities adopted in manufacturing, their involvement in the implementation of innovations within the firms, and their understanding of technology-enabled supply chain capabilities. The final data analysis to be completed was the 405 complete responses that were gathered based on the six months period (July 2025 to Sep 2025) of time to help complete the research objectives.. They were evaluated on a 7-point scale ranging from strongly disagree to strongly agree, including the options of disagree, slightly disagree, cannot say, and somewhat agree The sample size of 405 is considered representative as it satisfies the criterion of being ten times the number of statements included in the structural model qiven by Nunnally, J C, and Bernstein, I H

Scale development and questionnaire design

The research instrument that was used in the study was created in four phases. The stage one began with determining the various antecedents (in the conceptual framework) based on the review of the detailed literature and the most important items and statements used to measure the antecedents. The draft questionnaire has been developed based on the comprehensive literature review and this has also been discussed with the experts in the industry to ascertain that the research instrument will be content valid. In the second round, the questionnaire was revised based on the suggestions provided by the four senior industry experts. The second phase ensures the content validity of the questionnaire, having been thoroughly reviewed in accordance with expert recommendations. Conduct the third step by assessing face validity with a pilot poll involving 52 industry executives. The pilot survey findings were analyzed for reliability, item duplication, language consistency, and descriptive analysis of the received replies, among other factors. The modified questionnaire was utilized in the final data collection from the respondents.

Statistical methods

The research objectives were met by using the different statistical techniques in the analysis of the responses collected. The sample demographics are reported in the frequency distribution. Cronbach alpha was used to test the internal consistency of the antecedents incorporated in the measurement scale, and the adoption of technology-enabled supply chain capabilities SEM-PLS method was adopted to analyze the structural model through SmartPLS. It was by the use of the NCA method that the required and adequate condition of the antecedents that were included in the model was obtained Lastly, the FsQCA method was used to verify the various forms in the modeling of the technology enabled supply chains adopted by the manufacturing firms in India. The method of NCA and FsQCA has been used because of the fact that the description of various factors included in the definition of the adoption of the technology-enabled supply chain capabilities and their impact on manufacturing firm performance.

Data analysis and interpretation

This section summarizes the conclusions and insights derived from the statistical analysis employed to achieve the research objective. The analysis has been performed on the initial set of responses obtained from individuals working at various selected manufacturing organizations in India who participated in the survey Section 4.1 contains the demographic data of the employees who participated in the survey Section 4.2 outlines the results of several statistical assumptions examined for the primary responses obtained from the survey, encompassing assessments of internal consistency reliability, construct validity, item multicollinearity, and common method bias Section 4.3 gives the results of the PLS-SEM approach utilized to evaluate the proposed structural model, following the NCA method, to identify the antecedents that fulfill the roles of requirement and sufficiency in the adoption of technology-enabled supply chain capabilities within enterprises. The study report finishes by detailing the established roles of the selected antecedents in the adoption of technology-enabled supply chain capabilities by manufacturing firms in India.

Sample demographics

The initial responses were obtained among the 405 senior industry executive who have over 5 years of experience working in manufacturing companies and understands the widespread innovations taken by firms over the past years. The assumption is that the sample represents the population and to be able to establish valid conclusions, the response was gathered among the industry executives of varying demographics Table 1 illustrates the frequency distribution of those customers who were involved in survey

Table1: Demographic attributes

Demographic profile	**Sub category**	**Frequency (%)**
Gender	Male Female	258 64.3 % 147 35.7 %
Work Experience	Less than 8 Years 8 to 13 Years 14 to 20+ Years	180 44.4 % 155 38.6 % 70 17.2 %
Age- Group	Less than 30 Years 31 to 35 Years 36 to 45 Years Above 46 Years	129 31.8 % 154 38.3 % 86 20. 8 % 37 9.1 %
Designation	Junior Managers Middle Managers Senior Managers	106 26.1 % 180 44.9 % 119 29.1 %
Industry	Automobile Pharmaceutical Textile Electronics Wire & Cables	84 23.6 % 80 18.7 % 79 18.4 % 85 19.4 % 77 19.9 %

