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Pursuing supply chain ecosystem health under environmental turbulence: a supply chain learning approach

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ABSTRACT
Although supply chain ecosystem health (SCE Health) is receiving attention in relation to environmental uncertainty, its conception and measurement are largely undocumented, and how to pursue SCE Health under environmental turbulence is unclear. Supply chain learning (SCL) is an important way to build dynamic capabilities, and whether it can empower the achievement of SCE Health is worthy of investigative study. Therefore, grounded in the dynamic capabilities theory, a survey data-based structural equation modelling (SEM) approach is employed. Based on four experts' opinions and an in-depth literature review, 47 measurement items (11 for SCL, 28 for SCE Health, and 8 for environmental turbulence) were identified in the questionnaire design. Further, 208 valid questionnaires from the field survey of supply chain management (SCM)-related firms in China were collected and used for SEM analysis. The results show that the internal learning of SCL stimulates its external learning. SCL empowers the pursuit of SCE Health, which is strengthened under higher environmental turbulence. The theoretical framework and results also derive practical insights and support from 11 interviewees of five companies.

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KEYWORDS
Supply chain learning; ecosystem health; environmental turbulence; dynamic capabilities theory; structural equation modelling

1. Introduction

The supply chain ecosystem (SCE) is an emerging community in the field of supply chain management (SCM), particularly amid the unparalleled disruption to supply chains caused by the COVID-19 pandemic, which clearly demonstrates the vulnerability of the globalised economy (Ivanov 2021; Kähkönen et al. 2023; Li et al. 2021). To better deal with the challenges brought by the increased complexity, supply chains have experienced structural changes from chains to networks, and changes in relationships from dyad to triad (Choi and Wu 2009). The SCE is described as a set of interdependent and coordinated organisations that share common adaptive challenges and shape a creative base to achieve competitive advantage and superior performance (Batista et al. 2019; Ketchen, Crook, and Craighead 2014). These continuous changes warn enterprises that their future development is no longer dependent on themselves alone, but also on the supply chain partners within the business ecosystem, particularly in SCE (Flint, Lusch, and Vargo 2014).

Previous research has mainly focused on the performance of the SCE, including product quality, supply chain service levels, supply chain market reach, and management quality (Viswanadham and Samvedi 2013). These indicators highlight the importance of the 'supply chain' but ignore the function of an 'ecosystem'. Supply chain viability is also an emerging concept of growing importance in operations management, which emphasises the capability to survive and remain viable under uncertainty and disruptions, particularly during the COVID-19 pandemic (Ivanov and Dolgui 2020; Mohammed, Jabbour, and Diabat 2023; Ruel et al. 2021). 'Ecosystem' is one of the future research directions in the existing literature on supply chain viability, and considers ecosystem evolution through disruption–reaction balancing in the open system context (Hosseini, Ivanov, and Blackhurst 2022; Ivanov and Keskin 2023b). From an 'ecosystem' perspective, the topic of supply chain viability focuses on survival and recovery in times of crisis and disruption. Following this trend, our research sets out to establish a measurement more than 'survival-oriented' but 'ecosystem development-oriented' to assess the conditions of SCE (Ivanov et al. 2023a). SCE is a typical and specific part of the business ecosystem

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(Liu, Aroean, and Ko 2019), while 'business ecosystem health' has motivated many researchers to evaluate the overall performance of the business system (Iansiti and Levien 2004). Inspired by 'supply chain viability', 'business ecosystem health', and focused on the attributes of SCE, the first research question is proposed: ***What are the features of SCE Health?***

Dynamic capabilities theory emphasises relocating organisational resources and capabilities to match with the environment, and learning is one of the central elements (Eisenhardt and Martin 2000). As a typical dynamic capability, SCL is a process of the focal firm acquiring, assimilating, exploiting, managing, and monitoring information and knowledge across internal functions and from external partners (Flint, Larsson, and Gammelgaard 2008; Huo, Haq, and Gu 2019). Previous research has shown that SCL is a crucial element in enhancing the efficiency and effectiveness of SCM, and mainly involves acquiring knowledge and information to master changes in technology and markets (Bessant, Kaplinsky, and Lamming 2003), adjusting the strategic arrangement for customer satisfaction and value (Flint, Larsson, and Gammelgaard 2008; Spekman, Spear, and Kamauff 2002), and achieving mutually beneficial strategic and operational goals (Willis, Genchev, and Chen 2016). In the SCE context, the goal of learning is not just limited to achieving the good performance of each company, but of the entire SCE (Viswanadham and Samvedi 2013). However, whether SCL can be an effective way to pursue SCE Health has not been studied. Thus, we extract the second research question: ***Can SCL be an effective path to pursue SCE Health?***

Shocked by COVID-19 and geopolitical instability, environment turbulence – as an important factor in the SCE – will also have a significant impact on the enterprise and overall business ecosystem health performance, particularly regarding technology and market turbulence (Hanvanich, Sivakumar, and Hult 2006; Viswanadham and Samvedi 2013). Existing views mainly focus on how technology turbulence affects supply chain participants' ability in knowledge sharing, technology transfer, and collaboration effectiveness (Wang et al. 2015; Wei, Zhu, and Yuan 2020). Further, under high market turbulence, more accurate information is needed to grasp market opportunities, make investment decisions, and maintain good relationships with external partners (Wang et al. 2015). However, little work to date has examined the role of environmental turbulence at the intersection between SCL and SCE Health. Thus, the third research question is derived: ***How does environmental turbulence moderate the relationship between SCL and SCE Health?***

To answer these questions, we adopt the dynamic capabilities theory to construct the conception of SCE Health and explore the relationship between SCL and SCE Health. Specifically, we first describe SCE Health from three aspects – 'productivity', 'robustness', and 'niche creation' – based on the results of the science mapping analyses in SCE Health related-research. Second, our research utilises the structural equation modelling (SEM) approach with 208 questionnaires collected from the field survey of SCM-related firms in China, presenting a novel framework to illustrate how SCL empowers SCE Health under the moderation of environmental turbulence. Third, in-depth interviews with 11 practicing experts from five companies in the supply chain field are conducted, generating practical insights and support for the proposed theoretical framework. The empirical results indicate that the internal element of SCL positively improves its external aspects from both supplier learning and customer learning perspectives. This has a positive impact on the achievement of SCE Health, and the pursuit of SCE Health through SCL practices is strengthened under higher environmental turbulence.

