



Identifying the pathways through digital transformation to achieve supply chain resilience: an fsQCA approach

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Abstract

The manufacturing industry has placed a greater emphasis on digital transformation, especially under the impact of COVID-19. However, the influence mechanism between digital transformation and supply chain resilience is still a topic of discussion. Resource orchestration theory indicates that a firm not only need to emphasize the investment of resources but also pays attention to the allocation of resources. Therefore, based on the resource orchestration theory, this study divides the digital transformation into digital transformation breadth and digital transformation depth and combines R&D spending (R&D intensity and R&D employee) and contingency factors (firm size) to construct a theoretical path of “digital transformation-supply chain resilience.” This research uses fuzzy sets qualitative comparative analysis to explore how to configure the digital transformation to achieve high supply chain resilience based on data from 193 listed manufacturing firms. Using the fsQCA software, it was discovered that there were no necessary conditions for achieving high supply chain resilience; sufficient condition analysis revealed that there are six paths to achieving high supply chain resilience, four of which can be summarized as digital transformation driven and the other two as R&D spending driven. These several approaches highlight the complicated causal relationship between digital transformation and supply chain resilience, as well as give theoretical and practical recommendations for firms looking to implement digital strategies and enhance their supply chains.

Keywords Digital transformation · Supply chain resilience · Resource orchestration theory · R&D intensity · R&D Employee · fsQCA · Firm size

Introduction

Manufacturing is the national economy’s theme and foundation. Manufacturing’s digital revolution is an important way for businesses to grow. As a major public health event, the outbreak of COVID-19 has led to the global economic recession and makes enterprises face the crisis of supply chain interruption (Magableh 2021; Ramanathan et al. 2021), environmental sustainability (Yang et al. 2021), human health (Irfan et al. 2022), and environmental quality issues (Wen et al. 2022). And the impact of COVID-19 disruptions has exacerbated supply and demand uncertainties, loss of key

suppliers, transport breakdown, temporary closure of suppliers, and changes in market demand (Kohl et al. 2022). Under the complicated and harsh circumstances of the worldwide epidemic, Chinese firms have demonstrated significant supply chain resilience. In the post-epidemic period, digital empowerment of enterprise development has also injected a significant push into the development of firms. Digitalization has also become a critical tool for businesses to combat the epidemic and improve their competitiveness (Elavarasan et al. 2021). Many traditional firms, especially manufacturing firms, are still in the exploratory stage of the application of digital technology. In the new digital era, the use of digital technology to reshape firms and supply chains has become an important way for enterprises to improve supply chain resilience.

Enterprise digital transformation is the utilization of emerging technologies as the basis for solutions to improve the way information transferred and communicated between enterprises and increase the efficiency and effectiveness of communication among members. Consumer

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behavior will be radically changed by the business model innovations brought about by digital transformation, and accomplishing a successful digital transformation also necessitates specific assets and capabilities (Verhoef et al. 2021). In today's increasingly VUCA world, firms must digitally change and improve their digital maturity to become more agile (Fletcher and Griffiths 2020).

Current interest in digital transformation (Hanelt et al. 2021, Nadkarni and Prügl 2021, Matarazzo et al. 2021) and supply chain resilience (Al Naimi et al. 2020; Chowdhury and Quaddus 2017; Min 2019; Novak et al. 2021; Kamalahmadi et al. 2022) are two main research directions. Traditional research focuses on the relationship between digital transformation and other aspects using methods such as regression analysis, but there are still few studies on how to leverage digital technology to increase supply chain resilience. And traditional research rarely studies how to orchestrate resources and other factors to improve the supply chain resilience from the resource orchestration theory. To address the aforementioned issues, this research primarily employs the fuzzy set qualitative comparative analysis method to investigate how to orchestrate digital transformation resources to reveal the complicated causal relationship between digital transformation and supply chain resilience. This paper mainly addresses the following questions:

1. Dimension division of digital transformation degree based on resource orchestration theory.
2. Whether there exist necessary conditions to achieve high supply chain resilience.
3. How to configure digital transformation, R&D spending, and contingency factors to achieve high supply chain resilience.

The contributions of this study lie in that: (1) based on resource orchestration theory, we categorize digital transformation into two categories: digital transformation depth and digital transformation breadth. (2) From the perspective of configuration, this study employs the fuzzy set qualitative comparative analysis to uncover the complex asymmetric causal relationship between digital transformation and supply chain resilience. (3) The study finds six paths to high supply chain resilience, four of which are driven by digital transformation and two of which are digital transformation absence, which might guide the implementation of digital transformation in the manufacturing industry.

The rest of this research is organized as follows: The second section is a “Literature review and model building.” The third section is the “Methodology.” The fourth section is the “Results analysis,” the fifth section is the “Discussion,” and the last section is the “Implications.”