The data in Table 1 indicate that out of 405 industry executives associated with manufacturing enterprises in India, 258 (64.3%) participated in the survey, including 147 (35.7%) males and females, respectively. The findings indicate that 180 (44.4%) has fewer than 8 years of work experience, 180 (44.4%) have 8 to 13 years of experience, and 155 (38.6%) executives have between 14 and beyond 20 years of experience Seventy respondents (17.2%) are under 30 years of age, 129 respondents (31.8%) are aged between 31 and 35 years, and 154 executives are aged between 36 and 45 years Regarding designation, 106 respondents (26.2%) hold junior manager positions, 180 respondents (44.9%) are classified as middle managers, and 119 respondents (29.1%) are part of senior management within the firms Ultimately, the results indicate that the data were collected from executives in manufacturing firms across five sectors: Automobile (23.6%), Pharmaceutical (18.7%), Textile (18.4%), Electronics (19.4%), and Wire and Cables (19.9%).

4.2 Reliability and validity analysis

The research article encompassed various aspects inside the research instrument (‘*redistributed manufacturing’*, ‘*supply chain innovation for risk management and competitive advantage’, ‘manufacturing servitization via TAM’, ‘human-computer interaction framework for AI in logistics’, ‘supply chain improvement and blockchain based traceability system’)* as the independent factors influencing the adoption of technology-enabled supply chain capabilities by India's manufacturing firms. The instrument quality was considered and then hypothesis was tested and results reached. The Cronbach alpha coefficient was employed to assess the internal consistency of the items and the reliability of the antecedents chosen within the research instruments. The application of the CFA approach is intended to determine the construct validity of the instrument. Additionally, item multicollinearity is examined through the variance inflation factor (VIF), and the presence of common method bias is assessed using both the Harman single factor test and the marker variable approach.

Reliability analysis

Cronbach’s alpha was used to test the reliability of the research instrument and it must be higher than 0.7 in each of the scales constructs. An alpha of 0.7 indicates a significant link among the pieces inside a construct Table 2 delineates the results of the reliability analysis. The findings reveal that the various constructs that were incorporated into the research tool meet the Cronbach alpha requirement of above 0.7 *(Redistributed manufacturing=0.884, Collaborative new product development with forecast & resource sharing =0.898, = Human-computer interaction framework for AI in logistics 0.912, Improvement in Firm performance =0.897, Supply Chain Improvement =0.867, Blockchain-based traceability =0.854)* Consequently, the research instruments employed in the study affirm the existence of consistent reliability.

Construct validity

The CFA approach was also used to test the construct validity. Convergent validity of the measurement scale that comprised of variables of the adoption of technology-enabled supply chain was analyzed in terms of construct loadings of the items applied in the research, composite reliability and average variance extracted estimates of each construct in the scale. To establish the convergent validity of the measuring scale, the construct loadings for each item must above 0.7, and the Composite Reliability (CR) and Average Variance Extracted (AVE) for each construct should surpass 0.7 and 0.5, respectively (Hair et al, 2010). The discriminant validation of the measurement scale that measures the antecedents that affect the adoption of open AI of manufacturing firms was done via the use of the HTMT ratio and the Fornell Larcker criteria The anticipated square root of the Average Variance Extracted (AVE) for each construct should exceed the correlation of that construct with other constructs in the scale, and the ratio of the two constructs included in the scale should be below 0.85 in the Heterotrait-Monotrait (HTMT) ratio (Fornell, C, & Larcker, D F, 1981). Additionally, the collinearity of items in the scale was assessed using the VIF estimate, which is expected to be below 3 Tables 3, 4, and 5 present the findings of the Confirmatory Factor. Analysis conducted to evaluate the concept validity, encompassing both convergent and discriminant validity, of the employed measuring instrument.