This research contributes to the literature in the following three respects. First, to the best of our knowledge, this study is the first to identify the concept of SCE Health and to comprehensively evaluate it by considering an in-depth literature review (particularly the science mapping analysis) and four experts' opinions, presenting a new view of the intersection between SCL and SCE Health. Second, grounded in the dynamic capabilities theory, we design a framework to construct SCE Health via the path of SCL, which not only theoretically enriches the SCL application in the SCM field, but also furnishes new insights for practitioners to achieve the higher goal of SCE Health. Third, this study demonstrates the moderating mechanisms of environmental turbulence in the post-COVID-19 era, confirming that environmental turbulence can also be a positive factor in achieving SCE Health under the paths of SCL.

The remainder of this paper is structured as follows. Section 2 discusses the theoretical framework and hypotheses development. Section 3 introduces the methodology (a mixed-methods approach combining qualitative interviews and quantitative empirical survey) and the data collection process. Section 4 presents the empirical and interview results. Section 5 provides the discussion of findings, theoretical contributions, and managerial implications of the study. Finally, Section 6 concludes the study, and outlines the research limitations and directions for future study.

2. Theoretical framework and hypothesis development

2.1. From business ecosystem health to SCE Health

2.1.1. Business ecosystem health

Good business models can be likened to well-functioning biological ecosystems, in which different species depend on each other and adapt to changes in the environment to co-evolve. Moore (1993) first developed the concept of business ecosystem from biology into economics and presented the concept of business ecosystem. Subsequent studies have focused on suitable performance indicators to assess the benefits of the business ecosystem, such as enterprise performance indicators, value systems, supply chain collaboration, collaboration benefits, and social network analysis (Ivanov 2021). In the process, increasing numbers of scholars have realised that the 'health condition' of the business ecosystem is crucial (Iansiti and Levien 2004; Song, Chen, and Yu 2022). The health of a business ecosystem affects the future development and longevity of the entire system (den Hartigh, Tol, and Visscher 2006).

The existing research on 'business ecosystem health' mainly falls into two categories. One category focuses on the definitions; it argues that business ecosystem health reflects the overall situation of its development process, organisational operation, pressure adaptation, and self-recovery after being threatened (Iansiti and Levien 2004). The other focuses on the measurement of business ecosystem health. Iansiti and Levien (2004) measure it from the three dimensions of productivity, robustness, and niche creativity, while den Hartigh, Tol, and Visscher (2006) carry out health evaluation at the system level and enterprise level, respectively. Moreover, Song, Chen, and Yu (2022) define ecosystem network health from the dimensions of connectivity with the ecosystem, visibility in the market, and diversity of partners, clarifying that ecosystem network health affects credit quality directly and indirectly. However, as SCE is a typical business model and business ecosystem, there is a lack of research on health measurement in the SCM community. Therefore, 'SCE Health' is a potential topic worthy of discussion and in-depth research.

2.1.2. SCE and its health

It is well known that the supply chain is a typical and specific business model/structure, and previous research integrates business models with SCM (Liu, Aroean, and Ko 2019). Corresponding to the business ecosystem, as an emerging topic in the field of SCM, SCE can be regarded as a product of the evolution of the supply chain and the supply chain network (Ketchen, Crook, and Craighead 2014; Melnyk et al. 2022). An SCE consists of the elements of the supply chain and the entities that influence the products, materials, information, and financial flows (Viswanadham and Samvedi 2013). It is distinguished from the supply chain network by the necessity to continuously coordinate and manage these flows (Adner 2017). Exit barriers can also help to distinguish ecosystems from networks. Compared to the supply chain network concept, the closer relationships and collaborations in SCE are formed across a broader array of stakeholders (Ketchen, Crook, and Craighead 2014), which means that firms can leave most networks readily, while exit is quite difficult within ecosystems because of a heightened set of interdependencies in the ecosystem.

The evolution from supply chain network to SCE does not occur naturally, but requires ecosystem-level competencies or skills to create value for individual members and networks, and the adaption of all members (both competitors and collaborators) in the SCE to changes in the ecosystem (Ketchen, Crook, and Craighead 2014). Viswanadham and Samvedi (2013) describe SCE performance in terms of product quality, supply chain service levels, supply chain market reach, and management quality. Further, three key features capture successful SCEs – co-opetition, pursuing dual goals for value creation (for the organisation itself and the ecosystem), and knowledge and skills (Nambisan and Baron 2013).

SCE practices are spreading across industries and countries. Soumaya (2014) focuses on the transition from supply chains to ecosystems and investigates the Canadian Information Communications Technology ecosystem based on longitudinal cases of the entire lifecycle process and a multilevel perspective on the value–creation and value–capture processes. She confirms that the building and development of SCE requires a balance between value–co-creation and value–capture, and can result in massive innovation. Tripathi and Gupta (2021) analyse India's current SCE from nine identified macro factors; namely, government support, regulations, business environment, human resources, infrastructure, innovation capability, technological advancements, cybersecurity, and digital awareness based on an international comparison framework covering 126 nations, and pointing to the significant transformation to a smarter SCE in the Fourth Industrial Revolution. SCE also greatly influences China's industrial development and economic construction. Taking the steel industry as an example, 'steel SCE' includes resource service providers, steel production enterprises, trade service providers, logistics processing service providers, technology service providers, financial service institutions, steel customers, and other participants. The steel industry drives coordinated development of the new material industry, modern trade logistics industry, industrial service industry, industrial finance industry, and urban service industry. China has also selected 12 cities as pilot projects to build an industrial chain and SCE. Through mechanism innovation, factor clustering, platform building, digital intelligence empowerment and policy support, a synergetic, competitive, cooperative and symbiotic SCE is formed by leading enterprises, supporting enterprises, universities, scientific research institutes, third-party platforms, and financial institutions.

Supply chain viability is a novel decision-making setting for operations research and management science (OR/MS) that emerged during the COVID-19 pandemic (Ivanov and Keskin 2023b; Münch and Hartmann 2023; Sawik 2023). Ivanov (2022, 4) defines viability as the ability of a supply chain to maintain itself and survive in a changing environment through the re-design of structures and re-planning of performance with long-term impacts. The concept of supply chain viability highlights survivability and adaptability as central elements, with a dynamically adaptable and structurally changeable network as one important determinant (Ivanov and Dolgui 2022; Ivanov and Keskin 2023b). Inspired by the concept of supply chain viability (Ivanov and Dolgui 2020) and the views of den Hartigh, Tol, and Visscher (2006) and Song, Chen, and Yu (2022), we put forward the concept of 'SCE Health' to describe the long-term and sustainable evolution, development and value creation of SCE members and the whole ecosystem, which contributes to the SCE community from the business ecosystem healthstream.