Literature review and model building

Digital transformation

Digital transformation is a multidimensional concept (Hanelt et al. 2021) that can affect a firm performance to certain degrees. Digital transformation and the adoption of emerging technologies can also promote the sustainable development of supply chains (Stroumpoulis and Kopanaki 2022). In response to changing customer needs and fierce market competition, the manufacturing sector is also implementing digital transformation to improve its ability to coordinate supply chains in the post-COVID-19 era (Liu 2022). The ability of firms to embrace digital transformation is affected by many factors (Hamburg 2019), such as the intensity of external competition and the maturity of technology. But combing through the literature reveals that technology is the most critical factor for companies to digitally transform (Andriole et al. 2017). Digital transformation has been characterized as the application of information technology in prior studies. One widely held belief is that digitalization refers to the application of new digital technology to create significant commercial improvements. (Fitzgerald et al. 2014). Therefore, this research agrees with the concept of digital transformation that utilizes information technology elements to assist businesses in improving their business capabilities. Recent studies have shown that digital technology is employed in normal business operations to support firms in their digital transformation and value creation, which is consistent with this concept.

Digital transformation can help a company save costs and operate more efficiently. Previous studies have shown that although digital transformation accelerates economic performance, it portrays an inverse U-shaped relationship with environmental performance. In the case of low market volatility, digital transformation accelerates economic performance more rapidly. In contrast, higher digital transformation is associated with poorer environmental performance when market turmoil intensifies (Li 2022). Digital transformation can be classified into two types: regular digital transformation and excess digital transformation. While normal digital transformation is better for long-term performance (Zhai et al. 2022), excess digitalization is a short-term tactical plan, whereas normal digitalization is a long-term strategy (Miles et al. 1978). Some researchers analyzed the value creation process of digital transformation by dividing it into three dimensions: technical preparation, digital technology investigation, and digital technology development (Jafari-Sadeghi et al. 2021). Smaller firms concentrate on process innovation, while large and medium-sized businesses concentrate on

process optimization and the development of new products as part of their digital transformation (Balakrishnan and Das 2020). With the increased focus on digital research, some researchers will identify two dimensions of digital transformation by reviewing existing literature: technology and participants (Nadkarni and Prügl 2021).

According to McKinsey's research, the average level of digitization of supply chains is 43%, and the improvement of supply chain digitalization can better improve (Gezgin et al. 2017). Based on the SAP research, 84% of companies believe that digital change is critical to their survival, but only 3% have completed organization-wide digitalization. Digital technology can only play its part if it is applied in the right environment (Faruquee et al. 2021).

Previous literature has also examined the relationship between digital transformation and organizational resilience, and investment in digital technology can help organizations build physical infrastructure and support systems to enhance organizational resilience so that organizations can better sustain their operations in a crisis (He et al. 2022). In complex causal asymmetries, digital transformation can impact supply chain resilience. Digital technologies, for example, appear to be a required but insufficient necessary condition for achieving flexible supply networks in the research of agile supply chains and digital transformation (Shashi et al. 2020). The digital supply chain is primarily defined by digital maturity and the adoption of digital tools in the research of digital transformation and supply chain resilience, whereas supply chain resilience is influenced by digital maturity and digital tool adoption.

The current research on the dimensions of digital transformation is mostly based on the stage of digital transformation, digital maturity, and other areas of research. And there are relatively few researches on the transfer of digital transformation to the overall digital asset deployment of firms. However, studying the relationship between digital transformation and supply chain resilience from the perspective of digital transformation asset deployment is beneficial for us to further our understanding of digital transformation. Secondly, this paper study supply chain resilience by using resource orchestration theory helps to explain the paradox of the impact of digital transformation on firms in previous studies, according to the resource orchestration theory, effective use, and management of resources are more important than the resources themselves (Ye et al. 2022). Thus, we study the impact of digital transformation asset deployment on supply chain resilience from the perspective of asset orchestration, so as to have a more comprehensive understanding of digital transformation assets. Therefore, based on the resource orchestration theory, the digital transformation dimension is divided into depth and breadth. The digital transformation depth is defined as the scale of firm deployment of digital assets. The digital transformation breadth is

defined as the range of digital assets deployed by enterprise firms, such as big data, cloud computing, Internet of Things, and blockchain, so that these technologies interact and operate in synergy and are committed to helping firms transform and upgrade and create value.

Supply chain resilience

Global supply networks are at risk due to the breakout of COVID-19, and coping with supply chain interruptions is needed to strengthen supply chain resilience. The “resilience” phenomenon first came from ecology (Holling 1973), psychology (Luthar et al. 2000) and engineering (Youn et al. 2011). According to prior research, supply chain resilience primarily relates to a company's ability to recover from supply chain disruptions (Christopher and Peck 2004). So, researchers define supply chain resilience as a single dimension. Based on previous research, later scholars have divided supply chain resilience into two dimensions: resistance and recovery, where resistance refers to minimizing the impact of supply chain disruptions, and recovery refers to the ability to resume normal operations after supply chain disruptions (Wiedmer et al. 2021). Some studies have summarized supply chain resilience as supply chain readiness and supply chain agility and studied the relationship between big data and supply chain resilience (Manikas et al. 2022). Thus, supply chain resilience means that the supply chain is adaptable and able to react correctly to different situations (Tukamuhabwa et al. 2015).