Table 2 shows that the items used to measure the constructs incorporated in the measurement scale were identified to have loadings of greater than 07, CR and AVE are greater than 0.7 and 0.5 each, respectively, of the included constructs in the scale (Redistributed Manufacturing: CR=0.883, AVE=0.558, Collaborative new product development with: CR =0.898, AVE=0.596, Human-computer interaction framework for AI in logistics: CR=0.854,

The data indicate the presence of convergent validity in the measurement scale Table 4 presents the results of the HTMT ratio concerning the discriminant validity of the measuring scale.

The finding suggests that the existence of discriminant validity in the estimated values in the matrix was all below 0.85 Table 4 was the report of the results of the Fornell Larcker criteria. The findings show that the square root of the AVE of every construct in the matrix (first value in each column) was obtained to be larger than correlation estimates of every construct in the scale Therefore, the findings indicated the existence of discriminant validity of the scale of measurements. The VIF estimate of all the items that were utilized in the instruments in order to determine the scale of the instruments also reported a value of less than the required value of 3 and this indicates that the scale has no collinearity issues.

Statistical fit indices

Two statistical fitness indices such as-SRMR and NFI index are used to test the statistical fitness of the measurement model that is contained in the paper. The

SRMR of the estimated measurement model is estimated to be 0.038 and this is below the needed value of 0.08 and the NFI index is estimated to be 0.906, compared to the minimum value of 0.8 In this manner, the measurement model is statistically found satisfactory The second part dwells upon hypothesis testing.

Table 2: Convergent validity reliability, and multicollinearity

	Construct	**Constru**	**Mean (SD**	**Cronbach**	**Com**	**Ave**	**VIF**
R	Redistributed Manufacturing	0.7	4.9	0.884	0.883	0.558	2.31
R		0.8	4.9				1.96
R		0.7	4.9				1.91
R		0.7	4.8				1.85
R		0.7	4.9				2.03
R		0.6	4.9				1.95
C	Collaborative new product development with	0.7	4.6	0.898	0.898	0.596	1.95
C		0.8	4.7				2.31
C		0.8	4.7				2.11
C		0.6	4.7				2.04
C		0.8	4.6				2.37
C		0.7	4.6				2.06
H	Human-computer interaction framewor	0.8	4.5	0.912	0.911	0.720	3.19
H		0.8	4.5				2.78
H		0.8	4.6				2.38
H		0.7	4.5				3.11
IF	Improvement in Firm performan	0.7	4.8	0.897	0.897	0.637	2.15
IF		0.7	4.7				2.38
IF		0.8	4.7				2.56
IF		0.7	4.7				2.12
IF		0.8	4.7				2.22
S	Supply Chain Improvem	0.7	4.8	0.867	0.867	0.619	2.10
S		0.7	4.9				2.11
S		0.7	4.8				1.94
S		0.7	4.7				2.17
B	Blockchain-based traceabilit	0.6	4.9	0.854	0.854	0.596	1.84
B		0.8	5.1				1.91
B		0.7	4.9				2.04
B		0.8	5.1				2.08

Table 3: HTMT ratio for discriminant validity

	RDM	CNPD	HCL	IFP	SCI	BBTS
Redistributed Manufacturing (RDM)						
Collaborative new product development with forecast & resource sharing (CNPD)	0.647					
Human-computer interaction framework for AI in logistics (HCI)	0.726	0.645				
Improvement in Firm performance (IFP)	0.643	0.580	0.648			
Supply Chain Improvement (SCI)	0.761	0.630	0.805	0.684		
Blockchain-based traceability system (BBTS)	0.674	0.592	0.716	0.628	0.820	

Table 4: Fornell Larcker Criteria for discriminant validity

	RDM	CNPD	HCL	IFP	SCI	BBTS
Redistributed Manufacturing (RDM)	0.747					
Collaborative new product development with forecast & resource sharing (CNPD)	0.647	0.772				
Human-computer interaction framework for AI in logistics (HCI)	0.726	0.644	0.848			