Before defining the concept of SCE Health, it is important to identify the contributions from previous SCE-related research to obtain support for our definition of SCE health. Therefore, the VOSviewer (v-1.6.18) software, which can construct bibliometric networks and maps based on the paper abstract, title, and keywords was used to conduct a science mapping analysis. We query the database 'Web of Science' for keywords 'ecosystem health', 'platform health', and 'supply chain health', based on the practical expert opinions and extensive literature reviews of related research papers. Finally, 1701 relevant papers from 129,892 articles published between January 2013 and May 2022 (limited to the fields of 'economics and management' or 'business' or 'business finance') were selected. Figure 1 presents the result of the bibliographic mapping, identifying three clusters. Cluster 1 (red) presents the research subject and structure, including the keywords 'ecosystem' and 'supply chain', Cluster 2 (green) mainly reflects value creation, such as 'originality value' and 'performance', and Cluster 3 (blue) shows the connection between specific participants and activities in the 'platform'.

Under a structuralist approach to ecosystems, Adner (2017) suggests that four basic elements (activities, actors, positions, and links) collectively characterise the configuration of activities and actors required for a value proposition to materialise, and that these four elements can also be applied to SCE. Further, inspired by the measurement of business ecosystem health from productivity, robustness, and niche creation perspectives (Iansiti and

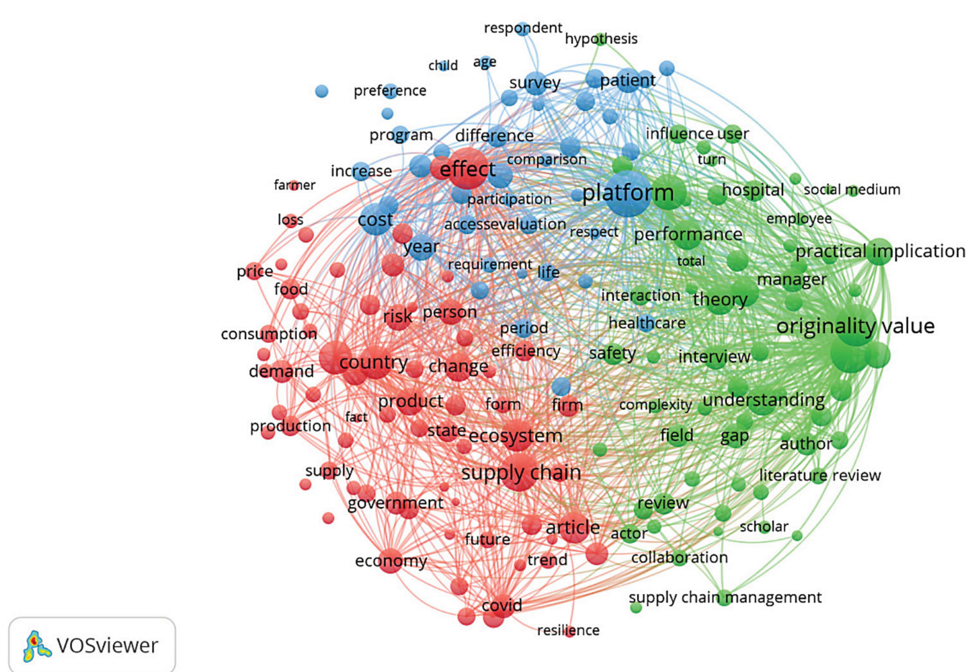

Figure 1. Bibliographic mapping of SCE Health research (1701 papers: 2013.01–2022.05).

Levien 2004), and combining the result of the science mapping analysis, we integrate productivity (reflecting the keywords ‘cost’ and ‘performance’ of science mapping analysis), robustness (reflecting the keyword ‘relationship’), and niche creation (reflecting the keyword ‘originality value’) with the operation and supply chain management (OSCM). Thus, we propose the concept of ‘SCE Health’ and define it as follows: *The supply chain can maintain its vigour (productivity) and control or minimise risk under external pressure (robustness) to capture more accurate targeted markets and occupy a higher market position for the purpose of better value co-creation with supply chain partners (niche creation).*

2.2. SCL empowering SCE Health

2.2.1. Definitions of SCL and its interaction based on dynamic capabilities theory

Under the changeable background of geopolitical instability and post-COVID-19, business information is the most important resource of an enterprise in the practice of SCM (Bechtsis et al. 2022). Being an important way to obtain information, learning is a necessary ability for the survival and development of an enterprise (Bessant, Kaplinsky, and Lamming 2003; Melnyk et al. 2022). Knowledge and learning are typical elements of dynamic capabilities in SCM, and enterprises must continually refresh, deploy, and preserve their knowledge to maintain outstanding long-term business performance, looking for new chances to acquire and integrate information (Pavlou and El Sawy 2011).

Dynamic capabilities play an increasingly important role, particularly in a turbulent environment. To achieve the sustainability of competitive advantage, a company should reconfigure organisational resources and, in particular, consider the match between resources and capabilities, and the environment (Eisenhardt and Martin 2000). Change and learning are considered key characteristics of dynamic capabilities (Laaksonen and Peltoniemi 2018). With the deepening of learning and expansion of knowledge acquisition channels, the research on dynamic capability theory in the supply chain field has developed rapidly. Yang, Zhang, and Chen (2008) first integrated the dynamic capability theory with SCM, clarifying the relationship between learning ability, knowledge innovation, and dynamic capability of the supply chain. The research of Laaksonen and Peltoniemi (2018) shows that dynamic capabilities change ordinary capabilities or the firm’s broader resource base, which may eventually cause a change in firm performance. They point to the importance of learning opportunities and measuring learning outcomes. SCL is a typical dynamic capability, which is a learning process using dynamic data and information from different suppliers, customers, and internal functions, and this dynamic characteristic builds SCL as a vital dynamic capability. Aslam et al. (2020) test entrepreneurial orientation and SCL orientation as two antecedents of Dynamic Supply Chain Capabilities, highlighting that the ability to learn with supply chain partners is vital to the building of dynamic capabilities.