In particular, as supply networks become increasingly complex and intertwined, the real world has reached a complex tipping point, which will also amplify the consequences of supply chain disruption risk and seriously undermine the resilience of the entire supply chain (Marcucci et al. 2022; Pimenta et al. 2022). Research in the field of supply chain management regard redundancy (Wieland and Wallenburg 2013), flexibility (Talluri et al. 2013), agility (Ivanov 2020), and collaboration (Scholten and Schilder 2015) as the main way to achieve supply chain resilience. Supply chain responsiveness can be improved by adding flexibility and redundancy to minimize expected supply chain costs and maximize expected service delivery when the supply chain faces supplier and environmental disruptions (Kamalahmadi et al. 2022; Piprani et al. 2022). Multidimensional supply chain flexibility improves supply chain flexibility in a high supply chain risk environment (Piprani et al. 2022). In addition, there are also literature studies on the role of supply chain innovation in improving supply chain resilience. The most resilient supply chain is the supply chain that introduced innovation before, and the knowledge preparation of firms is strengthened when the unforeseen supply chain disruption occurs (Orlando et al. 2022). Logistics has become even more important in the context of COVID-19, and in

this context, the digitization of logistics and supply chains is seen as an important tool for logistics resilience (Gupta et al. 2022). Resilience is not only about recovery after a disruption event, but also about the ability to adapt and transform. Engineering resilience regards the supply chain as a closed system (Holling, 1996), while socio-ecological resilience views the supply chain as an open system that needs to change based on events and environmental changes (Adobor and McMullen 2018). In the new environment and conditions, returning to the original state may not be the best option for the business; instead, it is necessary to adapt the company's product line to changes in the environment and develop and produce products that meet the needs of society and the public through the reorganization of business processes. This fits nicely with the concept of social-ecological resilience. As a result, we believe supply chain resilience is important to cope with supply chain disruption (Ivanov 2021a).

Current research on resilience focuses on the perspective of complexity (Novak et al. 2021; DeCampos et al. 2022), such as viewing the supply network as a complex adaptive system or studying the relationship between supply network complexity and supply chain resilience (Wieland and Durach 2021). Supply network complexity can be divided into upstream complexity, downstream complexity, and internal complexity (Akin Ateş et al. 2022), or horizontal complexity, vertical complexity, and spatial complexity (Bode and Wagner 2015), and external complexity and internal complexity (Isik 2011). The most prominent problems in the supply chain are sharing data and information, transparency, and visualization. Previous research has also shown the role of digital technology in improving the ability of the supply chain to cope with the supply chain risks (Pimenta et al. 2022). Digital technology will become an increasingly important aspect of business resilience in the future, and almost every company must rely on data analytics, digital tools, and automation to improve its ability to respond to risk (Elgazzar et al. 2022). Therefore, the implementation of digital transformation by enterprises can be a good solution to the pain points in the supply chain (Preindl et al. 2020). We discovered that there are few studies on digital transformation and supply chain resilience in the relevant literature, and fewer studies based on the resource orchestration theory to investigate digital transformation. The resource orchestration theory not only emphasizes the importance of its resources, but also pays more attention to the allocation and combination of resources. Given these facts, we mainly adopt the resource orchestration view and divide digital transformation into two aspects: digital transformation breadth and depth. And study the relationship between digital transformation depth and breadth and supply chain resilience. So, according to our research, the depth and breadth of digital transformation have a strong impact on supply chain resilience.

Conceptual model

We may infer from the literature review that digital transformation plays an essential role in establishing supply chain resilience. Supply chain resilience is enhanced by combining digital transformation with R&D spending and firm size. However, digital transformation and supply chain resilience are currently two independent streams of research. The component of digital transformation has not been fully explored from the perspective of resource orchestration. And supply chain resilience is the consequence of various antecedent factors interacting. As a result, based on the resource orchestration theory, we divided digital transformation into digital transformation depth and digital transformation breadth, and integrated R&D intensity, R&D employee, and firm size to investigate how the interaction between antecedents promotes supply chain resilience. To investigate the relationship between digital transformation and supply chain resilience, this research proposes a theoretical model based on configuration theory, as shown in Fig. 1.