Improvement in Firm performance (IFP)	0.647	0.583	0.649	0.798		
Supply Chain Improvement (SCI)	0.760	0.629	0.805	0.684	0.787	
Blockchain-based traceability system (BBTS)	0.672	0.591	0.712	0.630	0.816	0.722

Table 5: Statistical Fitness Index

Fitness Index	Saturated model	Estimated model
SRMR	0.038	0.038
D ULS	0.627	0.627
D G	0.314	0.314
Chi-square	640.788	640.788
NFI	0.918	0.918

PLS SEM with NCA approach

The study aims to analyze the structural model that illustrates the impact of many chosen antecedents on the adoption of technology-enabled supply chains by manufacturing enterprises in India. The paper incorporated seven distinct variables in the structural model, including (*redistributed manufacturing, supply chain innovation for risk management and competitive advantage, manufacturing servitization via TAM, human-computer interaction framework for AI in logistics, supply chain improvement, blockchain based traceability system and improvement in firm performance*) as the independent factors influencing the adoption of technology-enabled supply chain All included variables are of lower order and reflective in nature. The adoption of a technology-enabled supply chain is an endogenous variable in the structural model and a lower-order, reflecting construct The suggested structural model evaluates the impact of the chosen antecedents on the adoption of technology-enabled supply chains inside Indian manufacturing enterprises The seven hypotheses were analyzed using the SEM-PLS methodology. The outcomes of the hypothesis testing are presented in Table 6, and the structural model is illustrated in Figure 2.

Table 6: Findings from the PLS-SEM analysis

Exogenous Construct	**Endogenous Construct**	**Path Coefficient**	**Standard error**	**T stats**	**R Square (Q^2)**	Remark
Redistributed Manufacturing (RDM)	Improvement in firm performance	0.178	0.055	3.255**	47.6 % (451)	Supported
Collaborative new product development with forecast & resource sharing (CNPD)		0.156	0.057	2.675**		Supported
Human-computer interaction framework for AI in logistics (HCI)		0.158	0.065	2.486**		Supported
Supply Chain Improvement (SCI)		0.193	0.070	2.739**		Supported
Blockchain-based traceability system (BBTS)		0.133	0.061	2.204**		Supported

The hypothesis testing results confirm the five hypotheses when the impact of Redistributed Manufacturing, Collaborative new product development with forecast and resource sharing, Human-computer interaction framework with AI in logistics, Supply Chain Improvement, Blockchain-based traceability system takes place in terms of adopting technology-enabled capability in supply chain use in Indian manufacturing companies. The findings did not however corroborate the two-hypothesis that entailed the effect of supply chain innovation of risk management and competitive advantage, manufacturing servitization through TAM, on the usage of technology-enabled supply chain capabilities in Indian manufacturing companies When comparing the path coefficients, the largest contribution to the relations is considered when the case is Supply Chain Improvement (path coefficient= 0.193). It is succeeded by the Redistributed Manufacturing (path coefficient= 0.178), research also identified the substantial favourable impact on the technology-enabled supply chain adoption behavior of the enterprises. The other meaningful positive effect is identified as in case of Human-computer interaction framework of AI in logistics ((path coefficient = 0158). Collaborative new product development with forecast and resource sharing (path coefficient = 0.156) and Blockchain-based traceability system (path coefficient = 0.133) on the use of technology-enabled supply chain capabilities in Indian manufacturing companies supply chain innovation of risk management and competitive advantage, manufacturing servitization through TAM are not found to play an important role in the adoption of technology-enabled supply chain capabilities in Indian manufacturing company.