As a vital learning path, SCL has attracted increasing attention in SCM from scholars and practitioners alike. Bessant, Kaplinsky, and Lamming (2003) suggest that SCL comprises inter-organisation learning behaviours. Flint, Larsson, and Gammelgaard (2008) emphasise that learning occurs and is focused on supply chain issues and solutions. Gong et al. (2018) confirm that SCL supports the orchestration of internal and external resources in multi-tier sustainable SCM practices. Previous literature has provided a range of varying conceptualisations of SCL, but, to date, remains non-standardised. Meanwhile, inspired by the definition of Huo, Haq, and Gu (2021), we can capture the SCL structure from the perspectives of supplier learning, customer learning, and internal learning. Supplier learning is the acquisition, assimilation, and exploitation of materials and supply-related knowledge from suppliers, whereas customer learning is the acquisition, assimilation, and exploitation of preferences and market-related knowledge from customers. By contrast, internal learning is the acquisition, assimilation, and exploitation of product development and manufacturing-related knowledge embedded within functions.

Supplier learning and customer learning are the learning processes deriving from the external environment of an organisation, and collectively referred to external learning (Gong et al. 2018). In the context of SCE, external learning and internal learning are not independent, but closely related, internal learning triggering and stimulating external learning (Yu et al. 2022). In other words, external learning does not occur in isolation, but is a result of the confrontation and combination of organisations’ internal experience (Holmqvist 2003). The deepening of the internal learning process generates new demand for knowledge. To fill the knowledge gaps, companies need to find other learning paths. External learning from supply chain partners is a good choice, and can update a firm’s knowledge base after the assimilation and transformation of knowledge obtained from their suppliers and customers (Huo, Haq, and Gu 2021). The aggregations of external learning and internal learning are tied together in joint learning cycles, while internal learning is what drives the learning of external collaborations (Holmqvist 2003). Therefore, the following hypotheses are presented:

H1. Internal learning is positively related to external learning.

H1a. Internal learning is positively related to supplier learning.

H1b. Internal learning is positively related to customer learning.

2.2.2. SCL empowering SCE Health

SCL significantly influences the management of the production and operations ecosystem, and has drawn attention from both theoretical research and empirical analysis. The research on SCL can be divided into (i) indirect concepts, including 'deliberate learning mechanisms' (Berghman, Matthyssens, and Vandenbempt 2012); 'knowledge transfer' (Blome, Schoenherr, and Eckstein 2014); 'learning orientation' (Hanvanich, Sivakumar, and Hult 2006); and 'learning through sustainability initiatives' (Silvestre et al. 2020) and (ii) direct concepts, which generally fall under the spotlight in the SCM field, specifically inventory performance (Yao, Dong, and Dresner 2012); integrating supply chain and customer value creation (Zhu, Krikke, and Caniels 2018); product innovation (Li, Wang, and Zhao 2018); service performance (Huo, Haq, and Gu 2019); flexibility performance (Huo, Haq, and Gu 2021); and operational and financial performance (Ul Haq 2021). Due to the increasingly complex and volatile environments, SCL is also associated with reducing the negative influence of supply chain disruptions (Baghersad et al. 2022), building resilience (Chen, Li, and Linderman 2022; Evenseth, Sydnes, and Gausdal 2022), and improving supply chain risk management (Manhart, Summers, and Blackhurst 2020).

As mentioned above, SCL is a systematic process of the acquisition, assimilation, and exploitation of knowledge. Spekman, Spear, and Kamauff (2002) suggest six preconditions for the implementation of SCL: trust, communication, the type of relationship, decision-making style, culture, and win–win orientation. SCL is a process of constantly dynamic adjustment, showing the characteristics of dynamic capabilities. Bessant, Kaplinsky, and Lamming (2003) divide SCL into three phases: The first step is 'set up', driven by 'triggers' (e g., under crisis or new opportunities) to establish a set of procedures to promote SCL; the second step is 'operating', translating the procedures to routines and norms, and then reflecting on the behaviour between and within firms; the third step is 'sustaining' – that is, realising continuous learning through management processes and a mechanism which needs to be identified and highlighted. During these three steps, learning ability is dynamically deepened, thereby further empowering sustainable development.

Previous research has proved that SCL is an efficient way to pursue SCE Health in different aspects. Blome, Schoenherr, and Eckstein (2014) and Li, Wang, and Zhao (2018) suggest that SCL has advantages in improving productivity and service efficiency, which constitute the 'productivity' dimension. Mubarik et al. (2022) confirm that SCL can resist external disturbance to maintain robustness and resilience, which constitutes the 'robustness' dimension. As for the 'niche creation' dimension, Zhu, Krikke, and Caniels (2018) and Berghman, Matthyssens, and Vandenbempt (2012) propose that value co-creation can be achieved by strengthening SCL. Based on these research studies, we focus on the relationship between SCL and SCE Health and propose the following hypotheses:

H2. There is a direct and positive relationship between SCL and SCE Health.

H2a. There is a direct and positive relationship between supplier learning and SCE Health.

H2b. There is a direct and positive relationship between internal learning and SCE Health.

H2c. There is a direct and positive relationship between customer learning and SCE Health.

2.3. Moderation of environmental turbulence

Companies' SCE involves the dynamic external environment, and is deeply embedded in environmental turbulence, particularly in the post-COVID-19 era. The process of SCL empowering SCE Health is no exception. Environmental turbulence is a crucial environmental component that affects strategy and performance, and boosts uncertainty and risk in business operations (Wang et al. 2015). Following the research of Hung and Chou (2013), this study explores environmental turbulence from the perspectives of technological turbulence and market turbulence. Technological turbulence refers to the rapid and unpredictable technology development embedded in products and services, and is closely related to technological knowledge; market turbulence is the degree of variation in customer preference and product demand in the industry as a whole, and is closely related to market knowledge (Hung and Chou 2013). Environmental turbulence is the primary external factor influencing the link between a firm's dynamic capabilities and performance (Tsai and Hung 2016; Wang et al. 2015). Thus, this study focuses on how environmental turbulence moderates the relationship between SCL and SCE Health based on the dynamic capabilities theory.

First, a turbulent market is characterised by unpredictable and frequent changes in customer preferences. Companies must understand market trends and change their operations accordingly, requiring more data and knowledge to make wise decisions (Wang et al. 2015). Second, rapid technical advancements will challenge firms' technology acquisition ability. In a highly turbulent technology environment, a company may concentrate on keeping up with and satisfying external technical demands, while simultaneously identifying and removing the obstacles to new technology (Song et al. 2005). To overcome the challenges and subsequently seize opportunities, companies urgently need to create dynamic skills.