Methodology

Fuzzy-set qualitative comparative analysis

The fuzzy set qualitative comparative analysis breaks down the barriers between qualitative and quantitative research and brings them together (Ragin 1999). The QCA method surpasses typical regression research's dependence on a simple linear relationship, as Ragin (2009) said, since the causes and conditions of social phenomena are frequently inter-related rather than isolated, explaining social phenomena requires a holistic and configurational approach. At present, QCA mainly contains three specific operation methods: crisp set QCA, multi-value set QCA, and fuzzy set QCA (Rihoux and Ragin 2008), given fsQCA dealing with not only category problems but also with varying degrees and partial affiliation, and has the dual properties of qualitative analysis

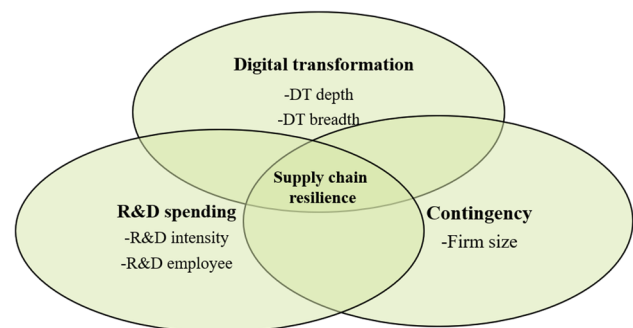


Fig. 1 Estimated causal relationships in the conceptual model

and quantitative analysis (Ragin 2008). We employ fsQCA as the research method of this study.

Sample selection and data sources

This article's samples came primarily from the CSMAR Database; we primarily use the CSMAR digital transformation database. Given the focus of this research is on the influence of digital transformation on supply chain resilience, supply chain resilience is the firms' ability to recover from interruptions. This study focuses on data from the year 2020, for the first quarter of firms in 2020 was the most affected by COVID-19, while the second to the fourth quarters were the recovery phase (Lin et al. 2021). We get 2032 pieces of data based on industry kinds where manufacturing firms are represented by C13-C42. Then, R&D spending data was filtered, and a total of 873 pieces of data were collected by picking the 2020 data. A total of 199 pieces of data were retrieved after matching R&D investment with digital transformation data. After eliminating the missing data, 193 pieces of complete production data were found. The specific data screening process is shown in Table 1.

Measurement and calibration of results and antecedents

Measurement of results and antecedents

DT breadth We are mainly based on the relevant data of the degree of digital transformation provided by the CSMAR database, of which digital technology mainly includes artificial intelligence technology, blockchain technology, cloud computing technology, big data technology, digital technology application. We will judge the DT breadth according to the number of types of these technologies adopted by enterprises.

DT depth It refers to the frequency and extent to which firms use digital technologies; in this study, we primarily assess the depth of digital transformation using the sum of the frequencies of the above five technologies publicly revealed by publicly traded firms as supplied by the CSMAR database. The greater the overall number of frequencies, the deeper the

firm's digital transformation is, and vice versa; the depth of digital transformation is insufficient.

R&D spending It mainly refers to the degree of support of enterprises for R&D activities. In the dimensions of R&D spending, we mainly adopt R&D intensity and R&D employees to measure.

R&D intensity It is measured by the ratio of the amount of R&D spending to the operating income of the enterprise, the higher the R&D intensity indicator, the stronger the R&D intensity of the enterprise, and vice versa.

R&D employee It is measured by the ratio of the total number of R&D employees; the higher the indicator, the higher the number of R&D employees in the enterprise; and the lower the indicator, it indicates that the number of R&D employees in the enterprise is less.

Firm size Given the listed company's total asset size is too large, we rely on academically sound research to substitute firm size with the natural logarithm of the enterprise's entire assets (Al-Najjar and Taylor 2008).

Supply chain resilience In this study, we mainly used the growth rate of main business revenue in each quarter of 2020 to measure the business operations of each quarter; the first quarter of 2020 is the quarter most affected by COVID-19, and the second, third, and fourth quarters are the recovery quarters, so this study takes the average of the two, three, and four quarters minus the value of the first quarter, and then divided by the absolute values of the first quarter to measure the supply chain resilience.

Calibration of results and antecedents

Since uncalibrated data is less readable and reasonable, the QCA method needs to calibrate the measured circumstances into the idea of sets. Due to the lack of an external standard reference in this study, to avoid subjective bias caused by a lack of theory and experience in the calibration process, this study follows the mainstream QCA research using objective quantile values for calibration methods, that is, use results and antecedent of 90%, 50%, and 10% quantile

Table 1 Data filtering process

Step	Database	Filter	Data obtained
1	DT database	Year: 2020 Industry type: C13–C42	2032 data
2	R&D spending database	Year: 2020	873 data
3	Final data for steps 1 and 2	Match by stock code	199 data
4	Final data for step 3	Remove 6 incomplete data	193 data

Table 2 Fuzzy set calibration

Sets	Fuzzy set calibration		
	Fully in	Crossover point	Fully out
DT breadth	4	3	1
DT depth	61	11	2
R&D intensity	13.95	6.04	3.27
R&D employee	0.43	0.18	0.085
Firm size	24.2	22.47	20.8
Resilience	4.39	0.7	−0.28

