International Journal of Operations and Production Management

Unleashing the power of supply chain learning: an empirical investigation

Journal:	*International Journal of Operations and Production Management*
Manuscript ID	IJOPM-09-2022-0555.R2
Manuscript Type:	Research Paper
Keywords:	Supply chain learning, Operational resilience, Information processing theory, Supply chain management

Unleashing the power of supply chain learning: an empirical investigation

Abstract

Purpose – Organisational learning plays a critical role for firms to keep abreast of a supply chain environment filled with volatility, uncertainty, complexity, and ambiguity (VUCA). This study investigates the extent to which supply chain learning (SCL) affects operational resilience under such circumstances.

Design/methodology/approach – This study developed a research framework and underlying hypotheses based on SCL and information processing theory (IPT). An empirical test was carried out using secondary data derived from the 'Supply Chain Policy' launched by the Chinese government and two large related conferences.

Findings – SCL positively relates to operational resilience, and several moderators influence the relationship between them. We argue that digital-technological diversity could weaken the role of SCL in operational resilience, whereas customer concentration, and participating in a pilot programme could enhance the effect of SCL.

Practical implications – Firms should embrace the power of SCL in building resilience in the VUCA era. Meanwhile, they should be cautious of a digital-technological diversification strategy, appraise the customer base profile, and proactively engage in pilot programmes.

Originality/value – This research develops the SCL construct further in the context of China and empirically measures its power on operational resilience using a unique dataset. This contributes to the theorisation of SCL.

Keywords Supply chain learning, Operational resilience, Information processing theory, Supply chain management

1. Introduction

Organisational learning plays a critical role in a firm's success. By leveraging learning, organisations can better adapt to a dynamic business environment and increase their competitiveness, productivity, and innovation (Dodgson, 1993). In China, organisational learning is significant for firms' business and operations as well, largely because the business environment is fast-changing with high volatility, uncertainty, complexity, and ambiguity (VUCA). Under such circumstances, novel phenomena and new issues emerge constantly, yet no firms have prior experiences to refer to. Therefore, to seize potential opportunities and attain a competitive edge under fierce competition, firms should sometimes 'learn-by-doing', as expressed by a Chinese metaphor - '*crossing the river by touching the stones*'. In the supply chain context, organisational learning is even more important. This is the challenge posed by the harsh business environment and transition of competitive patterns, that is, the scenario where competition has been shifted from firms to supply chains (Christopher, 1992).

Moreover, the most challenging aspect is that the development of supply chain management (SCM) strategies and practices in China is still evolving (Liu and McKinnon, 2019). The supply chain environment has become more complicated and dynamic due to the development of newer forms of disruptive technology, supply shortages caused by the pandemic, and the unstable political environment (e.g. trade wars) (Alexander *et al.*, 2022; Sarkis, 2021). Therefore, to overcome these supply chain challenges, top managers are keen to absorb supply chain knowledge from their business partners. In other words, they are enthusiastic about reaping the rewards by leveraging supply chain learning (SCL).

Conceptually, SCL is derived from inter-organisational learning (Bessant *et al.*, 2003). According to Flint *et al.* (2008, p. 274), SCL occurs when '*multiple supply chain partners engaged in interaction where learning occurs and is focused on supply chain issues and solutions*'. Essentially, SCL goes beyond inter-organisational learning, which focuses on dyadic learning at an inter-firm level (Jia and Lamming, 2013), where supply chain members jointly learn to perform new activities, build new capabilities, and innovate (Silvestre, 2015). SCL is receiving increasing academic attention, with extant studies falling chiefly into three categories. The first, and largest, category focuses on the benefits of SCL, such as innovation diffusion (Flint *et al.*, 2005; Li *et al.*, 2018; Ojha *et al.*, 2016), performance improvement (Gosling *et al.*, 2016; Haq, 2021; Huo *et al.*, 2020; Spekman *et al.*, 2002), and dynamic supply chain capability cultivation (Aslam *et al.*, 2020). The second category concentrates on the triggers of SCL. For example, by investigating supply chain competency, Spekman *et al.*

(2002) found that multiple factors such as trust, communications, integrative mechanisms, decision-making style, and culture trigger SCL. Ojha *et al.* (2018) identified transformational leadership as a contributor to SCL in their exploration of supply chain ambidexterity. To study the factors enabling SCL, Huo *et al.* (2020) and Huo *et al.* (2021) identified IT applications and information sharing, respectively. Finally, the third category shows their interest in the conceptualised framework of the SCL process (Bessant *et al.*, 2003; Gong *et al.*, 2018; Silvestre, 2015; Silvestre *et al.*, 2020). Overall, SCL research is thriving, especially in recent years.

As SCM is evolving, many SCM phenomena have not been identified as of yet (Min *et al.*, 2019). This draws scholars' attention to the value of SCL, particularly in an era characterised by VUCA. To what extent is SCL valuable to supply chain managers for solving issues and problems and improving supply chain performance? The present study intends to explore the influence of SCL on operational resilience, an emerging performance indicator that is drawing the attention of academics and practitioners (DesJardine *et al.*, 2019; Li *et al.*, 2022b).

Operational resilience depicts the ability of a firm's operations to absorb and recover from disruptions (Essuman *et al.*, 2020). It is a crucial factor for firms to compete while countering difficult situations. It is known that operationally resilient firms can come up with alternate operational solutions when facing adversities. For example, during the COVID-19 outbreak, many manufacturers faced a severe disruption of upstream and downstream supply chains. Since disruptions happen regularly for firms and their supply chains in the VUCA context (Alexander *et al.*, 2022), resilience-building has become a major task for managers. Additionally, acquiring operational resilience is essential because a firm's operations act as a unique subsystem of the organisation, a principal value-creation function that produces revenues, and is also the immediately affected system under a disruption (Essuman *et al.*, 2020). Given that in emerging economies, supply chain disruption is a major vulnerability (Aman and Seuring, 2021), probing into the power of SCL on operational resilience in China is meaningful.

However, some circumstances could diminish or reinforce the effect of SCL on operational resilience. In a VUCA era filled with digital transformation and social-political changes, three scenarios - digital power, market trends, and institutional arrangements - which exert substantial influences on business and operations, cannot be ignored. Exploratorily, with the advent of digital economy, digital technology is rapidly transforming the business landscape, leading to greater efficiency and quality (Westerman and Bonnet, 2015). Accordingly, the market is witnessing new trends, as customers are demanding increasingly sophisticated requirements in their service experiences (Min *et al.*, 2019). Further, to meet the many new challenges, institutional support is becoming critical, especially in emerging economies (Wei *et al.*, 2020). In this sense, this study is intended to investigate the extent to which these emerging circumstances may impact the relationship between SCL and operational resilience in China. Specifically, this study concentrates on three factors related to these scenarios: digital-technological diversity, customer concentration, and pilot programme. Digital-technological diversity points to the application of diverse digital technologies, a factor that enables firms to move towards a more productive and sustainable business (Chauhan *et al.*, 2022). Customer concentration reflects the concentration of the firm's customer base as an important element that improves firms' operations (Patatoukas, 2012). Pilot programmes are an institutional arrangement related to government policy that encourages firms to initiate business in an uncertain environment. Building upon these considerations, this study seeks to answer the following two research questions:

- RQ1: To what extent does SCL contribute to operational resilience?
- RQ2: How does the influence of SCL on operational resilience vary under different moderators (i.e. digital-technological diversity, customer concentration, and a pilot programme)?

To better explain the phenomenon of SCL observed in the China's supply chain environment, we adopt the theoretical lens of information processing theory (IPT). IPT posits how firms can effectively utilise information to perform well, especially when facing a high level of uncertainty (Galbraith, 1974). As Huber (1991) stated, an organisation learns through its processing of information. Several studies have applied IPT to explain organisational learning. For instance, Xie *et al.* (2022) verified that organisational learning could help firms improve their organisational resilience capacity. Wei *et al.* (2011) claimed that intra-organisational learning could promote a firm's exploratory innovation. Likewise, Ignatius *et al.* (2012) revealed the positive influence of intra-firm technological learning on project success in new product development. In the context of SCM, some authors adopted IPT to explain supply chain phenomena, such as sustainable SCM (Busse *et al.*, 2017), supply chain integration (Flynn *et al.*, 2016), supply chain disruptions (Bode *et al.*, 2011), and so on. The tenet for such use, as Busse *et al.* (2017) ascertained, comes from the close tie between IPT and the very essence of SCM. In this case, IPT has the potential to predict SCL phenomenon.

Apart from the theoretical conjecture, an empirical investigation was carried out from the announcement of the first 'Supply Chain Policy' in China and the two resulting large-scale conferences, to answer the research questions posed above. In October 2017, the Chinese government introduced a policy, '*the Guideline on Promoting Supply Chain Innovation and Application*' (SCIA), to promote SCM development in China (General Office of the State Council, 2017). Given that this was the first national document on the Chinese supply chains, this policy is recognised as a milestone in Chinese SCM. The measurement of SCL was therefore performed via a unique conference dataset closely related to the SCIA policy.

The present study makes contributions to the research in the following ways: First, we further develop the SCL construct in the contextualised setting of China. We argue that the content of SCL in China is not confined to the knowledge of supply chains only. The indigenous knowledge specific to supply chain policies should be incorporated, given the critical role the Chinese government played in promoting SCM. Further, we develop a novel SCL measurement using a unique secondary dataset. The methods adopted by prior empirical studies are case- or/and survey-based. The former may have limited generalizability, and the latter, especially those with single-source respondents, face potential common method bias. However, secondary data can address these concerns by utilising longitudinal and multi-source datasets. Second, this study includes operational resilience as a valuable component influenced by SCL, which the extant literature has not focused on. Moreover, to better understand SCL, three factors are taken to examine the interaction between them (intrinsic or extrinsic) as well as their relationship. Third, this study is the first attempt to use the theoretical lens of IPT to interpret the SCL phenomenon. This offers a new lens to explain SCL.

The remainder of this paper is structured as follows. The following section offers a literature review of SCL and IPT. Section 3 develops research hypotheses, including the effect of SCL on operational resilience and the moderating role of three factors. Section 4 describes the research design. Section 5 presents empirical results and robustness tests, and Section 6 discusses the implications and limitations of this study, and future directions of research.