The research results on the positive effects of environmental turbulence are well documented. SCL offers companies the capacity to acquire information and knowledge through a variety of channels, tracking the demands and preferences of supply chain partners and enhancing organisational performance and innovativeness (Li, Wang, and Zhao 2018; Mubarik et al. 2022; Wei, Zhu, and Yuan 2020). Generally, companies are able to grasp useful technological knowledge and market knowledge accurately in a relatively stable environment. Hanvanich, Sivakumar, and Hult (2006) confirm that the strength of the relationship between learning and organisational performance is stronger in highly turbulent environments than in environments with low turbulence. This study posits that companies can set themselves apart from rivals by developing a unique advantage through SCL under high environmental turbulence, thereby improving their dynamic capabilities and empowering SCE Health. Thus, we present the following hypotheses:

H3. Technological turbulence plays a positive moderating role between SCL and SCE Health.

H4. Market turbulence plays a positive moderating role between SCL and SCE Health.

Figure 2 presents the theoretical framework of this research.

3. The methodology

3.1. Questionnaire design

The questionnaire was initially created in English and then translated into Chinese. To achieve cross-cultural equivalence, we employed a back-translation strategy. To ensure its validity and reliability, the questionnaire was designed with 47 measurement items adapted through an extensive review of the literature (see Appendix A for complete questionnaire and details). Before the formal survey, we invited four professors majoring in SCM to provide comments on the questionnaire, and carefully examined the measures to ensure clarity and understandability. After synthesising the literature review results with feedback from the professors, we refined the wording in the questionnaire and estimated the time required to complete it. The independent, moderating, and dependent variables are all measured by multi-item scales. Each item used a seven-point Likert-type scale ('1' indicates 'strongly disagree' and '7' indicates 'strongly agree'). Firm annual revenue and employee number are controlled to account for performance bias and extraneous effects, as these play an important role in explaining SCE Health. This is because large firms are expected to have more

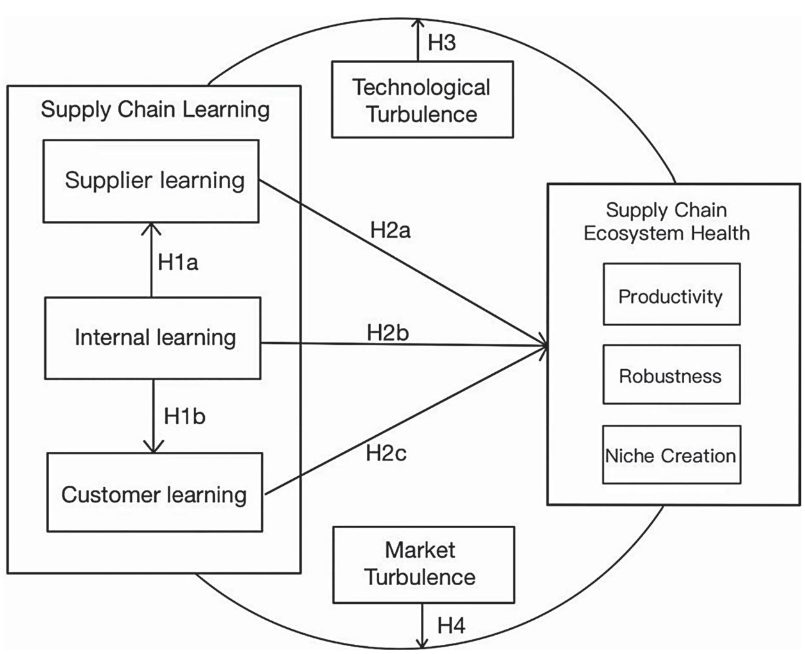

Figure 2. Theoretical framework.

resources and greater influence within the SCE (Wei, Zhu, and Yuan 2020).

3.2. Questionnaire distribution and data collection

From March 2021, questionnaires were distributed online through e-mail and WeChat along with a cover letter highlighting the research objectives and potential contributions, targeting the respondents engaged in practical OSCM work, mainly covering the operations and finance departments. To improve the response rate and address potential missing data issues, we used follow-up telephone calls and mailings (Frohlich 2002). Out of 520 companies contacted, a total of 403 questionnaires were distributed, and 220 usable questionnaires were returned. The response rate was 54.6%. The returned questionnaires were first selected through manual inspection (eliminating the extreme data that selected 1 or 7 for all the questionnaire questions). We then used Mahalanobis distance to delete severe outliers. Finally, 208 valid questionnaires were selected for further analysis. The sample size was acceptable based on the model complexity according to the research of Hair et al. (2006). The ownership, annual revenue, number of employees, and firm age of case companies are listed in Table 1.

Using statistical information and qualitative hypotheses, SEM is a useful method for presenting the connections between the dependent and the independent variables. SEM has been successfully applied in many SCL studies (Li, Wang, and Zhao 2018; Wei, Zhu, and Yuan 2020). Following the benefits of SEM in the SCL field, our research applied the methodology to analyse the collected data using SPSS version 26, and SEM was conducted using AMOS version 26.

Table 1. Respondents' profiles.

Variables	*N*	%
Ownership		
State-owned enterprises	72	34.6%
Private enterprises	105	50.4%
Joint venture enterprise	14	6.7%
Overseas-funded enterprises	6	2.9%
Others	11	5.3%
Annual revenue(mRMB)		
<1	18	8.7%
1–5	18	8.7%
5–20	16	7.7%
20–50	24	11.5%
50–100	16	7.7%
>100	116	55.8%
Employees		
<50	38	18.3%
51–100	19	9.1%
101–200	25	12.0%
>210	126	60.6%
Firm age(years)		
<5	26	12.5%
6–10	36	17.3%
11–15	39	18.8%
16–20	29	13.9%
>21	78	37.5%

4. The results

4.1. SEM results

4.1.1. Common method bias

To decrease the potential of common method bias (CMB), we employed tests before and after the questionnaire distribution. Before the questionnaire distribution, we made it clear that all information would be kept strictly confidential. To reduce contextual influences, we mixed the order of the measurement items appearing in the questionnaire. After questionnaire distribution, two methods were tested. First, Harman's single-factor test was adopted (Podsakoff et al. 2003). The analysis revealed eight factors with eigenvalues greater than 1.0, explaining 69.54% of the total variance, with the first factor explaining 46.74%, which is supported by Podsakoff et al. (2003). Second, following Mossholder et al. (1998), we compared two models: (i) all indicators loaded onto one factor (χ^2/DF = 4.176; IFI = 0.812; CFI = 0.811; RMSEA = 0.124), and (ii) each indicator loaded onto its own latent factor (χ^2/df = 2.193; IFI = 0.933; CFI = 0.932; RMSEA = 0.076). The second model is significantly superior to the first one, and the chi-square difference test comparing two models showed that $\Delta\chi^2 = 438.418$, ΔDF = 10, and $p < 0.000$, indicating that the two models are significantly different. In sum, CMB was not a problem in this study.