Table 3 Analysis of the necessary conditions for antecedents

	Consistency	Coverage
R&D employee	0.617864	0.583730
~ R&D employee	0.662759	0.580167
Firm size	0.674539	0.625217
~ Firm size	0.635517	0.566441
R&D intensity	0.622505	0.571856
~ R&D intensity	0.659156	0.592625
DT breadth	0.627032	0.623124
~ DT breadth	0.681757	0.570717
DT depth	0.610886	0.597264
~ DT depth	0.659030	0.559435

values (Schneider and Wagemann 2012). This calibration is supported by mainstream research, and the study's calibration anchors are as follows (Table 2):

Results analysis

Necessary condition analysis

Before conducting a sufficiency analysis, we conducted a necessary analysis, the results of which are displayed in Table 3, and it was found that no antecedent condition has coverage of the outcome variable greater than 0.9 (Ragin 2006). This shows that none of the five antecedent requirements are required to produce a result and that each condition is not sufficient to produce an outcome, implying that multiple antecedent conditions should be integrated for configuration analysis.

Sufficiency analysis of conditional configuration

The antecedent configurations that lead to high supply chain resilience are analyzed using the fsQCA3.0 software; these different configurations represent the configurations of different digital transformations that achieve uniform results, and the configurations found in this study are

named according to the configuration theorization process (Furnari et al. 2020).

We set the original consistency threshold to 0.8 and the frequency value to 3 in this study because, according to previous studies, the frequency setting can be set at 1.5% of the total number of cases, so the frequency threshold of the case was set to 3 in this study, and the PRI consistency was set to 0.5 based on the data in this study (Greckhamer et al. 2018). Table 4 shows the results of the QCA study, which reveal that six configurations have high supply chain resilience, four of which are digital transformation driven and two of which are R&D spending driven. The following is a detailed description of six different conditions that result in the same high supply chain resilience.

Table 4 shows the configuration of six first-order configuration schemes that, due to their high consistency and coverage, they are sufficient for attaining strong supply chain resilience (0.75, 0.57). In this study, there are a total of 6 digital transformation paths that can achieve high supply chain resilience. We rename path 1 to path 4 as digital transformation driven paths following a configuration naming procedure, where path 1 is DT depth and firm size as core conditions, DT breadth as peripheral conditions, and the absence of R&D intensity as a core condition; this configuration has a high level of consistency (0.80) and covers 31% of the set, explaining a large portion of the results that produce high supply chain resilience. Path 1 shows that even if the R&D intensity of the enterprise is not high, and the R&D expenditure is not enough, it can achieve higher supply chain resilience in the case of a large company with a relatively high degree of digital transformation. This means that in the case of a large company with a relatively high degree of digital transformation, the enterprise has used digital technology in the internal process. Path 1 shows that even if the R&D intensity of the enterprise is not high, and the R&D expenditure is small, it can achieve higher supply chain resilience in the case of a large company with a relatively high degree of digital transformation. This means that in the case of a large company with a relatively high degree of digital transformation, the enterprise has used digital technology in the internal process.

Path 2 is high supply chain resilience can be achieved by using DT depth, R&D employee, and firm size as the core conditions and DT breadth as a peripheral condition. This configuration has a high-level consistency (0.80), and the result is that 36% of sets are covered. Path 2 accounts for the largest proportion in achieving high supply chain resilience outcomes. This path indicates that high supply chain resilience can be achieved in the case of large firm size, a large number of R&D employees, and a high degree of digital transformation; it is similar to path 1, with the exception that path 1 lacks R&D intensity as a core condition, whereas path

Table 4 Configuration of high supply chain resilience in fsQCA

	Digital transformation driven				R&D spending driven	
	1	2	3	4	5	6
Digital transformation						
DT depth	●	●		•	⊗	⊗
DT breadth	•	•	●	•	⊗	⊗
R&D spending						
R&D intensity	⊗		⊗	⊗	⊗	●
R&D employee		●	●	•	●	●
Contingency						
Firm size	●	●	•		⊗	●
Raw coverage	0.31	0.36	0.26	0.28	0.24	0.25
Unique coverage	0.07	0.08	0.01	0.01	0.04	0.04
Consistency	0.80	0.80	0.85	0.83	0.86	0.85
Solution coverage				0.57		
Solution consistency				0.75		

Filled circle (black): core conditions’ presence; big circle with an X: core conditions’ absence; bullet: peripheral conditions’ presence, small circle with an x: peripheral conditions’ absence

2 has R&D employee as a core condition, indicating R&D intensity and R&D employee have a substitution.

Path 3 is supply chain resilience can be achieved with DT breadth and R&D employee as core conditions, firm size as a peripheral condition, and R&D intensity as a core condition’s absence. This configuration also has a higher level of consistency (0.85), and the results cover 26% of the sets. This path indicates that under large firm conditions, with a large number of R&D employees and high-level DT width, even with low R&D spending, large companies can achieve high supply chain resilience, which means that large companies that widely use internal information technology, with the efforts of many R&D employees, can also improve the ability to innovate.