2. Literature review and theoretical underpinning

2.1 Supply chain learning (SCL)

SCL posits multiple supply chain members engaged in learning, where the supply chain is a '*vehicle*' for gathering knowledge and learning (Spekman *et al.*, 2002, p.42). SCL is about both knowledge diffusion (Biotto *et al.*, 2012) and knowledge creation (Lambrechts *et al.*, 2012). Knowledge diffusion is the process through which knowledge is disseminated and used by other organisations (Lane *et al.*, 2021). Knowledge creation concerns '*knowledge addition and/or the correction of existing knowledge*' (Shin *et al.*, 2001, p.340). Nonaka (1994) argued that knowledge creation could occur within an organisation or through inter-organisational interaction. The process of SCL, as Bessant *et al.* (2003) proposed, could consist of three stages: setting-up, operating, and sustaining. Specifically, setting-up converges learning drivers to establish a learning environment, operating allows processes to address the learning agenda, and sustaining establishes benchmarking and measurements to maintain continuous learning.

SCL may have a positive impact on business performance. Flint *et al.* (2008) found that SCL could positively affect a firm's innovation, and hence its performance. Lisi *et al.* (2020) examined SCL in sustainable development and identified a positive relationship between green SCL and green innovation. In addition, some authors (e.g. Haq, 2021; Huo *et al.*, 2020; Huo *et al.*, 2021) have considered supplier learning, customer learning, and internal learning as dimensions of SCL and discovered that the latter two types were pertinent to operational performance, service performance, and flexibility performance, though supplier learning was not. Moreover, Haq (2021) reported that SCL could affect a firm's financial performance via other factors, such as the mediating role of operational performance. Nevertheless, a close examination of the extant literature yields no evidence on the influence of SCL on operational resilience. This gap suggests the need for an exploratory study in this area.

2.2 Information processing theory (IPT)

As Galbraith (1974) indicated, IPT identifies how an organisation can deal with uncertainty through information processing. The key elements of IPT can be identified as information processing needs, information processing capacity, and the congruence between needs and capacity (Tushman and Nadler, 1978). Processing needs are the information required by an organisation's strategy or environment (Egelhoff, 1991; Tushman and Nadler, 1978). As Galbraith (1974) noted, uncertainty creates information processing needs. Processing capacity refers to organisations' capability to utilise and structure information to efficiently support decision-making (Cegielski *et al.*, 2012).

According to IPT, an organisation may cope with increased uncertainty by either reducing the amount of information it needs or strengthening its capacity to process information (Galbraith, 1974). Normally, at the organisational level, uncertainty arises mainly from three aspects: task characteristics, interfirm relationships, and external environment (Bensaou and Venkatraman, 1995; Premkumar *et al.*, 2005). The interdependent nature of firms' tasks, as Cegielski *et al.* (2012) stated, could contribute to the degree of uncertainty firms face. This kind of uncertainty is also called as task uncertainty. Such uncertainty may arise from the complexity of a task, where higher complexity would create a higher level of uncertainty (Tushman and Nadler, 1978). Inter-organisational relationships are concerned with the connection between firms and their business partners (Bensaou and Venkatraman, 1995). In a supply chain, many factors influence the relationship between supply chain actors. To maintain a tight relationship, significant information is needed for processing (Premkumar *et al.*, 2005). The firm's external environment may also expose the firm to uncertainty (Cegielski *et al.*, 2012), arising from natural disasters, wars, political crises, market turbulence, technology advancement, and so on. The greater these uncertainties, the more information processing is required.

Another important implication of IPT is the fit between information processing needs and capacity. A better fit increases the likelihood of the best performance, where a poor fit could hinder performance (Egelhoff, 1991; Galbraith, 1974). This is because the misfit between information processing needs and capacity could result in schedule and budget overruns, as insufficient capacity cannot support decision-making; conversely, too much capacity incurs excess unnecessary costs (Galbraith, 1974; Tushman and Nadler, 1978). Empirical studies supported the rationale behind 'fit'. For example, Premkumar *et al.* (2005) identified a positive influence of matched information processing needs and capacity on procurement performance. Concerning IPT, Cheng and Krumwiede (2018) found that when knowledge processing capacity can handle the amount of knowledge required, firms obtain greater new product development gains. Likewise, Stock *et al.* (2021) confirmed a positive effect of the fit between knowledge processing needs and capacity by observing the knowledge-sharing requirements and knowledge-sharing quantity.

3. Hypothesis development

3.1 SCL and operational resilience

In IPT, the idea of 'fit' indicates that the performance of firms will suffer from the misalignment of information processing needs and capacity (Galbraith, 1974; Tushman and Nadler, 1978). Hence, to cope with uncertainty, firms can choose to either increase their processing capacity or decrease their processing needs (Galbraith, 1974). Supply chain actors engaging in SCL can be viewed as choosing a path to increase their knowledge processing capacity because SCL can provide firms with access to valuable knowledge from upstream suppliers, downstream customers, and third-party knowledge providers. Thus, through SCL, firms can enhance their capacity to utilise and structure current know-how and absorb and exploit new knowledge to advance supply chain operations, which fits well with Cegielski *et al.*'s (2012) interpretation of processing capacity.

We argue that SCL could enable firms to make a timely adjustment to operate stably and effectively in a highly uncertain business environment. First, given that SCL is characterised as boundary-spanning learning, firms can acquire operational experience and knowledge generated by other supply chain members. They can integrate them with their knowledge base. This may open gateways to new technical and administrative know-how that departs from extant organisational memory, increasing the opportunities for innovation and enhanced flexibility (Bao *et al.,* 2012). As SCL stimulates the combination of existing and newly learnt knowledge, firms incurring marginal time, effort, cost, or performance penalties are at an advantage to innovate (Zhu *et al.*, 2018a). The enhanced innovation further augments a firm's ability to develop alternative solutions geared toward resisting external uncertainty, significantly improving its operational resilience. Based on Ngai *et al.* (2011), we inferred that SCL could consistently provide supply chain members with the most cutting-edge knowledge on systems, procedures, technology, and benchmarking, enabling them to respond to task uncertainty quickly and efficiently.

Second, SCL can yield useful insights. Specifically, processing valuable knowledge from external stakeholders helps firms become more sensitive to upstream, downstream, and market changes (Tse *et al.*, 2016; Wang *et al.*, 2019). For example, learning from upstream suppliers indicates that firms are more likely to gain insights associated with supply market dynamics, which ultimately enable firms to respond effectively to supply uncertainty via adjusting production plans (Huo *et al.*, 2021). Meanwhile, learning from customers can help firms to know more about the market, which could assist them in reorganising their resources and capabilities (Huo *et al.*, 2021; Wang *et al.*, 2019). Additionally, through learning from third-party knowledge providers (e.g. industrial associations, third-party service providers, and competitors), firms are more likely to coordinate operational activities to reduce risk, contributing to their sustainable operations and stability in the face of external change.

Finally, and most importantly, SCL can help firms use best practices in which supply chain partners have successfully coped with the change and proactively responded to market changes, such as applying disruptive technologies to facilitate operations to withstand adversity (Modgil *et al.*, 2022). As Burnard *et al.* (2018) indicated, learning about the experiences of threats and disruptions from others could facilitate the development of resilience. According to the above arguments, we conjecture that:

H1. SCL positively impacts a firm's operational resilience.

3.2 Moderating factors

As postulated above, SCL may affect operational resilience; however, a better understanding of when and how SCL can improve such resilience is useful. Therefore, the moderating role of three factors - digital-technological diversity, customer concentration, and the pilot programme - as noted at the outset, are to be examined below.

3.2.1 Digital-technological diversity

Digital technologies are a combination of 'information, computing, communication and connectivity technologies' (Bharadwaj *et al.*, 2013, p. 471). Emerging digital technologies such as cloud computing, big data, artificial intelligence, and 3D printing have profoundly influenced business operations (Nambisan, 2017; Liu *et al.*, 2022a) and are closely linked to improving firms' resilience (Remko, 2020). Digital-technological diversity signifies the breadth of a firm's digital-technological portfolio.

Diversified digital technologies hold the promise to advance operations and enable intelligent and autonomous operational tasks (Choi *et al.*, 2022; Fatorachian and Kazemi, 2018), thus reducing task complexity. Tushman and Nadler (1978) assumed that complex tasks could create difficulty in predictability, and therefore incur greater information processing needs. This suggests that digital-technological diversity is likely to decrease the knowledge processing needs and weaken the role of learning in building resilience accordingly. In addition, the uncertainty caused by rapid technological advances could be mitigated by the broader digital technology portfolio of firms with more advantages in seizing emerging technological opportunities from scientific breakthroughs (Bolli *et al.*, 2020;

Subramanian *et al.*, 2018). In such cases, on the one hand, a diversified technical base could hinder interfirm knowledge transfer in SCL. Han *et al.* (2018) pointed out that the strongly increased overlapped knowledge reduces learning opportunities. Song *et al.* (2003) recognised that the interfirm knowledge transfer is more likely to happen on the condition that firms possess different technological expertise, as their current technological trajectory might affect the receptivity to knowledge gained from the outside. If firms' operational activities proceed along established technical paths, then they are less likely to incorporate external knowledge (Song *et al.*, 2003). Therefore, a diversified technological base, which indicates that the firm possesses knowledge in a broad range of technology domains, with established technological trajectories, practices, and procedures, would lower a firm's openness to knowledge sourced from external stakeholders through SCL.

On the other hand, leveraging diversified digital technologies could also reduce the value of knowledge gained via SCL in shaping a resilient organisation. Marhold and Kang (2017) argued that the need for firms to acquire external knowledge becomes less urgent as they can use their diverse internal knowledge to create alternative solutions when facing disruptions. This is also applied to the case of SCL: when disruptions occur, digital-technological diversity enables firms to develop novel solutions. This is because firms are exposed to diverse technological knowledge, a vital precondition of successful knowledge recombination. Apart from this, firms are more likely to develop flexible and outside-the-box thinking since they see how problems could be solved differently (Gao *et al.*, 2015). Thus, the second hypothesis is postulated as follows:

H2. The greater a firm's digital-technological diversity, the less positive the influence of SCL on its operational resilience.

3.2.2 Customer concentration

Of all the inter-organisational relationships, customers are the most pivotal for revenue generation (Yli-Renko and Janakiraman, 2008). Given that operations are a primary value-creation function to produce revenues, major customers have the power to influence a firm's strategies and practices at the operational level. Therefore, the influence of customers requires consideration.

Customer concentration is the extent to which a firm depends upon its major customers for financial resources (Zhu *et al.*, 2021a; Kim and Zhu, 2018). It is a critical characteristic that depicts the relationship between a firm and its customers (Huang *et al.*, 2016). A higher customer concentration, indicated as a more concentrated customer base, will decrease the firm's bargaining power, and consequently, make the firm more reliant on its customers (Liu *et al.*, 2022b). In addition, the firm is more prone to lower profitability (Hui *et al.*, 2019) and faces more uncertainty in long-term survival.