4.1.2. Construct reliability and validity

To ascertain the reliability of the measurement model, Cronbach's alpha and composite reliability (CR) were assessed (Fornell and Larcker 1981). We first tested the first-order constructs (productivity, robustness, and niche creation), and then the second-order constructs, including supplier learning, internal learning, customer learning, SCE Health, technological turbulence, and market turbulence (Wetzels, Odekerken-Schroder, and van Oppen 2009). The results in Table 2 show that Cronbach's alpha and CR values are well above the threshold value of 0.70 as recommended by Fornell and Larcker (1981), indicating that all the constructs are reliable.

As for the internal consistency and validity, two-dimensional validity (convergent and discriminant) was assessed and results are shown in Table 3. The values of average variance extracted (AVE) were used to assess convergent validity of the constructs, and the corresponding results indicate that the values of AVE were above the recommended threshold of 0.50; the satisfactory convergent validity was again supported. The

Table 2. CR and AVE of constructs.

Construct	Item	Unstd.	S.E.	*t*-value	*P*	Std.	SMC	1-SMC	Cronbach's alpha	CR	AVE
First-order constructs											
Productivity	P1	1.000				0.456	0.208	0.792	0.749	0.744	0.516
	P2	1.809	0.299	6.046	***	0.621	0.386	0.614			
	P3	2.547	0.560	4.546	***	0.977	0.955	0.045			
Robustness	R1	1.000				0.830	0.689	0.311	0.902	0.899	0.692
	R2	0.771	0.059	13.069	***	0.793	0.629	0.371			
	R3	0.780	0.059	13.218	***	0.799	0.638	0.362			
	R4	0.944	0.061	15.365	***	0.900	0.810	0.190			
Niche Creation	Var	1.000				0.748	0.560	0.440	0.890	0.887	0.664
	SV	0.975	0.077	12.588	***	0.888	0.789	0.211			
	IV	0.924	0.083	11.181	***	0.783	0.613	0.387			
	CV	0.938	0.079	11.922	***	0.833	0.694	0.306			
Second-order constructs											
Supplier Learning	SL1	1.000				0.733	0.537	0.463	0.835	0.841	0.570
	SL2	1.003	0.105	9.560	***	0.739	0.546	0.454			
	SL3	0.999	0.101	9.922	***	0.773	0.598	0.402			
	SL4	0.982	0.099	9.914	***	0.773	0.598	0.402			
Internal Learning	IL1	1.000				0.773	0.598	0.402	0.907	0.908	0.713
	IL2	0.937	0.076	12.362	***	0.800	0.640	0.360			
	IL3	1.047	0.078	13.414	***	0.854	0.729	0.271			
	IL4	1.172	0.079	14.757	***	0.941	0.885	0.115			
Customer Learning	CL1	1.000				0.813	0.661	0.339	0.840	0.860	0.673
	CL2	0.962	0.085	11.378	***	0.759	0.576	0.424			
	CL3	0.995	0.081	12.255	***	0.884	0.781	0.219			
SCE Health	NC	0.926	0.053	17.639	***	0.904	0.817	0.183	0.908	0.914	0.779
	P	1.000				0.892	0.796	0.204			
	R	1.083	0.067	16.278	***	0.851	0.724	0.276			
Technological Turbulence	TT1	1.000				0.867	0.752	0.248	0.931	0.932	0.774
	TT2	1.016	0.055	18.312	***	0.910	0.828	0.172			
	TT3	1.033	0.058	17.873	***	0.898	0.806	0.194			
	TT4	0.940	0.059	15.866	***	0.842	0.709	0.291			
Market Turbulence	MT1	1.000				0.883	0.780	0.220	0.904	0.905	0.704
	MT2	0.862	0.065	13.273	***	0.763	0.582	0.418			
	MT3	1.015	0.065	15.634	***	0.843	0.711	0.289			
	MT4	0.942	0.058	16.200	***	0.862	0.743	0.257			

Note: $*p < 0.05$. $***p < 0.001$.

Table 3. Assessment of discriminant validity.

	Mean	1	2	3	4	5	6	7	8
1. Firm annual revenue	4.680								
2. Firm employee number	3.150	.671							
3. Technological turbulence (TT)	4.746	−.221	−.018	**.880**					
4. Market turbulence (MT)	4.772	−.238	−.068	.821	**.839**				
5. Supplier learning (SL)	5.019	−.202	−.055	.553	.586	**.755**			
6. Internal learning (IL)	5.252	−.211	−.066	.486	.545	.613	**.844**		
7. Customer learning (CL)	5.192	−.161	.060	.500	.507	.642	.748	**.820**	
8. Supply chain health (SCH)	5.283	−.231	−.016	.516	.567	.744	.771	.706	**.883**

Note: Values of Square root of AVE are in bold.

discriminant validity of each construct was examined by comparing the square root of its AVE value to the correlations between this construct and the other constructs. The square root of AVE for each construct was greater than its correlation with other constructs, indicating adequate discriminant validity (Hair et al. 2006). Heterotrait–Monotrait (HTMT) analysis was adopted for the additional assessment of discriminant validity. Our result shows that the value is acceptable, meeting the threshold level of 0.90 (Gold, Malhotra, and Segars 2001; Teo, Srivastava, and Jiang 2008). The specific value is presented in Table 4.

The multicollinearity bias was also considered. According to the research of Giacalone, Panarello, and Mattera (2018), VIF > 10 indicates the presence of severe multicollinearity. Our result in Table 5 shows that the VIF of all the independent variables was less than 5, indicating that multicollinearity was not a severe problem in this research.

Table 4. Heterotrait-monotrait (HTMT) analysis results.

	Supplier learning	Internal learning	Customer learning	SCE health
Supplier learning				
Internal learning	0.773			
Customer learning	0.861	0.846		
SCE health	0.854	0.834	0.812	

Table 5. The VIF of independent variables.