Path 4 is DT depth and breadth, R&D employee as a peripheral condition, and R&D intensity absence as a peripheral condition. This configuration has a good level of consistency (0.83) and covers 28% of the data sets. This path indicates that the number of R&D employees is large, especially in small firms, and the degree of digital transformation is higher. Even if small firms have less scale and fewer funds to support R&D, a large number of R&D employees can help firms achieve a higher degree of digital transformation, and the higher the degree of digital transformation of enterprises, the higher the degree of digital transformation of enterprises; enterprises can predict possible risks.

Paths 5 and 6 were identified as R&D spending driven, path 5: R&D intensity and firm size as core conditions’ absence, R&D employee as core conditions’ presence, and DT depth and DT breadth as peripheral conditions. This configuration had a high level of consistency (0.86) and covered

24% of the results; Path 5 demonstrates that small businesses can still achieve high supply chain resilience even if their level of digital transformation is low, implying that R&D employees are critical to the normal operation of businesses.

Path 6 indicates in the case of R&D intensity, R&D employee and firm size as the core conditions, DT breadth as the core conditions’ absence, and DT depth as the peripheral conditions’ absence, this configuration shows a high level of consistency (0.85) and covered the 25% sets; this path shows that even if the enterprises do not have a high level of the digital transformation, as long as the firm size is enough big, large enterprise’s R&D spending and R&D employee, companies can also achieve high supply chain resilience. The reason is that the enterprise has enough financial support and enough R&D personnel, which indicates that the work of R&D employees is highly supported by the enterprise. Even if the current digitization level of the enterprise is not high, the R&D employee can quickly develop related products or technologies, and help enterprises well away from risks or adapt to new market and social needs by developing new products.

Robustness test

To ensure the robustness of the conclusions, we raised the frequency threshold of cases from 3 to 4 and continued to examine the configuration between digital transformation and high supply chain resilience. The results showed that the configuration of our results did not change, according to Greckhamer et al. (2018); the adjustment of the parameters does not result in a substantial change in the number,

components, consistency, and coverage of the configuration. The results of the resulting analysis can be considered reliable, that is, our results are of good robustness.

Discussion

Using the fsQCA approach, this study validates the relationship between digital transformation and supply chain resilience, and the results show that six configurations can achieve high supply chain resilience. Path 1: DT depth and firm size as core conditions, DT breadth as peripheral condition, and R&D intensity are absent as core conditions; Path 2: DT depth, R&D employee, and firm size are core conditions, DT breadth is the peripheral condition, and R&D intensity is absent as core condition; Path 3: DT breadth and R&D employee are core conditions, while the firm size and R&D intensity are peripheral conditions. Path 4 is DT depth and breadth, R&D employee as a peripheral condition, and R&D intensity absence as a peripheral condition. These four paths to high supply chain resilience can be named digital transformation driven; Path 5: R&D intensity and firm size are absent as core conditions; R&D employees are absent as core conditions; and DT depth and breadth are absent as peripheral conditions; Path 6: R&D intensity, R&D employees, and firm size as core conditions, DT breadth as core condition's absence, and DT depth as peripheral condition's absence; this approach can be referred to as digital transformation absence. The significance of these six configurations in demonstrating the configuration relationship between digital transformation and supply chain resilience is significant.

The first four paths show that digital transformation breadth and depth of asset deployment can improve supply chain resilience. Previous studies have also proved that the deployment of blockchain technology, RFID, and Industry 4.0 technologies can improve the transparency of the supply chain (Rogerson and Parry 2020), thus contributing to the improvement the supply chain resilience. With the help of big data analysis, artificial intelligence, and other digital assets, enterprises can obtain valuable information from massive data (Li et al. 2021). As for the relationship between digital transformation and supply chain resilience, we found that, unlike previous studies, simple linear relationship between digital transformation and supply chain resilience, our research shows that there is a complex causal relationship between digital transformation and supply chain. These four paths also show that the breadth and depth of digital asset allocation in digital transformation are crucial to achieving high supply chain resilience, which is also consistent with previous research; that is, the depth and breadth of technology utilization have a significant impact on the firm operation (Li, 2019). For example, in Path 1 and Path 2, the