Regarding inter-organisational relationships, a higher dependence on other supply chain members indicates a firm's lack of control and power, and would bring about greater uncertainty (Bode *et al.*, 2011; Flynn *et al.*, 2016). Therefore, higher knowledge processing needs could be expected in firms with more concentrated customers. In this case, the positive effect of SCL on operational resilience could be magnified. First, the knowledge gained from SCL can be easier to transfer and apply in addressing supply chain disruptions when firms have a more concentrated customer base. Firms tend to invest more resources to build strong relationships and foster mutual trust with their major customers, which could contribute to the quality and efficiency of knowledge acquisition (Zhou *et al.*, 2014). Meanwhile, the firm's knowledge may be idiosyncratic and context-specific. Hence, using this knowledge to deal with disruptions effectively means that firms must apply the knowledge they learnt their own context and the knowledge must have a certain level of tailoring (Maritan and Brush, 2003). It must be noted that a dispersed customer network largely improves the difficulty of knowledge application, since it is hard for focal firms to customise knowledge based on the characteristics of a large customer base.

Second, for firms with more concentrated customers, processing and applying the knowledge obtained through SCL is more effective. This is because when a firm is highly dependent upon major customers, the change in one major customer's demand could directly impact the firm's operations (Zhu *et al.*, 2021a). The knowledge gained from those major customers is of great significance in sensing and responding to the demand change, enabling firms to remain operationally stable and flexible. Bode *et al.* (2011) have a consistent view that firms tend to maintain stable relationships with customers upon whom they depend significantly. This increases firms' motivation to maintain stability by taking proactive steps to cope with the increasing uncertainty. For instance, by learning about supply chain partners' experiences of coping with emergencies, firms may learn how their customers would respond in similar situations and make corresponding reactions, such as modifying production schedules, changing market strategies, and developing new products. Thus, we propose our third hypothesis:

H3. Customer concentration positively affects the relationship between SCL and operational resilience.

3.2.3 Pilot programme

The term 'pilot' is political in nature with the tenet of 'experimentation'. It is 'reserved for rigorous early evaluations of a policy… before that policy has been rolled out nationally and while it is still open to adjustment' (Jowell, 2003, p. 11). A pilot programme refers to a policy programme restricted by geography and time (Ettelt *et al.*, 2015). As Bailey *et al.* (2017) stated, policymakers choose to implement pilot programmes due to some degree of '*ambiguity and conflict around the conception and implementation*' (p. 211) of a particular policy. Since the role of a pilot programme is to test the likely impact of a policy before it is fully implemented, the result of pilot programmes would result in the proof of the policy's effectiveness, its adjustment, or even its abandonment (Jowell, 2003).

Pilot firms are selected to implement and engage in the pilot programme. Pilot firms accumulate practical experience learnt from performing an action and maintain an attitude of curiosity in the face of new challenges (People's Daily, 2018). The pilot programme is in line with the 'learning-by-doing' process; that is, pilot firms need to test the new ideas instead of duplicating existing paradigms. Hence, these firms have little experience to follow and no predecessors to learn from. Thus, pilot firms face a higher level of uncertainty thanks to the uncertain business world. To perform well and achieve the policy goals, pilot firms have greater knowledge processing requirements.

By investigating the role of national policy pilots, Ettelt *et al.* (2022) suggested that pilot programmes encouraged experimentation with ideas and development of innovative solutions. This argument implies that pilot firms are early pioneers of innovative operation modes or processes, which enables them to generate unique technical and administrative know-how. Therefore, given that a key task of the pilot programme is to test potential practices and disseminate successful experience, pilot firms have more incentives to actively engage in SCL and diffuse their experience or learn from others. Additionally, their supply chain partners are also more likely to engage in the learning process to acquire their valuable knowledge. The frequent communication and deep involvement of multiple supply chain actors indicate that more valuable knowledge would be shared and disseminated through SCL. Moreover, pilot firms will then better apply knowledge to facilitate operational resilience. Li *et al.* (2022a) assumed that a pilot programme provides firms preferential treatment from the government such as the additional support of dedicated policies and funds. Thus, pilot firms are equipped with more resources that can be organised to absorb relevant knowledge to deal with emergencies. In this way, SCL-induced knowledge processing fits well with the pilot firms' enhanced processing requirements, leading to outstanding performances. Based on this, the last hypothesis is posited as follows:

H4. A pilot programme positively moderates the relationship between SCL and operational resilience. The relationship will be stronger for pilot firms compared to non-pilot firms.

The proposed research framework summarising the above hypotheses is shown in Figure 1.

Insert Figure 1

4. Research design

4.1 Construct development of SCL and data collection

As noted earlier, the research context is grounded on the first 'Supply Chain Policy' issued by the Chinese government in 2017, named '*the Guideline on Promoting Supply Chain Innovation and Application*' (SCIA). The China Federation of Logistics & Purchasing (CFLP) is the most influential organisation in the Chinese SCM community. As one of the policy panel members, the CFLP held several events disseminating the SCIA policy, such as conferences, pilot programmes, and training. These activities were meant to allow firms to experiment and innovate with supply chain operations.

In May 2018 and November 2019, the CFLP organised two conferences for disseminating the SCIA policy. Due to a 'top-down' policy implementation strategy in China, the SCIA policy was interpreted by government officials at the conferences. They encouraged firms to pursue supply chain innovation. However, without the government officials' and experts' interpretation and explanation, the participating firms might overlook some key issues in the SCIA policy paper. Therefore, the two conferences provided excellent opportunities for participating firms to learn about the practices of supply chain innovation under the SCIA policy framework. In this regard, the first conference aimed to introduce and explain the SCIA policy and share knowledge about its implementation. The second conference served a similar purpose, but it further reinforced the key features of the first conference. Most importantly, some firms were invited to respond to the SCIA policy and share their successful experiences.

Essentially, the CFLP provides an effective platform for firms to engage in SCL. Various supply chain actors may obtain supply chain-related knowledge, such as the conception of supply chain innovation, disruption technologies and their applications, best SCM practices, and resource accessibility provided by SCIA. Although the conferences did not offer formal academic-style lectures, they served as a knowledge hub in which all participating firms could share successful cases and useful knowledge and learn from each other's experiences. Specifically, in a conference, various activities such as keynote speeches, parallel presentation sessions, round table discussions, industrial exhibitions, and other social engagements (such as tea breaks and buffet/gala dinners) can provide opportunities to observe how others operate, ask questions, share stories, communicate casually (Aramo-Immonen *et al.*, 2016), and share and reflect on others' practices and experiences (Jeong *et al.*, 2018), which offer different forms of informal learning. Following on from Hartley and Allison (2002), we infer that participating firms could gain knowledge of SCM practices of other supply chain members as well as from the policy interpretation and speeches presented by government officials and experts at these two conferences. Participating firms then acquired, transferred, assimilated, and exploited this knowledge. In addition, these firms were members of different supply chains and occupied different supply chain positions. It should be noted that, under such a setting, the content of SCL has exceeded the traditional sense of SCL, that is, knowledge of supply chains; rather, it goes to the knowledge of supply chain policies, which is indispensable for Chinese firms to enjoy SCL.

Moreover, the construct development of SCL in the present study also fits with Bessant *et al.* (2003)'s three phases of SCL. In the setting up phase, triggers converge, and a learning network is established, probably by a third party. The present study examined two conferences organised by the CFLP to respond to firms' rising demand for supply chain-related knowledge. Next, some core processes, such as network creation (i.e. identifying and maintaining conference memberships), information management activities (e.g. keynote speeches, parallel presentation sessions, etc.), are aligned with the operating phase of SCL. Finally, the sustaining stage of SCL has a twofold mechanism: the consecutive annual conference setting and the benchmarking framework, built upon the model of leading pilot firms. Thus, the SCL construct was identified from the two conferences based on the agenda and list of participating firms provided by the CFLP.

Among the participating firms mentioned above, this study targeted the publicly listed firms. Figure 2 depicts the data collection process. The list provided by the CFLP shows that the conferences had 711 participating units consisting of 645 firms and 66 government agencies, industrial associations, and universities. In the second step, we also cross-checked the data to avoid missing information. Particularly, we searched the public information about two conferences on the internet (e.g. through news articles, company news, and some conference pictures) to verify participating firms. Additionally, we collected information about the keynote speakers, participants in the roundtable discussion and parallel forums, industrial exhibitions, and senior membership of the advisory board from official websites and news releases. Next, we checked whether the 645 participating firms were listed firms using TianYanCha, a widely accepted data source containing information about Chinese firms. This check yielded 79 listed firms that engaged in SCL. To test the moderating role of the pilot programme, we collected relevant data from a specific pilot programme launched in October 2018, to implement SCIA effectively and ensure supply chain innovation. In the programme, 266 firms were accredited as pilot firms. We then verified whether the 79 listed firms were approved as pilot firms or not. Finally, other data were collected from the China Stock Market & Accounting Research (CSMAR) database, a leading and widely used data source for Chinese listed firms, related to the 79 sample firms between 2018 and 2019. Owing to missing data, the final sample consisted of 130 firm-year observations.

Insert Figure 2

4.2 Construct measurement

Table I presents the construct and measurement, which also notes the data sources.

Insert Table I

SCL. As indicated above, three binary indicators were developed to measure SCL. First, participation: did the firm participate in the conference? (yes=1, no=0). Second, the extent of communication and interaction: did the firm communicate and interact with other supply chain members during the conferences, such as giving a keynote speech, chairing the roundtable discussion, engaging in parallel forums, or setting up an exhibition? (yes=1, no=0). Third, membership: was the firm nominated as a senior member in the advisory board responsible for proactively sharing experiences as well as communicating and providing valuable insights and suggestions? (yes=1, no=0).

Operational resilience. Following Li *et al.* (2022b), operational resilience is measured as the change in operating revenue per unit production cost (ORPPC) before and after facing external adversity, as shown in equation (1). This is because, within a given period, a smaller decline in a firm's performance indicates greater resilience. For example, for operational resilience in 2019, we set the average ORPPC from 2016 to 2018 as the benchmark.

$$Operational\ resilience = \frac{ORPPC_t}{\sum_{t-3}^{t-1} \frac{ORPPC}{3}} \tag{2}$$

Digital-technological diversity. The measurement of digital-technological diversity follows that of prior studies dealing with digital transformation and diversity. The digital transformation literature (see Tu and He, 2022; Wu *et al.*, 2022) identified firms' adoption of digital technologies using the occurrence of certain keywords in firms' open reports. As in other studies on diversity (Kahiluoto *et al.*, 2020), digital-technological diversity was calculated as in equations (2) and (3). f_i is the frequency of a certain keyword for each firm and F is the total keyword frequency of all the digital technologies of this firm. H equals zero when the firm adopted only one kind of technology, and H increases as the number of technologies and/or the evenness among different technologies increased. Then, to facilitate interpretation, digital-technological diversity was calculated by the exponential of H, such that the index could be explained on a linear scale. Digital-technological diversity is equal to zero when firms do not adopt digital technologies.

$$H = -\sum_{i=1}^{n}\left(\frac{f_i}{F} \times \ln\frac{f_i}{F}\right) \tag{3}$$

$$digital - technological\ diversity = e^H \tag{4}$$

Customer concentration. As with prior studies (e.g. Zhu *et al.*, 2021a), customer concentration was assessed by utilising the ratio of the top five customers' sales to the total annual sales.