Figure 2: Importance-performance map

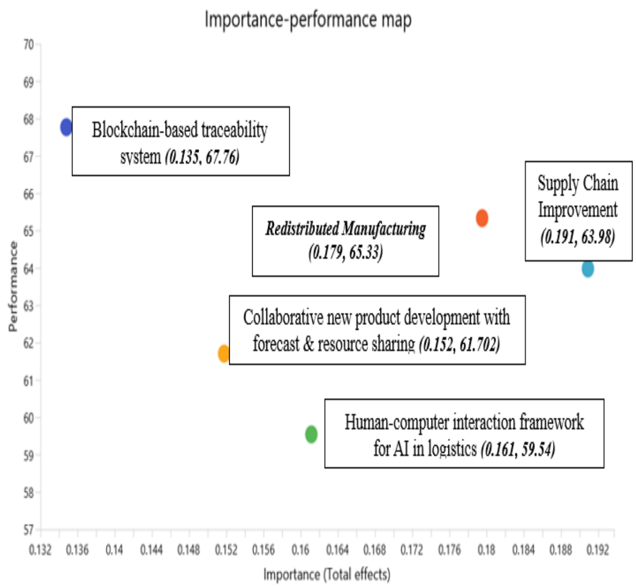


Table 7: NCA & FsQCA

Percentile	Improvement in Firm performance	Redistributed Manufacturing	Collaborative new product development with forecast & resource sharing	Human-computer interaction framework for AI in logistics	Supply Chain Improvement	Blockchain-based traceability system
0.000%	1.204	1.976	NN	NN	1.503	NN
10.000%	1.764	1.976	NN	NN	1.503	1.684
20.000%	2.324	1.976	NN	NN	1.503	1.760
30.000%	2.884	1.981	NN	1.727	1.503	2.269
40.000%	3.444	1.981	NN	2.451	1.503	2.269
50.000%	4.005	1.981	NN	2.451	1.503	2.269
60.000%	4.565	1.981	NN	2.451	1.503	2.508
70.000%	5.125	1.981	NN	2.593	1.503	2.508
80.000%	5.685	3.016	NN	2.759	1.503	2.508
90.000%	6.245	4.863	NN	2.759	1.503	4.763
100.000%	6.806 (6.80%)	6.252 (82.66%)	1.510 (0.25%)	6.454 (89.19%)	6.508 (90.95%)	5.416 (54.27%)
Effect size		0.184	0.001	0.210	0.252	0.256
Accuracy		92.965%	99.749%	87.186%	84.422%	94.472%

3. DISCUSSION

This research gives an idea of the essential factors that affect the adoption of technology-enabled supply chain capabilities in manufacturing companies in India for improving their firm performance Out of the seven antecedents, Redistributed Manufacturing, Collaborative new product development with forecast and resource sharing, Human-computer interaction framework of AI in logistics, Supply Chain Improvement, Blockchain-based traceability system, five of them were identified to have a significant impact on the adoption of technology-enabled supply chain capabilities practices for improving the firm performance .The most significant influence of Supply Chain Improvement (path coefficient =0.193) demonstrated that organizations with robust internal resources, such as technological infrastructure, leadership endorsement, and a culture geared towards innovation, are more likely to utilize technology-enabled supply chains RBC model of strategic management focuses more on internal capabilities as determinants of strategic choices like technology-empowered supply chain capabilities in companies for improving performance. The literature supports this and other firms that are not this prepared are likely to be challenged to effectively manage external relationships or to absorb external knowledge (Haylemariam et al, 2024). The second greatest contributor was Redistributed Manufacturing (path coefficient= 0.179), which implies that firms that want to outcompete their rivals view technology-enabled supply chain as a strategic resource to tap into external knowledge, speed-up innovation, and offer differentiated products (Ahmed et al 2024), as technology-enabled supply chain increases firms capabilities and also improves their performance to adapt to market demands and technology disruptions technology-enabled enables firms to stay in highly competitive markets. The human computer interaction framework for AI in logistics was also found to have a significant positive effect (path coefficient = 0.161), this supports the notion that dynamic and unpredictable markets compel enterprises to pursue more collaborative and exploratory avenues of innovation.