digital transformation depth and firm size are the core conditions, while digital transformation breadth is the peripheral condition, and there is a substitution relationship between R&D intensity absence and R&D employees. Both paths show that for large firms, by deploying a large number of digital assets, digital asset deployment breadth can strengthen the connection between organizations and improve supply chain transparency. At the same time, for enterprises, in the daily supply chain management, only a single asset is rarely deployed, but multiple digital assets are deployed (Marić et al. 2021). A single digital asset may have no combination of multiple digital assets to maximize its value of digital assets. And the digital asset deployment depth allows enterprises to explore the value of digital assets. By deploying digital assets in-depth, enterprises can process a large amount of information. Especially in the face of a crisis, strong information processing capability can improve the agility of the supply chain, thus improving the flexibility of the supply chain. Our research also found that not all large enterprises deploy digital transformation in-depth; for some large enterprises when the number of R&D employees is large and the digital transformation breadth is the core condition, the supply chain resilience can be improved even if the R&D intensity is not enough. This shows that large enterprises can deepen the connection between supply chain members by widely deploying digital technology, which is significantly different from previous studies. Previous studies have shown that the breadth of digital technology asset deployment has no significant impact on the agility of the supply chain (Wamba et al. 2020), and the possible explanation for this finding is that previous research focused on the linear relationship of digital asset allocation, while our research reveals from the configuration perspective that for large enterprises, even if the digital transformation depth is not enough, as long as the number of R&D employees and digital transformation breadth as the core conditions, even if R&D investment is insufficient, the supply chain flexibility can be improved. For small enterprises, our research has also confirmed that the depth and breadth of digital asset allocation play an important role in improving supply chain resilience. The reason is that for small and medium-sized enterprises, even if R&D investment is insufficient, as long as there is enough R&D employees, the supply chain resilience can be improved. The possible reason is that with the outbreak of COVID-19, SMEs pay more attention to supply chain management and improve their ability to cope with risks by deploying digital assets. For SMEs, surviving during the epidemic is the most important goal at present. The in-depth deployment of digital transformation can improve the ability of SME enterprises to cope with the risk of supply chain disruption. Therefore, supply

chain resilience can be improved by deploying digital transformation assets for SMEs.

Paths 5 and 6 confirmed the role of R&D spending in improving supply chain resilience; our research results show that small businesses, even in the case other conditions do not present, as long as they have enough R&D employees, also can realize high supply chain resilience; and R&D employee is the most precious asset of small and medium-sized enterprises. In the case of more R&D employees, enterprises have stronger R&D capabilities and speed, so they are better able to quickly adapt to the risk of supply chain disruption in a crisis. For large firms, even if the digital transformation degree is not high, under the R&D employees and R&D intensity as the core conditions' presence, can also achieve high supply chain resilience. Our results confirmed that the role of R&D spending to supply chain resilience; the reason is that large companies have enough financial support, as well as plenty of R&D employees. It shows that the work of R&D employees is highly supported by the enterprise. Even though the current digitization level of the enterprise is not high, R&D employees can quickly develop related products or technologies to help the enterprise well away from risks or adapt to the new market and social needs by developing new products. Our conclusions show that manufacturing digital transformation is an important content of improving supply chain resilience and is also an important way to improve supply chain resilience, of which 6 paths configurations are obtained in this study; there are four configurations based on the digital transformation, which suggests the implementation of digital technology for manufacturing enterprises to improve risk response-ability and the supply chain resilience, but the paths 5 and 6 show that digital transformation is not the only way to improve supply chain resilience (Queiroz et al. 2022). For example, some SMEs may not invest a lot of funds to support digital transformation due to their scale and the limitations of R&D investment (Bak et al. 2020). Therefore, SMEs can implement digital transformation based on their reality. For large enterprises, the number of R&D employees can be expanded to improve the enterprise's ability to cope with risks and improve supply chain resilience (Chopra et al. 2021).

Compared with other previous studies, there are three main differences between our study and previous studies: First, compared with other previous studies, most of them studied digital transformation as a factor of a single dimension and rarely subdivided digital transformation into different dimensions; Second, previous studies mostly emphasize the enterprise itself has the resources; few studies have emphasized resource configuration, and the orchestration is very important to achieve the competitive advantage of the enterprise; therefore, this study based on the theory of resource arrangement, research enterprise besides has the resources and also needs to how to configure the asset for

high supply chain resilience as our 6 configurations have shown. Third, most previous studies on digital transformation are based on traditional linear regression to analyze the linear relationship between digital transformation and results, while this study is on how antecedent conditions are configured to produce high supply chain resilience from the configuration perspective. In conclusion, in addition to the six paths obtained, our study is substantially different from previous studies.

Implications

Theoretical significance

Our research contributes to the literature on supply chain management in the following three aspects. First, past studies have discussed the influence of digital assets employment in the digital transformation on supply chain management, as past research on supply chain management has concentrated on big data (Rialti et al. 2019), artificial intelligence (Toorajipour et al. 2021), blockchain technology (Cole et al. 2019), etc., while in normal supply chain operations, few enterprises only focus on a single digital technology's influence on supply chain; instead, they concentrate on enhancing supply chain capabilities through a combination of digital technologies. Digital assets work together to produce a better ecological environment, which might help the supply chain function normally. Compared with previous studies that only focused on digital assets' impact on supply chain operation, this paper studies the impact of two dimensions of digital transformation on supply chain resilience from a holistic perspective, which can more comprehensively reveal how digital transformation acts on supply chain resilience.