Pilot programme. The pilot programme is one of the important dissemination activities to promote the SCIA policy. The measure was evaluated as a dummy variable determining whether a firm is included in the policy programme.

Control variables. A set of control variables encompassing both firm and industry levels were considered to remove alternative influence factors of operational resilience. The five variables are age, size, profitability, R&D intensity, and state ownership at the firm level. Firm age represents the years since incorporation, which was logarithm-transformed. Firm size was measured as the natural logarithm of the number of employees. Firm profitability was measured by the return on assets. As to R&D intensity, the consideration was to control for the firms' innovation. Finally, state ownership was a dummy variable equal to 1 if the firm is state-owned and 0 otherwise to indicate whether the state is the ultimate controller of a firm.

At the industry level, industry concentration and munificence, were controlled. Industry concentration was measured as the sum of the squared market share of each firm that operates in the same industry. Industry munificence represents firms' growth possibilities. Specifically, the industry-level total sales for the previous ten years were regressed in time for each industry and sample year. Industry munificence was measured as the regression slope coefficient divided by the mean sales in the same timespan (Jacobs *et al.*, 2015).

4.3 Research modelling

Various control variables were included in the model to reduce the endogeneity concerns. Additionally, firm-level fixed effects were controlled to remove any unobservable time-invariant firm characteristics. Similarly, the year-level fixed effect helped capture those unobservable time-specific effects.

To test ***H1***, we constructed the regression model to estimate how SCL is related to a firm's operational resilience, as Equation (4) below shows:

$$\begin{aligned} Operational\ resilience_{i(t+1)} = {} & \beta_0 + \beta_1\ Supply\ chain\ learning_{it} \\ & + \beta_2 Firm\ age_{it} + \beta_3 Firm\ size_{it} + \beta_4 Firm\ profitability_{it} \\ & + \beta_5 R\,\&\,D\ intensity_{it} + \beta_6 State\ ownership_{it} \\ & + \beta_7 Industry\ concentration_{it} + \beta_8 Industry\ munificence_{it} \\ & + \alpha_i + \delta_t + \varepsilon_{it} \end{aligned} \tag{5}$$

To test for the moderating effect (***H2-H4***), the moderators (i.e. digital-technological diversity, customer concentration, and pilot programme) and their interactions with SCL were added separately in Equation (5), as follows:

$$\begin{aligned} Operational\ resilience_{i(t+1)} = {} & \beta_0 + \beta_1\ Supply\ chain\ learning_{it} \\ & + \beta_2\ Moderator_{it} + \beta_3\ Supply\ chain\ learning_{it} \times Moderator_{it} \\ & + \beta_4 Firm\ age_{it} + \beta_5 Firm\ size_{it} + \beta_6 Firm\ profitability_{it} \\ & + \beta_7 R\,\&\,D\ intensity_{it} + \beta_8 State\ ownership_{it} \\ & + \beta_9 Industry\ concentration_{it} + \beta_{10} Industry\ munificence_{it} + \alpha_i + \delta_t + \varepsilon_{it} \end{aligned} \tag{6}$$

Where α_i and δ_t indicate firm- and year-level fixed effects, respectively. ε_{it} represents the error term. To avoid the potential influence of multicollinearity, variables were mean-centred to compute interaction terms. A one-year lag for all independent and control variables was employed to cope with the reverse causality concern and reflect the causal relationship.

5. Results

5.1 Empirical findings

Table II presents the summary of correlations, means, and standard deviations of all variables. The correlation coefficients were below 0.40, indicating a low likelihood of multicollinearity. Table III exhibits the results with six models based on the regression analysis. Model 1 shows all control variables and the firm/year-level fixed effects. Model 2 adds the independent variable SCL to the previous model. Models 3 to 5 add the moderators of digital-technological diversity, customer concentration, and pilot programme, respectively. Finally, Model 6 includes all three moderators and interaction terms.

First, Table III shows that the coefficient of SCL was significantly positive in Model 2 ($\beta = 0.035, p < 0.05$), indicating that SCL is positively related to a firm's operational resilience; hence ***H1*** was supported. Regarding the moderating effects, the interaction between SCL and digital-technological diversity was significantly negative ($\beta = -0.016, p < 0.05$ in Model 3, $\beta = -0.014, p < 0.05$ in Model 6). Thus, ***H2*** was supported. There was a significant positive interaction between SCL and customer concentration ($\beta = 0.230, p < 0.01$ in Model 4, $\beta = 0.214, p < 0.01$ in Model 6). Accordingly, ***H3*** was supported. Similarly, the positive coefficient of the interaction term indicated a positive moderating effect of the pilot programme ($\beta = 0.068, p < 0.05$ in Model 5, $\beta = 0.072, p < 0.05$ in Model 6). Thus, ***H4*** was supported.

Insert Table II

Insert Table III

To better understand the moderating effect, simple slopes at the high (+1 standard deviation above the mean) and low (−1 standard deviation above the mean) levels of corresponding moderators were plotted. As shown in Figure 3a, when a firm has a high level of digital-technological diversity, the simple slope was not statistically significant (β=-0.021, p>0.1). In contrast, the simple slope was positively significant (β=0.042, p<0.05) with low diversity. These results indicated an interference effect of digital-technological diversity. Concerning customer concentration, a higher concentration would lead to a higher level of operational resilience (β=0.060, p<0.01), while insignificant association (β=-0.039 p>0.05) was shown under a low level of concentration (see Figure 3b). Figure 3c shows that firms participating in the pilot programme see a significantly positive influence of SCL (β=0.046, p<0.01), while an insignificant effect (β=-0.026, p>0.1) was present for non-pilot firms.

Insert Figure 3

5.2 Robustness tests

Table IV summarises the results of the robustness tests. Due to limited space, only the results for the hypothesised variables were reported. First, we replaced the measurement of the dependent variable. The time window to calculate operational resilience was changed from a three-year window to a wider range, namely, four years, to capture the change in a firm's performance in a longer time interval. The results were largely consistent with the above findings.

Second, two alternative measures of digital-technological diversity were employed. First, the digital technology-related keywords were further classified into five categories: artificial intelligence, blockchain, cloud computing, big data, and digital technology application. Digital-technological diversity was then calculated based on the new classification. Second, we used industry-adjusted digital-technological diversity as the proxy, computed as the firm's digital-technological diversity divided by the average diversity value of all firms from the same industry, to address industry heterogeneity. The findings remained unchanged.

Third, as the measure of the pilot programme was a dummy variable, a new scale was used. After the initiation of the pilot programme, the pilot firms' performance was evaluated, and those that outperformed were chosen to act as demonstration firms. Taking this differentiation into account, demonstration firms, that is, firms that performed better in the programme, were assigned a higher value (i.e. 2), and the rest of the pilot firms were set a lower value (i.e. 1). This gave rise to consistent results.

Then, an additional control, operational efficiency, was included to support our research further. The efficiency level indicates the amount of operational resources that could be leveraged to survive crises (DesJardine *et al.*, 2019). Referencing Lam *et al.* (2016) and Zhu *et al.* (2021b), operational efficiency was measured using stochastic frontier estimation, modelling the firm's relative efficiency by converting operational input resources (i.e. the number of employees, cost of goods sold, and capital expenditure) into operational output (i.e. operating income). The results were still consistent.

Insert Table IV

6. Discussion and implications

The study develops the construct of SCL and empirically examines its impact on operational resilience in China. Moreover, three moderators are used to test whether the relationship between them varies. The empirical analysis results are interesting. SCL enables firms' resilience-building, and the relationship between SCL and operational resilience weakens with high digital-technological diversity. It is enhanced through a concentrated customer base and firms' engagement in the pilot programme. The discussion and implications of the results are provided as follows.

6.1 Research and theoretical implications

6.1.1 Development of the SCL construct

A close examination of extant SCL literature finds that the content of SCL is concerned with SCM-related knowledge. In the present study, the construct of SCL is conceptualised and further developed in a Chinese context. Given that the Chinese government plays a significant role in promoting SCM (e.g. the announcement of the SCIA policy), for which SCL is encouraged, the knowledge associated with supply chain policies announced by the Chinese government is supposed to be essential. This finding corroborates the discourse regarding the undertaking of SCM studies in China. Indeed, the uniqueness of the socio-economic setting makes China an interesting and appropriate research context for SCM, and the SCM phenomena in China have distinct features (Liu and McKinnon, 2016). Moreover, exploring the Chinese SCM phenomena requires an intimate understanding of the contexts, particularly the prominent role of the government (Liu and McKinnon, 2019). An extension of SCL to the policy environment verifies this need.

6.1.2 Effects of SCL on operational resilience

While many efforts were carried out to investigate the possible influence of SCL, few empirical studies investigate the relationship between SCL and operational resilience. Drawing upon IPT, our results verify the positive role of SCL to operational resilience, demonstrating the importance of SCL for firms' survival in a VUCA environment. The study contributes to the SCL literature by extending the current understanding of SCL. SCL helps firms to resist adversity by increasing firms' knowledge processing capacity. On the one hand, this finding supports the claim of Zhu *et al.* (2018b) that the performance of firms could be promoted through increased processing capability, given that the VUCA era induces greater knowledge processing needs. This finding corroborates the results of prior empirical studies on the benefit of SCL regarding a firm's operations (Haq, 2021; Huo *et al.*, 2021). Additionally, the present study is consistent with studies identifying the role of learning in enabling a resilient firm (see Battisti *et al.*, 2019).

6.1.3 Moderating role of three factors

6.1.3.1 Digital-technological diversity. The findings reveal that diversified digital technologies could weaken the influence of SCL on operational resilience. This result is aligned with the view of Chen *et al.* (2013). They contend that low technological diversity can enable firms to accumulate technological competence in adjacent fields and produce a higher learning effect. The influence of digital technologies has been a popular topic in the field of SCM. Furthermore, differing from prior studies which appreciated the role of various digital technologies in building resilience individually, such as AI (Modgil *et al.*, 2022), big data (Bag *et al.*, 2021), this study provides a unique perspective in exploring the role of digital-technological diversity. First, the breadth of the firm's digital technology portfolio is investigated instead of a specific technology. Second, rather than directly influencing resilience, we included digital technologies as a potential factor, exploring its interaction with SCL. Essentially, the measurement pertinent to the diversity of digital technologies is developed. This significantly substantiates the moderating role of digital-technological diversity.