Technology-enabled firms have been able to share the innovation risk and accelerate the development cycle and better manage the changes in the competitive markets (Fu et al, 2024) since the firms operating in the high uncertain markets tend to use technology-enabled supply chain as the risk hedging and adaptation process for improving firm performance. It was also established that collaborative new product development, forecast and resource sharing (path coefficient = 0.156) positively affected technology-enabled supply chain capabilities, and this showed the applicability of internal culture and flexibility of the firm for improvement Companies with a positive attitude to experimentation, structural and decision-making flexibility are more capable of leveraging external knowledge (Liu, 2023), which may imply that a flexible and open-minded culture is a precondition of the successful implementation of external cooperation. Lastly, the traceability system using

Blockchain (path coefficient = 0.133) has been discovered to have a big effect in the adoption of technology-enabled supply chain, thereby suggesting that the future-orientation and opportunity-seeking firms have a greater tendency to adopt technology-enabled supply chain The proactive type of firms has a higher likelihood of seeking external knowledge and having innovation and forming partnerships before the others (Marzi et al, 2023). The research, nevertheless, noted that the risks management and competitive advantage of the supply chain innovation, manufacturing servitization through TAM did not significantly influence technology-enabled supply chain of the companies .This might be because there seems to be a discrepancy between policy formulation and concrete execution in India In spite of such initiatives as Make in India and PLI, lots of companies might not see themselves sufficiently supported or they might not be aware of such benefits or have access to them. It also indicates a possible policy-practice gap, which is to be addressed through further research. Moreover, the ability to absorb knowledge which is commonly regarded as the fundamental facilitator of technology-enabled supply chain technology-enabled supply chain turned out to be not significant here (path coefficient = -0.055) In other cases, the absorptive capacity can be integrated within a larger concept including organizational readiness for improvement.

4. CONCLUSION

The paper is an in-depth empirical investigation of the most significant factors that drive technology-enabled adoption of supply chain in manufacturing helps companies in India to improve firm performance. This article was grounded in the theoretical frameworks of innovation theory and the resource-based perspective (RBV), and it examined seven factors, which include *redistributed manufacturing, supply chain innovation for risk management and competitive advantage, manufacturing servitization via TAM, human-computer interaction framework for AI in logistics, supply chain improvement, blockchain based traceability system and improvement in firm performance.* In this paper, it was revealed that five variables, including. Redistributed Manufacturing, Collaborative new product development with forecast and resource sharing, Human-computer interaction framework on AI in logistics, Supply Chain Improvement, Blockchain-based traceability system, play a crucial role in the adoption of technology-enabled supply chain and improves firm performance Organizational readiness was found to be the most effectual of these and it is evident that internal preparedness in terms of leadership support, infrastructure and collaborative capabilities is important Redistributed Manufacturing and Traceability system based on blockchain also emphasize the fact that companies with strategic objectives and behaviors of orientation towards the future tend to be more prone to technology-enabled supply chain practices for firm improvements. The importance of market uncertainty proves that environmental dynamism promotes the need by firms to have external collaboration as a means of remaining competitive and agile, and innovation and flexibility are just a measure of cultural adaptability needed in technology-enabled supply chain. Nonetheless, there is no significant influence of government support, policy, and knowledge absorptive capacity on technology-enabled supply chain for improvement in firm performance This research has practical implications on the managers and policymakers. The companies need to strive to improve their in-house preparedness, develop versatile innovation cultures, and become proactive Internal capabilities and strategic intent were more influential than external institutional elements in the adoption of technology-enabled supply chain by manufacturing in India for improving firm performance Indian companies should focus more on capacity building and strategic alignment in order to achieve the maximum of technology-enabled supply chain, but policy makers should make sure that innovation policies can be translated into practice