	Supplier Learning				Internal Learning				Customer Learning		
Independent Variables	SL1	SL2	SL3	SL4	IL1	IL2	IL3	IL4	CL1	CL2	CL3
VIF	1.846	2.097	2.380	2.894	2.880	2.294	3.297	2.559	2.665	3.753	4.941

4.1.3. Measurement model and structural model

The measurement model demonstrates that the latent constructs fundamental for testing the proposed structural model were assessed effectively based on the indicator variable (Paul and Maiti 2008). Confirmatory factor analysis (CFA) is a method to analyse the measurement model. The second-order model was applied for the purpose of structural model simplification. In order to verify the applicability of the second-order structure of SCE Health, we used the CFA of the first order and the second order, respectively. The target coefficient was calculated by comparing the CFA of the first order and the second order of SCE Health, which was very close to 1. The results imply that the second-order CFA could replace the first-order CFA and that the second-order model was suitable for the next stage of the research (Hair et al. 2014; Marsh and Hocevar 1985). According to the suggestion of Paul and Maiti (2008), a minimum of four tests of model fit should be satisfied with the acceptability and compatibility of the model. The CFA of the measurement model was performed, and the outcome is illustrated in Table 6. Six fit indices were accepted, indicating that the model fits the data very well.

The acceptance of the measurement model indicated that a structural model could be established. The structural model consists of three first-order and four second-order latent variables, and 22 observed indicator variables, and the structural model with loadings is presented in Figure 3. The fit indices results show that the model fitted the data satisfactorily. Other fit indices, although not strictly above the acceptable value, are very close. More details can be seen in Table 6.

Table 6. Fits statistics of the measurement model and structure model.

Fit index	Measurement model	Structure model	Acceptable value
Chi-square	473.417	494.373	
df	200	203	
Chi-square/df	**2.367**	**2.435**	≤ 5
CFI (Comparative fit index)	**0.927**	**0.917**	≥ 0.9
IFI (Incremental fit index)	**0.928**	**0.918**	≥ 0.9
TLI (Tucker Lewis index)	**0.916**	**0.906**	≥ 0.9
AGFI (Adjusted goodness of fit index)	0.798	0.772	≥ 0.8
PNFI (Parsimonious fit)	**0.763**	**0.763**	≥ 0.5
RMSEA (Root mean square of approximation)	**0.079**	0.083	≤ 0.08
GFI (Goodness of fit index)	0.840	0.817	≥ 0.9
NFI (Normed fit index)	0.882	0.868	≥ 0.9
RFI (Relative fit index)	0.863	0.850	≥ 0.9

Note: Values of acceptability are in bold. The acceptable values refer to the research of Jackson, Gillaspy, and Purc-Stephenson (2009).

4.1.4. Hypothesis testing

The results of the path analysis are exhibited in Table 7. From these results, it can be observed that hypotheses H1a, H1b, H2a, and H2c are supported at the level of $P < 0.001$, whereas hypothesis H2b is supported at the $P < 0.05$ level. Thus, the first set of hypothesis H1 is proved; that is, internal learning positively influences both customer learning and supplier learning. Further, the second set of hypothesis H2 is also supported. All three aspects of SCL have significant positive effects on SCE Health, and customer learning is the most important among them.

4.1.5. Mediation testing

The mediating effects of supplier learning (SL) and customer learning (CL) on the relationship of internal learning (IL) and SCE Health were tested using AMOS 26.0. To quantify the indirect effects, we first performed the Sobel test (Sobel 1982). The Sobel Z of SL on the relationship between IL and SCE Health was 3.950, indicating that partial mediation existed in the path of IL→SL→SCE Health. Similarly, the Sobel Z of CL was 4.036; partial mediation also existed in the path of IL→CL→SCE Health.

However, the Sobel test had a major flaw: it assumed that the sampling distribution was normal, while the sampling distribution was asymmetric with nonzero skewness and kurtosis (Bollen and Stine 1990). To avoid the influence of non-multivariate normality caused by large-scale samples, we tested the mediation effect by bootstrapping method with 5000 times following the research of Hayes (2009). The corresponding results are summarised in Table 8, indicating that IL improves SCE Health through the full mediation of SL and CL. Thus, H1a and H1b are re-supported. This also explains the potential reasons for H2b being less significant than the other hypothesis – namely, internal learning exerts more influence on SCE Health through the indirect effects on external learning.

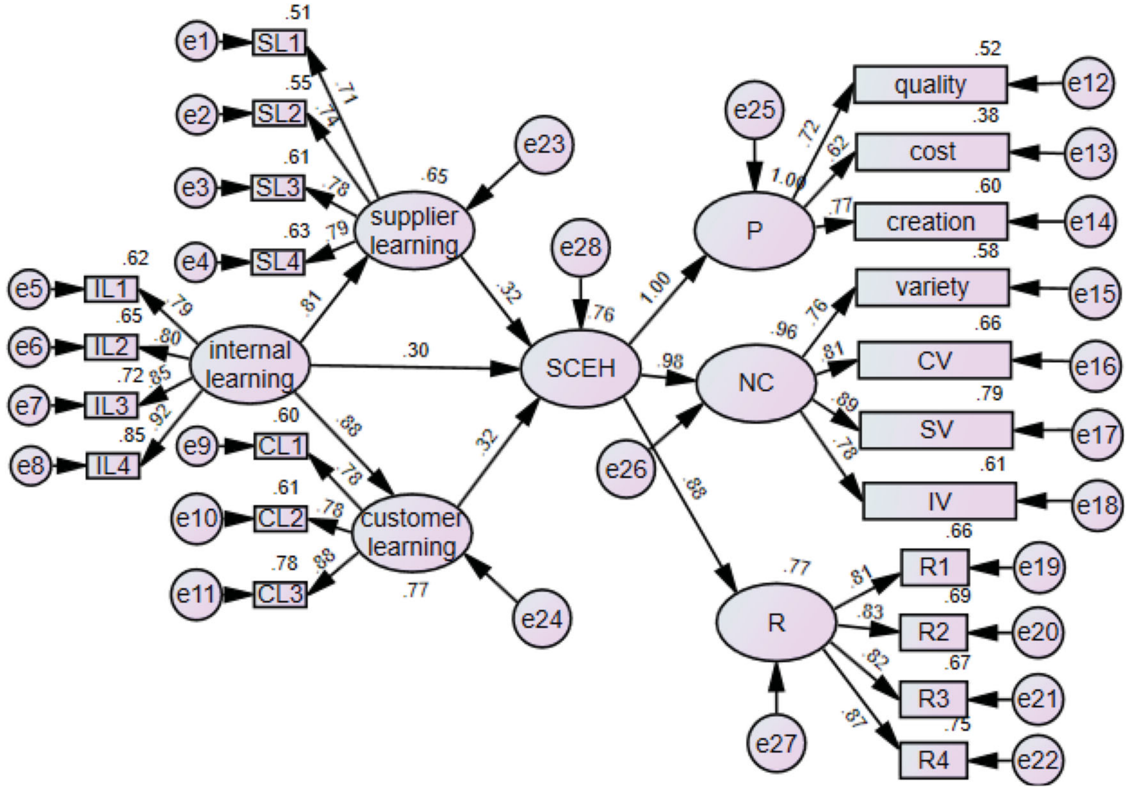

Figure 3. The structural equation model of proposed model constructs and indicators with loadings.