6.1.3.2 Customer concentration. As evident in empirical analysis, customer concentration could magnify the effect of SCL. Researchers have devoted substantial attention to exploring the influence of customer concentration on organisational outcomes, as customers are one of the most crucial stakeholders. Nonetheless, the findings remain controversial (Zhu *et al.*, 2021a). This study provides empirical evidence supporting the 'bright side' of a concentrated customer base. Inherently, customers are more powerful (Huo, 2012), as firms rely heavily on their customers. As a result, customers, especially major ones, can influence firm performance (Zhu *et al.*, 2021a). Furthermore, a concentrated customer base forms a convenient environment to transfer and apply knowledge gained from SCL. Moreover, given that a firm's operations depend on revenues from transactions with customers, the impact of major customers is significant, and acquiring knowledge from them is very important to maintain flexible operations.

6.1.3.3 Pilot programme. The results show the positive moderating effect of a pilot programme, which is in line with preceding studies that highlight the possible influence of government interventions in responding to external adversities (Sheu, 2016). This study takes an empirical approach to examine the interplay between supply chain activities and government intervention by exploring the role of the government, an important stakeholder among supply chain members. A pilot programme plays an important role since it serves the objective of learning, testing, and evaluating the adaptability of a certain policy before its wider application (van Hoek, 2020). Additionally, a pilot programme's purpose may lie in discovering new things, which could be spread and diffused (Bailey *et al.*, 2017). Under this circumstance, pilot firms are motivated to share their experiences and actively absorb knowledge from others. Moreover, in emerging economies like China, becoming a pilot firm could be advantageous, as we identified the enabling role of the pilot programme.

6.1.4 Applicability of IPT to SCL

IPT suggests that firms deal with uncertainty through information processing, where good organisational performance relies on a proper alignment between information processing needs and capacity (Tushman and Nadler, 1978). The current study applies IPT to determine the effect of SCL on operational resilience and the setting in which the effects occur. From the IPT perspective, SCL, which enhances firms' knowledge processing capacity, meets the rising processing needs in the VUCA era and leads to a better performance outcome (i.e. operational resilience). Under different settings, including digital-technological diversity, customer concentration, and a pilot programme, the effect of SCL on operational resilience varies, weakening or strengthening.

The present study provides evidence to explain SCL through the theoretical lens of IPT. This perspective is distinct from other studies that viewed SCL in terms of the resource-based view (Ojha *et al.*, 2016), knowledge-based view (Roy, 2019), resource orchestration theory (Gong *et al.*, 2018), organisational learning (Mubarik *et al.*, 2021), dynamic capability (Aslam *et al.*, 2020; Chen *et al.*, 2019), and absorptive capacity (Huo *et al.*, 2021). The applicability of IPT in this research endeavour not only extends the theoretical groundings of SCL, but also advances the knowledge base of SCL.

6.2 Managerial implications

In addition to our research implications, this study's results also have significant managerial contributions. First, the research findings reveal that SCL is valuable for building firms' operational resilience. This suggests managers must grasp possible opportunities to pursue SCL and learn supply chain solutions and policies. Firms could actively interact with their supply chain partners, conduct training and workshops, and collaborate with other knowledge providers (such as third-party service providers, academic institutions, and industry associations). For firms operating in China, participating in renowned conferences is important. These conferences provide a chance to learn from the interpretation and explanation of policies; otherwise, they are likely to miss potential development opportunities. Moreover, managers should foster the 'learning culture' within the organisation and among the supply chain members. Activities could be carried out to encourage SCL, such as initiating regular meetings and discussions with supply chain partners to allow them to access SCM knowledge.

Second, the results manifest that digital-technological diversity could give rise to over-diversification problems, preventing firms from specialising in a specific technological area, hindering interfirm knowledge transfer, and eroding the value of knowledge gained from SCL. Additionally, adopting digital technologies is costly, requiring the investment of extensive resources. Therefore, managers should carefully launch the technological diversification strategy. It would be better for managers to concentrate on core digital technology closely related to their business operations rather than investing considerable resources in developing a full range of technologies.

Third, the findings provide insights for managers regarding the positive effect of customer concentration when firms are engaged in SCL. As the effect of SCL on operational resilience varies depending on the firm's customer concentration, managers should know more about their customer base profile. The more a firm understands about its relationship with supply chain partners, the better decisions it could make. This study finds that SCL can generate better outcomes for firms with a highly concentrated customer base. This result suggests that firms, especially those who are highly dependent on major customers, should dedicate more resources to SCL and actively engage in the learning activities. Firms should strengthen collaboration and coordination and build close relationships of mutual trust with major customers to facilitate knowledge transfer.

Then, managers should be aware of the government policy and seize the opportunity of SCM developing favoured by the policy environment. Firms are urged to proactively step forward to becoming pilot firms in policy programmes. In this way, they could obtain policy support from the government, such as in finance or taxation. Moreover, after the policy is announced, the pilot firms that synchronise with the development goal set by the government could accumulate relevant managerial experiences. As the pioneer in policy implementation, they could gain a first mover advantage over their competitors. Moreover, being a pilot firm brings a reputation and a responsibility to set a good example for other firms. Therefore, pilot firms need to embrace learning to improve themselves.

6.3 Limitations and future research

Despite the promising implications delivered by the study, some limitations should be considered. First, the data used in this study are limited to two years, given that the policy was announced only a few years ago. Therefore, future research using panel data covering a wider time range should be conducted. For example, researchers may pay close attention to conferences, such as frontier or recent trending topics related to Chinese SCM. Second, the scope of this study could be widened by considering how SCL may impact other firm- or supply chain-level constructs. The current study focuses on how and under what conditions SCL can influence firms' operations, that is, their operational resilience. Future research may focus on the relevance between SCL and other phenomena, such as, operational efficiency, risk management, and the underlying mechanisms transferring SCL into firm value, to gain a more holistic view of SCL.

References

Alexander, A., Blome, C., Schleper, M.C. and Roscoe, S.(2022),"Editorial: "Managing the "new normal": the future of operations and supply chain management in unprecedented times",*International Journal of Operations & Production Management*,Vol.42 No.8,pp.1061-1076.

Aman, S. and Seuring, S.(2021),"Analysing developing countries approaches of supply chain resilience to COVID-19",*The International Journal of Logistics Management*,Vol. ahead-of-print.doi:10.1108/IJLM-07-2021-0362

Aramo-Immonen, H., Kärkkäinen, H., Jussila, J.J., Joel-Edgar, S. and Huhtamäki, J.(2016),"Visualizing informal learning behavior from conference participants' Twitter data with the Ostinato Model",*Computers in human behavior*,Vol.55,pp.584-595.

Aslam, H., Blome, C., Roscoe, S. and Azhar, T.M.(2020),"Determining the antecedents of dynamic supply chain capabilities",*Supply Chain Management*,Vol.25 No.4,pp.427-442.

Bag, S., Dhamija, P., Luthra, S. and Huisingh, D.(2021),"How big data analytics can help manufacturing companies strengthen supply chain resilience in the context of the COVID-19 pandemic",*The International Journal of Logistics Management*,Vol. ahead-of-print.doi:10.1108/IJLM-02-2021-0095.

Bailey, S., Checkland, K., Hodgson, D., McBride, A., Elvey, R., Parkin, S., Rothwell, K. and Pierides, D.(2017),"The policy work of piloting: Mobilising and managing conflict and ambiguity in the English NHS",*Social Science & Medicine*,Vol.179,pp.210-217.

Bao, Y., Chen, X. and Zhou, K.Z.(2012),"External learning, market dynamics, and radical innovation: Evidence from China's high-tech firms",*Journal of Business Research*,Vol.65 No.8,pp.1226-1233.

Battisti, M., Beynon, M., Pickernell, D. and Deakins, D.(2019),"Surviving or thriving: The role of learning for the resilient performance of small firms",*Journal of Business Research*,Vol.100,pp.38-50.

Bensaou, M. and Venkatraman, N.(1995),"Configurations of interorganizational relationships: A comparison between US and Japanese automakers",*Management science*,Vol.41 No.9,pp.1471-1492.

Bessant, J., Kaplinsky, R. and Lamming, R.(2003),"Putting supply chain learning into practice",*International journal of operations & production Management*,Vol.23 No.2,pp.167-184.

Bharadwaj, A., El Sawy, O.A., Pavlou, P.A. and Venkatraman, N.V.(2013),"Digital business strategy: toward a next generation of insights",*MIS quarterly*,Vol. 37, No. 2,pp.471-482.

Biotto, M., De Toni, A.F. and Nonino, F.(2012),"Knowledge and cultural diffusion along the supply chain as drivers of product quality improvement: The illycaffè case study",*The International Journal of Logistics Management*,Vol.23 No.2,pp.212-237.

Bode, C., Wagner, S.M., Petersen, K.J. and Ellram, L.M.(2011),"Understanding responses to supply chain disruptions: Insights from information processing and resource dependence perspectives",*Academy of Management Journal*,Vol.54 No.4,pp.833-856.

Bolli, T., Seliger, F. and Woerter, M.(2020),"Technological diversity, uncertainty and innovation performance",*Applied Economics*,Vol.52 No.17,pp.1831-1844.

Burnard, K., Bhamra, R. and Tsinopoulos, C.(2018),"Building organizational resilience: Four configurations",*IEEE transactions on engineering management*,Vol.65 No.3,pp.351-362.

Busse, C., Meinlschmidt, J. and Foerstl, K.(2017),"Managing information processing needs in global supply chains: A prerequisite to sustainable supply chain management",*Journal* *of Supply Chain Management*,Vol.53 No.1,pp.87-113.

Cegielski, C.G., Jones-Farmer, L.A., Wu, Y. and Hazen, B.T.(2012),"Adoption of cloud computing technologies in supply chains: An organizational information processing theory approach",*The international journal of logistics Management*,Vol.23 No.2,pp.184-211.

Chauhan, C., Parida, V. andDhir, A. (2022),"Linking circular economy and digitalisation technologies: A systematic literature review of past achievements and future promises",*Technological Forecasting and Social Change*,Vol.177, 121508.

Chen, H., Genchev, S.E., Willis, G. and Griffis, B.(2019),"Returns management employee development: antecedents and outcomes",*The International Journal of Logistics Management*,Vol.30 No.4,pp.1016-1038.