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REFERENCES

1. Ahmed, F, Rahman., M. U, Rehman, H. M, Imran, M, Dunay, A., & Hossain, M B (2024b) Corporate capital structure effects on corporate performance pursuing a strategy of innovation in manufacturing companies Heliyon, 10(3), e24677 https://doi.org/10.1016/j.heliyon.2024.e24677.
2. Akter, S, Fosso Wamba, S, Gunasekaran, A, Dubey, R, & Childe, S J (2016) How to improve firm performance using big data analytics capability and business strategy alignment? International Journal of Production Economics, 182, 113–131 https://doi.org/10.1016/j.ijpe2016.08.018.
3. Bag, S, Gupta, S, Kumar, S, & Sivarajah, U (2021) Role of technological dimensions of Industry 40 in supply chain resilience: Empirical evidence from manufacturing firms International Journal of Production Research, 59(15), 4569–4592 https://doi.org/10.1080/00207543.2020.1858254.
4. Chen, J, Damanpour, F, & Reilly, R R (2019) Understanding antecedents of new product development speed: A meta-analysis Journal of Operations Management, 65(5), 447–471 https://doi.org/10.1002/joom.1038.
5. Crossan, M M, & Apaydin, M (2010) A multi-dimensional framework of organizational innovation: A systematic review of the literature Journal of Management Studies, 47(6), 1154–1191 https://doi.org/10.1111/j.1467-6486.2009.00880x.
6. Dubey, R, Gunasekaran, A, Childe, S J, Papadopoulos, T, & Fosso Wamba, S (2019) Impact of big data analytics capability on supply chain agility and organizational flexibility: Empirical evidence from manufacturing firms International Journal of Production Research, 57(10),3192–3212. https://doi.org/10.1080/00207543.2018.1546670
7. Dubey, R, Gunasekaran, A, Childe, S J, Papadopoulos, T, Fosso Wamba, S, & Roubaud, D (2021) Upstream supply chain visibility and complexity

effect on focal company's sustainable performance: Indian manufacturers' perspective Annals of Operations Research, 290(1–2), 343–367 https://doi.org/10.1007/s10479-019-03334-0.

8. Dul, J (2016) Necessary condition analysis (NCA): Logic and methodology of "necessary but not sufficient" causality Organizational Research Methods, 19(1), 10–52 https://doi.org/10.1177/1094428115584005.

9. Fiss, P C (2011) Building better causal theories: A fuzzy set approach to typologies in organization research Academy of Management Journal, 54(2), 393–420 https://doi.org/10.5465/amj2011.60263120.

10. Fu, X, Zanello, G, Contreras, C, & Ding, X (2024b) Innovation under constraints: the role of open innovation in Ghana Industry and Innovation, 444–474 https://doi.org/10.1080/13662716.2024.2319798.

11. Gunasekaran, A, Yusuf, Y Y, Adeleye, E O, & Papadopoulos, T (2017) Agile manufacturing practices: The role of big data and business analytics with multiple case studies International Journal of Production Research, 55(15), 4444–4457 https://doi.org/10.1080/00207543.2016.1275875

12. Haylemariam, L G, Oduro, S, & Tegegne, Z L (2024b) Entrepreneurial agility and organizational performance of IT firms: A mediated moderation model Journal of Entrepreneurship Management and Innovation, 20(2), 75–92 https://doiorg/107341/20242024.

13. Ivanov, D, & Dolgui, A (2021) OR-methods for coping with the ripple effect in supply chains during COVID-19: Managerial insights and research implications International Journal of Production Economics, 232, 107921.

14. Ivanov, D, Dolgui, A, Das, A, & Sokolov, B (2019) Digital supply chain twins: Managing the ripple effect, resilience, and disruption risks by data-driven optimization, simulation, and visibility International Journal of Production Research, 57(24),8293–8310 https://doi.org/10.1080/00207543.2018.1488086.

15. Khan, S A R, Yu, Z, & Golpîra, H (2022) Configurational analysis of supply chain digitization and sustainable performance: Evidence from emerging economies Technological Forecasting and Social Change, 174, 121256 https://doi.org/10.1016/jtechfore2021.121256.

16. Kohtamäki, M, Einola, S, & Rabetino, R (2020) Exploring servitization through the paradox lens: Coping practices in servitization International Journal of Production Economics, 226, 107619 https://doi.org/10.1016/j.ijpe2020.107619

17. Kohtamäki, M, Parida, V, Oghazi, P, Gebauer, H, & Baines, T (2019) Digital servitization business models in ecosystems: A theory of the firm Journal of Business Research, 104, 380–392 https://doi.org/10.1016/jjbusres2019.06.027.