Second, this study expands the understanding of digital transformation from the perspective of resource orchestration (Sirmon et al. 2011). Past studies tend to explore the impact of digital transformation on the supply chain from the perspective of a resource-based view and dynamic capabilities, the resource-based view and dynamic capabilities can only reveal the resources and capacity to form the role of enterprise competitive advantage. From the perspective of resource orchestration theory, this study not only emphasizes the interaction of multiple resources but also proposes that digital transformation is divided into two dimensions: digital transformation breadth and depth from the perspective of resource orchestration, which extends previous studies on digital transformation (Sirmon et al. 2011). This study believes that for the normal operation of the supply chain, the common allocation and coordination between different assets is more important than the resources themselves (Chirico et al. 2011). In order to overcome these limitations of conventional research and better understand the effects of

digital transformation on supply chain resilience, it is possible to analyze the depth and breadth of digital transformation on supply chain resilience from the perspective of resource orchestration.

Third, the configuration theory and the QCA method are used in this work to overcome the methodological restrictions of traditional strategy research. There are few studies about how the antecedent conditions are configured to jointly lead to a certain result from the holistic perspective, and traditional research on digital transformation mainly based on traditional linear regression methods. As a result, this study is one of the few to apply the fsQCA technique to the fields of digital transformation and supply chain, which is in line with the call of international mainstream journals to extend the methodological foundation of the area of supply chain and offer new research methods (Ketchen et al. 2021). The study's findings verified the importance of the complex causal relationship between digital transformation and supply chain resilience. In this study, four of the six paths to high supply chain resilience are digital transformation driven, demonstrating the critical role of digital transformation in achieving supply chain resilience. Our analysis also showed that there were two main paths which are IT spending driven, suggesting that although the digital transformation is important, firms should implement a digital strategy tailored to their specific requirements. This explains why some studies claim that firms can benefit from and suffer losses from digital transformation.

Practical implications

First, the COVID-19 outbreak has exposed the supply chain's susceptibility, which also prompts firms to focus more on strengthening the supply chain's resilience to better manage risks. Digital transformation is the key way to improve the operation efficiency of the supply chain. Therefore, according to the conclusion of our study, enterprises can improve the ability of the supply chain to deal with risks by deploying diversified digital technologies and enhancing their application capabilities of digital technologies. However, our conclusion also shows that implementing digital transformation is not the only way to improve supply chain resilience. As a result, firms can implement their digital strategy in compliance with their unique conditions and the six paths our study suggests.

Second, by implementing the digital transformation, firms need to combine its breadth and depth because the use of diversified digital technologies can enhance relationships between supply chain participants and encourage data and information sharing between firms. And firms also need to strengthen the depth of the digital transformation, through the in-depth implementation of digital technology; firms can analyze the operation in real-time, monitor the possible risks

in the supply chain, and deploy some coping strategies in advance to improve the risk resistance of the supply chain. Therefore, supply chain managers can jointly improve supply chain resilience by deploying diversified digital technologies combined with the depth of digital transformation and fully mastering their implementation.

Third, conventional linear thinking should be abandoned by decision-makers who want to implement a digital transformation, and supply chain resilience cannot be enhanced by a single component. Supply chain resilience is also a comprehensive dimension; for the decision-makers of the enterprise, they should implement the digital strategy from the configuration and holistic perspective, and in addition to digital transformation, firms need to improve supply chain resilience from the other angle: for example, from the perspective of R&D investment and firm size, correctly implementing digital transformation should be considered from the macro and overall perspective.

Limitations and future research directions

Like other studies, this research also has the following limitations.

First: this research mainly from the perspective of resource orchestration theory is to investigate the influence of digital transformation, R&D investment, and firm size on supply chain resilience, but this research also can reveal the synergistic effect between digital transformation employment and several other factors; only limited explanations can be provided for enterprise resource selection and allocation. Therefore, future research can also be carried out from other perspectives, such as enterprise strategy, institutional logic, business model, and innovation.

Second: this study mainly explains how to improve supply chain resilience from the perspective of supply chain enterprises' resources, but in addition to their resources, firms still need to combine the resources among supply chain members, because the enterprise itself has limited resources, especially for the supply chain enterprises. In the future, we can discuss how to jointly allocate internal and external resources to improve supply chain resilience from the perspective of resource dependence theory.

Finally, we can investigate a current research issue that has appeared in supply chain management in the future. We might also look at a new supply chain research topic: supply chain viability (Ivanov 2021b; Münch and Hartmann 2022), and green supply chain and sustainable supply chain (Nureen et al. 2022; Fang et al. 2022; Jinru et al. 2021). Among them, supply chain viability is a higher state than supply chain resilience, through the implementation of key strategies at the operational, tactical, and strategic levels, to improve the maturity of the supply chain and help the supply chain withstand long-term disruptions

(Sarkar et al. 2022). And the research on green supply chain and sustainable supply chain is also a direction worthy of study in the future. Besides, this study mostly relies on secondary data to assess the relationship between digital transformation and supply chain resilience; however, data can be acquired in the future through questionnaires and interviews, which may give managers with new insights.

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Data availability Availability of data and materials can be accessed by the corresponding author.

Declarations

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