Chen, Y.M., Yang, D.H. and Lin, F.J.(2013),"Does technological diversification matter to firm performance? The moderating role of organizational slack",*Journal of Business Research*,Vol.66 No.10,pp.1970-1975.

Cheng, C.C.J. and Krumwiede, D.(2018),"Enhancing the performance of supplier involvement in new product development: the enabling roles of social media and firm capabilities",*Supply Chain Management*,Vol. 23 No. 3, pp. 171-187.

Choi, T.M., Kumar, S., Yue, X. and Chan, H.L.(2022),"Disruptive technologies and operations management in the Industry 4.0 era and beyond",*Production and Operations Management*,Vol.31 No.1,pp.9-31.

Christopher, M.(1992),Logistics and Supply Chain Management,Pitman Publishing,London.

DesJardine, M., Bansal, P. and Yang, Y.(2019),"Bouncing back: Building resilience through social and environmental practices in the context of the 2008 global financial crisis",*Journal of Management*,Vol.45 No.4,pp.1434-1460.

Dodgson, M.(1993),"Organizational learning: a review of some literatures",*Organization studies*,Vol.14 No.3,pp.375-394.

Egelhoff, W.G.(1991),"Information-processing theory and the multinational enterprise",*Journal of international business studies*,Vol.22 No.3,pp.341-368.

Essuman, D., Boso, N. and Annan, J.(2020),"Operational resilience, disruption, and efficiency: Conceptual and empirical analyses",*International journal of production economics*,Vol.229,p.1-11.

Ettelt, S., Mays, N. and Allen, P.(2015),"The multiple purposes of policy piloting and their consequences: Three examples from national health and social care policy in

England",*Journal of Social Policy*,Vol.44 No.2,pp.319-337.

Ettelt, S., Williams, L. and Mays, N.(2022),"National policy piloting as steering at a distance: The perspective of local implementers",*Governance*,Vol.35 No.2,pp.385-401.

Fatorachian, H. and Kazemi, H.(2018),"A critical investigation of Industry 4.0 in manufacturing: theoretical operationalisation framework",*Production Planning & Control*,Vol.29 No.8, pp.633-644.

Flint, D.J., Larsson, E. and Gammelgaard, B.(2008),"Exploring processes for customer value insights, supply chain learning and innovation: an international study",*Journal of business logistics*,Vol.29 No.1,pp.257-281.

Flint, D.J., Larsson, E., Gammelgaard, B. and Mentzer, J.T.(2005),"Logistics innovation: a customer value‐oriented social process",*Journal of business logistics*,Vol.26 No.1,pp.113-147.

Flynn, B.B., Koufteros, X. and Lu, G.(2016),"On theory in supply chain uncertainty and its implications for supply chain integration",*Journal of Supply Chain Management*,Vol.52 No.3,pp.3-27.

Galbraith, J.R.(1974),"Organization design: An information processing view",*Interfaces*,Vol.4 No.3,pp.28-36.

Gao, G.Y., Xie, E. and Zhou, K.Z.(2015),"How does technological diversity in supplier network drive buyer innovation? Relational process and contingencies",*Journal of operations management*,Vol.36,pp.165-177.

General Office of the State Council (2017), *the Guideline on Promoting Supply Chain Innovation and Application*, (in Chinese), available at: http://www.gov.cn/zhengce/content/2017-10/13/content_5231524.htm.

Gong, Y., Jia, F., Brown, S. and Koh, L.(2018),"Supply chain learning of sustainability in multi-tier supply chains: A resource orchestration perspective",*International Journal of Operations & Production Management*,Vol.38 No.4,pp.1061-1090.

Gosling, J., Jia, F., Gong, Y. and Brown, S.(2016),"The role of supply chain leadership in the learning of sustainable practice: toward an integrated framework",*Journal of Cleaner Production*,Vol.137,pp.1458-1469.

Han, J., Jo, G.S. and Kang, J.(2018),"Is high-quality knowledge always beneficial? Knowledge overlap and innovation performance in technological mergers and acquisitions",*Journal of Management & Organization*,Vol.24 No.2,pp.258-278.

Haq, M.Z.U.(2021),"Supply chain learning and organizational performance: evidence from

Chinese manufacturing firms",*Journal of Knowledge Management*,Vol. 25 No. 4,pp. 943-972.

Hartley, J. and Allison, M.(2002),"Good, better, best? Inter-organizational learning in a network of local authorities",*Public Management Review*,Vol.4 No.1,pp.101-118.

Huang, H.H., Lobo, G.J., Wang, C. and Xie, H.(2016),"Customer concentration and corporate tax avoidance",*Journal of Banking & Finance*,Vol.72,pp.184-200.

Huber, G.P.(1991),"Organizational learning: The contributing processes and the literatures",*Organization science*,Vol.2 No.1,pp.88-115.

Hui, K.W., Liang, C. and Yeung, P.E.(2019),"The effect of major customer concentration on firm profitability: competitive or collaborative?",*Review of Accounting Studies*,Vol.24 No.1,pp.189-229.

Huo, B., Haq, M.Z.U. and Gu, M.(2020),"The impact of IT application on supply chain learning and service performance",*Industrial Management & Data Systems*,Vol.120 No.1,pp.1-20.

Huo, B., Haq, M.Z.U. and Gu, M.(2021),"The impact of information sharing on supply chain learning and flexibility performance",*International Journal of Production Research*,Vol.59 No.5,pp.1411-1434.

Huo, B.(2012),"The impact of supply chain integration on company performance: an organizational capability perspective",*Supply Chain Management*,Vol.17 No.6,pp.596-610.

Ignatius, J., Leen, J. Y. A., Ramayah, T., Hin, C. K. and Jantan, M.(2012),"The impact of technological learning on NPD outcomes: The moderating effect of project complexity",*Technovation*, ol.32 No.(7-8),pp. 452-463.

Jacobs, B.W., Swink, M. and Linderman, K.(2015),"Performance effects of early and late Six Sigma adoptions",*Journal of Operations Management*,Vol.36,pp.244-257.

Jeong, S., Han, S.J., Lee, J., Sunalai, S. and Yoon, S.W.(2018),"Integrative literature review on informal learning: Antecedents, conceptualizations, and future directions",*Human Resource Development Review*,Vol.17 No.2,pp.128-152.

Jia, F. and Lamming, R.(2013),"Cultural adaptation in Chinese-Western supply chain partnerships: Dyadic learning in an international context",*International Journal of Operations & Production Management*,Vol.33 No.5,pp.528-561.

Jowell, R.(2003).*Trying it Out: The Role of 'pilots' in Policy-making: Report of a Review of Government Pilots*.Cabinet Office,Strategy Unit.

Kahiluoto, H., Mäkinen, H. and Kaseva, J.(2020),"Supplying resilience through assessing diversity of responses to disruption",*International Journal of Operations & Production Management*,Vol.40 No.3,pp.271-292.

Kim, D.Y. and Zhu, P.(2018),"Supplier dependence and R&D intensity: The moderating role of network centrality and interconnectedness",*Journal of Operations Management*,Vol.64,pp.7-18.

Lam, H.K., Yeung, A.C. and Cheng, T.E.(2016),"The impact of firms' social media initiatives on operational efficiency and innovativeness",*Journal of Operations Management*,Vol.47,pp.28-43.

Lambrechts, F., Taillieu, T., Grieten, S. and Poisquet, J.(2012),"In-depth joint supply chain learning: towards a framework",*Supply Chain Management: An International Journal*,Vol.17 No.6,pp.627-637.

Lane, J.N., Ganguli, I., Gaule, P., Guinan, E. and Lakhani, K. R.(2021),"Engineering serendipity: When does knowledge sharing lead to knowledge production?",*Strategic management journal*,Vol.42 No.6, pp.1215-1244.

Li, J., Fang, L., Chen, S. and Mao, H.(2022a),"Can low-carbon pilot policy improve atmospheric environmental performance in China? A quasi-natural experiment approach",*Environmental Impact Assessment Review*,Vol.96,pp.1-13.

Li, M., Wang, Z. and Zhao, X.(2018),"The role of indigenous technological capability and interpersonal trust in supply chain learning",*Industrial Management & Data Systems*,Vol.118 No.5,pp.1052-1070.

Li, Y., Wang, X., Gong, T. and Wang, H.(2022b),"Breaking out of the pandemic: How can firms match internal competence with external resources to shape operational resilience?",*Journal of Operations Management*,pp.1-20.

Lisi, W., Zhu, R. and Yuan, C.(2020),"Embracing green innovation via green supply chain learning: The moderating role of green technology turbulence",*Sustainable Development*,Vol.28 No.1,pp.155-168.

Liu, Q., Trevisan, A.H., Yang, M. and Mascarenhas, J.(2022a),"A framework of digital technologies for the circular economy: Digital functions and mechanisms",*Business Strategy and the Environment*,Vol.31,pp.2171–2192.

Liu, W., Liu, X. and Choi, T.M.(2022b),"Effects of supply chain quality event announcements on stock market reaction: An empirical study from China", *International Journal of Operations & Production Management*,Vol.ahead-of-print.

Liu, X. and McKinnon, A.C.(2016),"Theory development in China-based supply chain management research: A literature review",*The International Journal of Logistics Management*,Vol.27 No.3,pp.972-1001.

Liu, X. and McKinnon, A.C.(2019),"Practical relevance of theory-driven supply chain management research: Evidence from China",*The International Journal of Logistics Management*,Vol.30 No.1,pp.76-95.

Marhold, K. and Kang, J.(2017),"The effects of internal technological diversity and external uncertainty on technological alliance portfolio diversity",*Industry and Innovation*,Vol.24 No.2,pp.122-142.

Maritan, C.A. and Brush, T.H.(2003),"Heterogeneity and transferring practices: implementing flow manufacturing in multiple plants",*Strategic Management Journal*,Vol.24 No.10,pp.945-959.

Min, S., Zacharia, Z.G. and Smith, C.D.(2019),"Defining supply chain management: in the past, present, and future",*Journal of Business Logistics*,Vol.40 No.1,pp.44-55.

Modgil, S., Gupta, S., Stekelorum, R. and Laguir, I.(2022),"AI technologies and their impact on supply chain resilience during COVID-19",*International Journal of Physical Distribution & Logistics Management*,Vol.52 No.2,pp.130-149.

Mubarik, M.S., Bontis, N., Mubarik, M. and Mahmood, T.(2021),"Intellectual capital and supply chain resilience",*Journal of Intellectual Capital*,Vol.23 No.3,pp.713-738.