18. Li, Y, Tang, Y, & Zhang, Q (2023) How digital supply chain innovation drives firm performance: Evidence from manufacturing firms International Journal of Production Economics, 255, 108719 https://doi.org/10.1016/j.ijpe2023.108719

19. Liu, C, Shang, Y, & Wang, J (2022) Supply chain resilience in the post-COVID-19 era: Insights from manufacturing firms International Journal of Logistics Management, 33(4), 1158–1182.

20. Liu, L (2023) Green innovation, firm performance, and risk mitigation: evidence from the USA Environment Development and Sustainability, 26(9),24009–24030 https://doi.org/10.1007/s10668-023-03632-z

21. Marzi, G, a, Fakhar Manesh, M, Caputo, A, Pellegrini, M M, Department of Management, Mathematics and Statistics (DEAMS), Cognitive configurations affecting open innovation adoption in SMEs [Journal-article] Technovation, 119, 102585 https://doi.org/10.1016/j.technovation2022.102585.

22. Opazo-Basáez, M, Vendrell-Herrero, F, & Bustinza, O F (2022) Uncovering productivity gains of digital and green servitization: Implications from the automotive industry Technological Forecasting and Social Change, 174,121227 https://doi.org/10.1016/j.techfore2021.121227.

23. Queiroz, M M, & Fosso Wamba, S (2022) Blockchain adoption in supply chain and its impact on firm performance: A resource-based view International Journal of Production Economics, 247,108400 https://doi.org/10.1016/j.ijpe2022.108400.

24. Queiroz, M M, Fosso Wamba, S, Machado, M C, & Telles, R (2020) Smart manufacturing and Industry 40 readiness: The perspective of supply chain management International Journal of Production Economics, 224, 107547 https://doi.org/10.1016/j.ijpe.2019.107547.

25. Raddats, C, Zolkiewski, J, Story, V M, Burton, J, Baines, T, & Bigdeli, A Z (2019) Interactively developed capabilities: Evidence from dyadic servitization relationships International Journal of Operations & Production Management, 39(4), 469–494 https://doi.org/10.1108/IJOPM-09-2017-0542.

26. Ragin, C C (2008) Redesigning social inquiry: Fuzzy sets and beyond University of Chicago Press

27. Richard, P J, Devinney, T M, Yip, G S, & Johnson, G (2009) Measuring organizational performance: Towards methodological best practice Journal of Management, 35(3), 718–804 https://doi.org/10.1177/0149206308330560

28. Saberi, S, Kouhizadeh, M, Sarkis, J, & Shen, L (2019) Blockchain technology and its relationships to sustainable supply chain management International Journal of Production Research, 57(7), 2117–2135

29. Teece, D J (2007) Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance Strategic Management Journal, 28(13), 1319–1350 https://doiorg/101002/smj640.

30. Venkatesh, V, & Bala, H (2008) Technology acceptance model 3 and a research agenda on interventions Decision Sciences, 39(2), 273–315 https://doi.org/10.1111/j.1540-5915.2008.00192x.

31. Wamba, S F, Gunasekaran, A, Akter, S, Ren, S J F, Dubey, R, & Childe, S J (2020) Big data analytics and firm performance: Effects of dynamic capabilities Journal of Business Research, 70, 356–365 https://doi.org/10.1016/j.jbusres2016.08.009

32. Wieland, A, & Wallenburg, C M (2013) The influence of relational competencies on supply chain

resilience: A relational view Journal of Business Logistics, 34(3), 205–221 https://doi.org/10.1111/jbl.12019.
33. Zhu, Q, Krikke, H, & Caniels, M C J (2018) Integrated supply chain risk management: A systematic review and future research directions International Journal of Logistics Management, 29(2), 489–514 https://doi.org/10.1108/IJLM-03-2017-0083..

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