Nambisan, S.(2017),"Digital entrepreneurship: Toward a digital technology perspective of entrepreneurship",*Entrepreneurship theory and practice*,Vol.41 No.6,pp.1029-1055.

Ngai, E.W., Chau, D.C. and Chan, T.L.A.(2011),"Information technology, operational, and management competencies for supply chain agility: Findings from case studies",*The Journal of Strategic Information Systems*,Vol.20 No.3,pp.232-249.

Nonaka, I. (1994),"A dynamic theory of organizational knowledge creation",*Organization science*,Vol.5 No.1,pp.14-37.

Ojha, D., Acharya, C. and Cooper, D.(2018),"Transformational leadership and supply chain ambidexterity: Mediating role of supply chain organizational learning and moderating role of uncertainty",*International Journal of Production Economics*,Vol.197,pp.215-231.

Ojha, D., Shockley, J. and Acharya, C.(2016),"Supply chain organizational infrastructure for promoting entrepreneurial emphasis and innovativeness: The role of trust and learning",*International Journal of Production Economics*,Vol.179,pp.212-227.

Patatoukas, P.N.(2012),"Customer-base concentration: Implications for firm performance and capital markets: 2011 American accounting association competitive manuscript award winner",*The accounting review*,Vol.87 No.2,pp.363-392.

People's Daily(2018),"The origin of 'crossing the river by touching the stones'",in Chinese,available at: http://cpc.people.com.cn/n1/2018/0412/c69113-29921565.html(accessed 20 June 2022)

Premkumar, G., Ramamurthy, K. and Saunders, C.S.(2005),"Information processing view of organizations: an exploratory examination of fit in the context of interorganizational relationships",*Journal of Management Information Systems*,Vol.22 No.1,pp.257-294.

Remko, v.H.(2020),"Research opportunities for a more resilient post-COVID-19 supply chain – closing the gap between research findings and industry practice",*International Journal of Operations & Production Management*,Vol.40 No.4,pp.341-355.

Roy, V.(2019),"Decoding the elemental arcs of superior performance in sustainable supply chains: A knowledge-based view",*Management Decision*,Vol.57 No.9,pp.2570-2592.

Sarkis, J.(2021),"Supply chain sustainability: learning from the COVID-19 pandemic",*International Journal of Operations & Production Management*,Vol.41 No.1,pp.63-73.

Sheu, J.B.(2016),"Supplier hoarding, government intervention, and timing for post-disaster crop supply chain recovery",*Transportation Research Part E: Logistics and Transportation Review*,Vol.90,pp.134-160.

Shin, M., Holden, T. and Schmidt, R.A. (2001),"From knowledge theory to management practice: towards an integrated approach",*Information processing & management*,Vol.37 No.2,pp.335-355.

Silvestre, B.S., Silva, M.E., Cormack, A. and Thome, A.M.T.(2020),"Supply chain sustainability trajectories: learning through sustainability initiatives",*International Journal of Operations & Production Management*,Vol.40 No.9,pp.1301-1337.

Silvestre, B.S.(2015),"Sustainable supply chain management in emerging economies: Environmental turbulence, institutional voids and sustainability trajectories",*International Journal of Production Economics*,Vol.167,pp.156-169.

Song, J., Almeida, P. and Wu, G.(2003),"Learning-by-hiring: When is mobility more likely to facilitate interfirm knowledge transfer?",*Management science*,Vol.49 No.4,pp.351-365.

Spekman, R.E., Spear, J. and Kamauff, J.(2002),"Supply chain competency: learning as a key component",*Supply Chain Management*,Vol.7 No.1,pp.41-55.

Stock, G.N., Tsai, J.C.A., Jiang, J.J. and Klein, G.(2021),"Coping with uncertainty: Knowledge sharing in new product development projects",*International Journal of Project Management*,Vol.39 No.1, pp.59-70.

Subramanian, A.M., Wang, B. and Chai, K.H.(2018),"Does technological diversity help or hurt small firms? The moderating role of core technological coherence",*IEEE Transactions on Engineering Management*,Vol.66 No.3,pp.299-311.

Tse, Y.K., Zhang, M., Akhtar, P. and MacBryde, J. (2016),"Embracing supply chain agility: an investigation in the electronics industry",*Supply Chain Management: An International Journal*,Vol.21 No.1,pp.140-156.

Tu, W. and He, J.(2022)."Can Digital Transformation Facilitate Firms' M&A: Empirical Discovery Based on Machine Learning. Emerging Markets Finance and Trade",Vol. ahead-of-print.doi:10.1080/1540496X.2022.2093105

Tushman, M.L. and Nadler, D.A.(1978),"Information processing as an integrating concept in organizational design",*Academy of management review*,Vol.3 No.3,pp.613-624.

van Hoek, R.(2020),"Developing a framework for considering blockchain pilots in the supply chain – lessons from early industry adopters",*Supply Chain Management*,Vol.25 No.1,pp.115-121.

Wang, Z., Schoenherr, T., Zhao, X. and Zhang, S.(2019),"Intellectual capital, supply chain learning, and adaptability: A comparative investigation in China and the United States",*IEEE Transactions on Engineering Management*,pp.1-16.

Wei, J., Sun, C., Wang, Q. and Pan, Q.(2020),"The critical role of the institution-led market in the technological catch-up of emerging market enterprises: Evidence from Chinese enterprises",*R&D Management*,Vol.50 No.4,pp.478-493.

Wei, Z., Yi, Y. and Yuan, C.(2011),"Bottom-up learning, organizational formalization, and ambidextrous innovation",*Journal of Organizational Change Management*,Vol. 24 No. 3,pp. 314-329.

Westerman, G. and Bonnet, D.(2015),"Revamping your business through digital transformation",*MIT Sloan management review*,Vol.56 No.3,pp.1-5.

Wu, K., Fu, Y. and Kong, D.(2022),"Does the digital transformation of enterprises affect stock price crash risk?",*Finance Research Letters*,Vol.48, pp.1-7.

Xie, X., Wu, Y., Palacios-Marqués, D. and Ribeiro-Navarrete, S.(2022),"Business networks and organizational resilience capacity in the digital age during COVID-19: A perspective utilizing organizational information processing theory",*Technological Forecasting and Social Change*,Vol.177,pp.1-16.

Yli-Renko, H. and Janakiraman, R.(2008),"How customer portfolio affects new product development in technology-based entrepreneurial firms",*Journal of marketing*,Vol.72 No.5,pp.131-148.

Zhou, K.Z., Zhang, Q., Sheng, S., Xie, E. and Bao, Y.(2014),"Are relational ties always good for knowledge acquisition? Buyer–supplier exchanges in China",*Journal of Operations management*,Vol.32 No.3,pp.88-98.

Zhu, M., Yeung, A.C. and Zhou, H.(2021a),"Diversify or concentrate: The impact of customer concentration on corporate social responsibility",*International Journal of Production Economics*,Vol.240,pp.108214.

Zhu, Q., Krikke, H. and Caniëls, M.C.(2018a),"Supply chain integration: value creation through managing inter-organizational learning",*International journal of operations & production management*,Vol.38 No.1,pp.211-229.

Zhu, S., Dong, T. and Luo, X.(2021b),"A longitudinal study of the actual value of big data and analytics: the role of industry environment",*International Journal of Information Management*,Vol.60,pp.1-15.

Zhu, S., Song, J., Hazen, B.T., Lee, K. and Cegielski, C.(2018b),"How supply chain analytics enables operational supply chain transparency: An organizational information processing theory perspective",*International Journal of Physical Distribution & Logistics Management*,Vol.48 No.1,pp.47-68.

Table I. Construct measurement

Construct	Measurement	Data source
SCL	The sum of three binary indicators: 1) participation, 2) the extent of communication and interaction, and 3) membership	Firm list from CFLP
Operational resilience	$\frac{ORPPC_t}{\sum_{t-3}^{t-1}\frac{ORPPC}{3}}$	CSMAR
Digital-technological diversity	$e^{-\sum_{i=1}^{n}(\frac{f_i}{F}\times ln\frac{f_i}{F})}$	CSMAR
Customer concentration	The ratio of the top 5 customers' sales to the total annual sales	CSMAR
Pilot programme	Pilot firm= 1, otherwise, 0	Firm list released by policy panel members
Age	The natural logarithm of the number of years since firms' foundation	CSMAR
Size	The natural logarithm of the number of firm's employees	CSMAR
Profitability	Return on assets	CSMAR
R&D intensity	R&D expenditures over sales	CSMAR
State ownership	State-owned firm=1, otherwise, 0	CSMAR
Industry concentration	$\sum\left(\frac{Sales_i}{Total\ sales\ of\ firms\ in\ the\ same\ industry}\right)^2$	CSMAR
Industry munificence	Slope coefficient generated by regressing sales over ten years/mean sales in the same period	CSMAR

Table II. Descriptive statistics and correlations

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Operational Resilience	1											
2. Supply Chain Learning	0.056	1										
3.Digital-technological Diversity	0.146*	0.088	1									
4.Customer Concentration	0.012	0.051	-0.123	1								
5. Pilot Programme	-0.002	0.117	-0.138	-0.058	1							
6. Firm Size	0.090	0.044	0.056	-0.348***	-0.019	1						
7. Firm Age	-0.018	0.040	0.010	-0.067	-0.090	-0.144	1					
8. ROA	0.151*	-0.183**	-0.159*	-0.022	-0.015	0.101	0.007	1				
9. R&D Intensity	0.053	-0.119	0.237***	0.093	-0.149*	-0.095	-0.147*	0.152*	1			
10. State ownership	0.045	0.393***	-0.075	-0.031	0.105	0.345***	-0.076	-0.090	-0.235***	1		
11.Industry Concentration	-0.002	0.061	0.152*	-0.145*	-0.125	0.243***	0.037	-0.071	-0.174**	0.120	1	
12.Industry Munificence	-0.134	-0.034	0.159*	-0.066	-0.164*	-0.330***	-0.000	0.016	0.042	-0.208**	0.020	1
Mean	0.992	0.969	2.807	0.230	0.538	9.238	3.000	0.047	0.026	0.523	0.143	0.155
Standard deviation	0.100	0.948	2.192	0.232	0.500	1.547	0.263	0.048	0.055	0.501	0.159	0.081

Table III. Regression analysis results

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	1.544(0.434)	-0.085 (-0.024)	-0.064(-0.018)	-0.822(-0.254)	1.099(0.341)	2.055(0.694)
Control variable						
Size	0.276**(2.121)	0.251*(1.976)	0.285**(2.303)	0.330***(2.911)	0.242*(1.960)	0.364***(3.430)
Age	-0.775(-0.758)	-0.220(-0.215)	-0.317(-0.307)	-0.211(-0.220)	-0.573(-0.566)	-1.249(-1.295)
ROA	-0.570(-1.001)	-0.555(-1.005)	-0.771(-1.399)	-0.685(-1.408)	-0.747(-1.370)	-0.880*(-1.881)
R&D Intensity	-5.413**(-2.506)	-6.004***(-2.840)	-4.316*(-1.944)	-4.115**(-2.157)	-4.986**(-2.357)	-2.599(-1.366)
State ownership	0.316(0.369)	0.707(0.830)	0.596(0.711)	0.692(0.867)	0.439(0.524)	-0.043(-0.056)
Industry Concentration	-0.029(-0.068)	0.155(0.370)	0.014(0.034)	-0.057(-0.154)	0.001(0.003)	-0.454(-1.226)
Industry Munificence	-1.845(-1.464)	-1.636(-1.333)	-1.320(-1.106)	-1.504(-1.382)	-2.171*(-1.777)	-1.876*(-1.823)
Independent variable						
SCL		0.035**(2.130)	0.035**(2.155)	0.023(1.604)	0.028*(1.693)	0.010(0.711)
Moderator and interaction						
Digital-technological Diversity			-0.006(-0.510)			0.012(1.083)
SCL × Digital-technological Diversity			-0.016**(-2.361)			-0.014**(-2.451)
Customer Concentration				0.442**(2.051)		0.540**(2.596)
SCL × Customer Concentration				0.230***(4.031)		0.214***(3.926)
Pilot Programme					-0.267(-0.506)	-0.402(-0.853)
SCL × Pilot Programme					0.068**(2.050)	0.072**(2.588)
Firm-level fixed effects	Included	Included	Included	Included	Included	Included
Year-level fixed effects	Included	Included	Included	Included	Included	Included
Number of Observations	130	130	130	130	130	130
F-value	1.785**	1.932***	2.093***	2.703***	2.072***	3.216***
Adjusted R^2	0.305	0.345	0.389	0.498	0.381	0.573

Note(s): *p < 0.1, **p < 0.05, ***p < 0.01; T-value in parentheses; One-year lag between the dependent variable (operational resilience) and all independent variables.

Table IV. Results of robustness tests

Models	Main effect				Moderating effect					
	SCL	n	F-value	Adjusted R^2	SCL × Digital-technological Diversity	SCL × Customer Concentration	SCL × Pilot Programme	n	F-value	Adjusted R^2
1. Operational resilience measured based on a four-year window	0.033** (2.065)	128	2.336***	0.428	-0.014** (-2.376)	0.208*** (3.893)	0.072** (2.614)	128	3.778***	0.624
2. Diversity measured based on new categories					-0.025** (-2.350)	0.182*** (3.256)	0.066** (2.379)	130	3.193***	0.570
3. Industry-adjusted digital-technological diversity used					-0.035** (-2.504)	0.182*** (3.255)	0.063** (2.281)	130	3.192***	0.570
4. Alternative measurement of the pilot programme					-0.016*** (-2.942)	0.221*** (4.297)	0.051*** (3.792)	130	3.731***	0.623
5. Additional control included	0.037** (2.476)	125	2.477***	0.465	-0.014** (-2.501)	0.180*** (3.458)	0.073*** (2.744)	125	3.849***	0.642

Note(s): *p < 0.1, **p < 0.05, ***p < 0.01; T-value in parentheses; One-year lag between the dependent variable (operational resilience) and all independent variables.

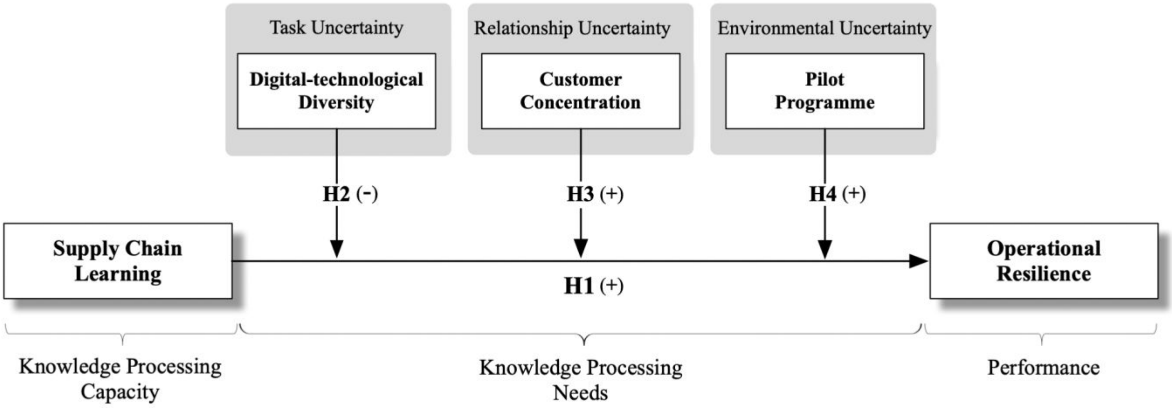


Figure 1. A research framework of supply chain learning and operational resilience

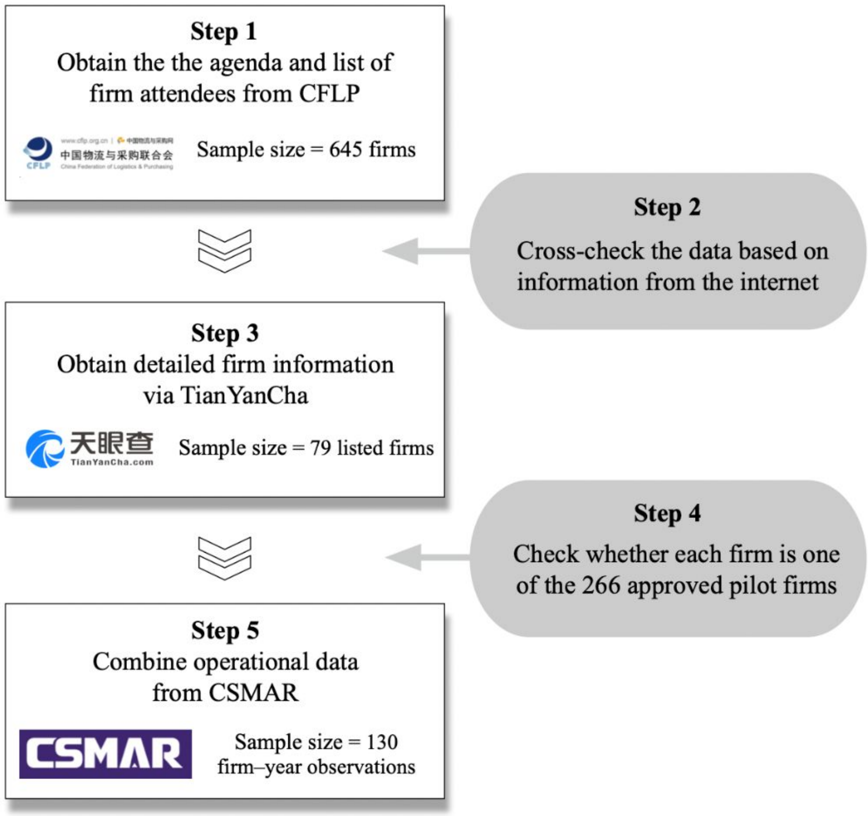
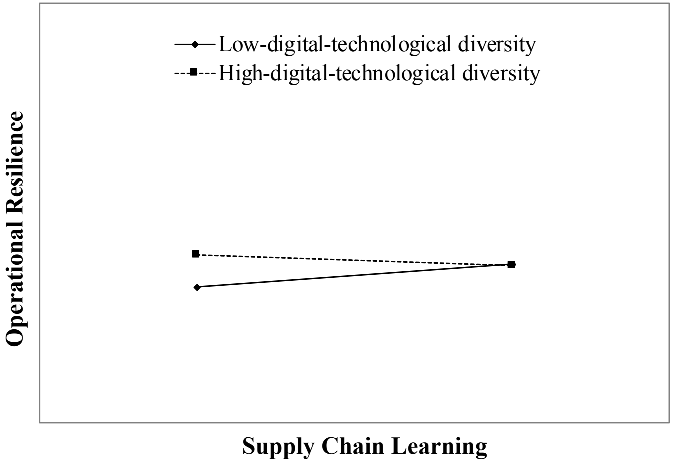
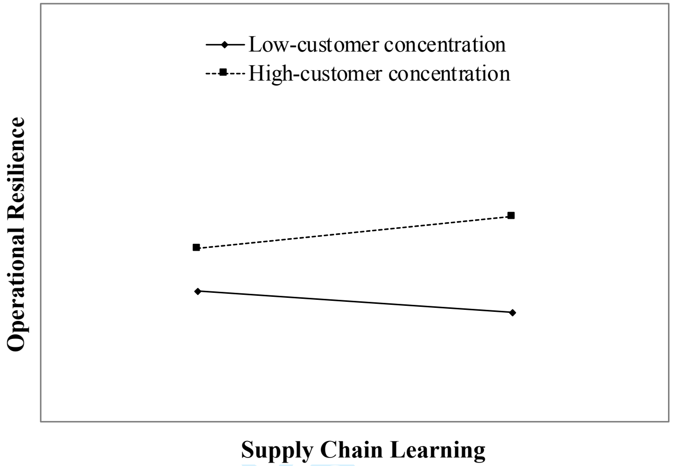


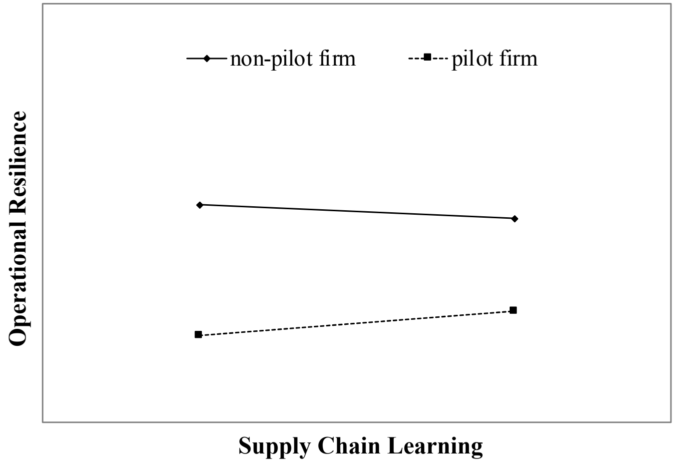
Figure 2. Data collection process



(a) Digital-technological diversity



(b) Customer concentration



(c) Pilot programme

Figure 3. Decomposing the moderating effects