Table 7. Path coefficients (standardised) and their significance values for measurement model.

Hypothesis	Path description			Estimate	S.E.	C.R.	*P*	Result
H1a	Supplier Learning	←	Internal Learning	0.806	0.085	9.354	***	Supported
H1b	Customer Learning	←	Internal Learning	0.877	0.083	10.747	***	Supported
H2a	SCE Health	←	Supplier Learning	0.315	0.051	4.377	***	Supported
H2b	SCE Health	←	Internal Learning	0.300	0.092	2.275	*	Supported
H2c	SCE Health	←	Customer Learning	0.324	0.051	4.377	***	Supported

Note: $*p < 0.05$. $***p < 0.001$; S.E. represent standard error and C.R. indicates Critical ratio.

4.1.6. Moderation testing

The hierarchical linear regression method was adopted to test the moderating effect of environmental turbulence on the relationship between SCL and SCE Health (Aiken and West 1991). We added two control variables (firm annual revenue and firm employee number) into the model in the first step (Model 1), an independent variable and moderating variables (SCL, technological turbulence, and market turbulence) into the model in the second step (Model 2), and their interaction items to test the moderating effect in the third step (Model 3). To avoid the potential threat of multicollinearity, all independent and moderating variables were centralised (Aiken and West 1991).

The results of the moderation effect of technological turbulence and market turbulence are shown in

Table 8. Direct, indirect and total effects between internal learning and SCE Health.

				Bootstrapping			
		Product of coefficients		Bias-corrected		Percentile	
	Point Estimate	SE	*Z*	Lower	Upper	Lower	Upper
Total Effects							
IL→SCE Health	0.586	0.071	8.254	0.469	0.750	0.466	0.744
Indirect Effects							
IL→SCE Health	0.376	0.145	2.593	0.162	0.710	0.126	0.650
Direct Effects							
IL→SCE Health	0.210	0.162	1.296	−0.090	0.503	−0.069	0.523

Note: 5000 bootstrap samples (Hayes 2009).

Table 9. The results of the moderation effect.

	Technological turbulence (TT)						Market turbulence (MT)					
	Model 1		Model 2		Model 3		Model 1		Model 2		Model 3	
Variables	*β*	*t* value	*β*	*t* value	*β*	*t* value	*β*	*t* value	*β*	*t* value	*β*	*t* value
Control variables												
Firm annual revenue	−0.400***	−4.441	−0.094*	−1.736	−0.029	−0.564	−0.400***	−4.441	−0.090*	−1.679	−0.054	−1.012
Firm employee number	0.252**	2.8	0.064	1.233	0.003	0.053	0.252**	2.8	0.065	1.263	0.026	0.51
Direct effects												
SCL			0.802***	17.031	0.726***	16.154			0.778***	15.989	0.753***	15.755
TT			0.029	0.62	−0.036	−0.804						
MT									0.069	1.417	0.017	0.727
Moderating effects												
SCL × TT					0.263***	6.236						
SCL × MT											0.154***	3.546
R^2	0.088		0.708		0.755		0.088		0.71		0.727	
Adjusted R^2	0.079		0.702		0.749		0.079		0.705		0.72	
R^2 change	0.088***		0.620***		0.047***		0.088***		0.622***		0.017***	

***$p < 0.001$. **$p < 0.01$. *$p < 0.1$.

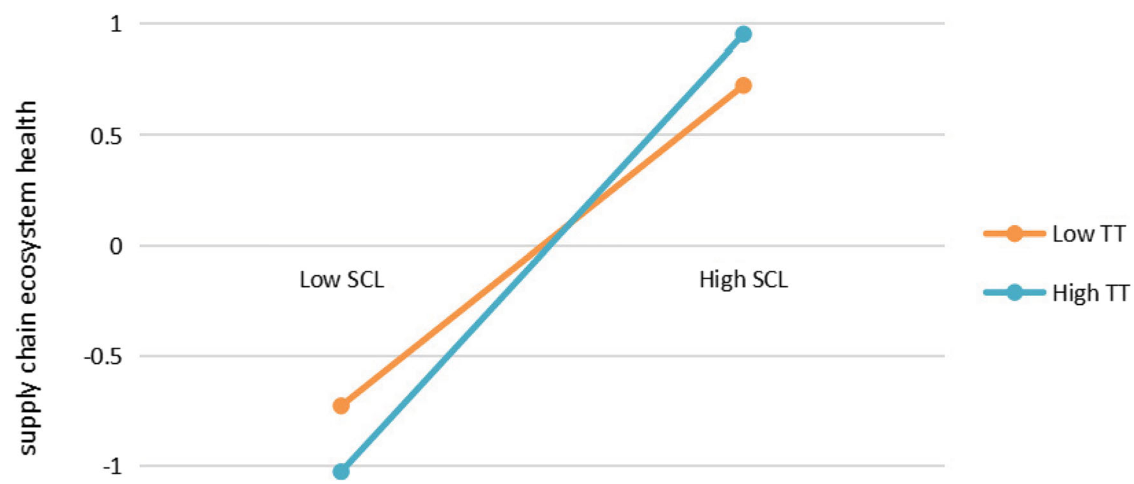

Figure 4. Simple slopes for the interaction effect of SCL and technological turbulence on SCE Health.

Table 9. The coefficient for the interaction term of SCL and technological turbulence is significant ($\beta = 0.263$, $P < 0.001$), confirming that technological turbulence plays a positive moderating role between SCL and SCE Health; thus, H3 is supported. The results also demonstrate that the interaction term between SCL and market turbulence is positive and significant ($\beta = 0.154$, $P < 0.001$), thus supporting H4.

To acquire insights into the moderating role of environmental turbulence, this study followed the method of Aiken and West (1991) to visualise the correlations between SCL and SCE Health under different levels of environmental turbulence. Specifically, this study classified environmental turbulence into two categories – low (one standard deviation below the mean) and high (one standard deviation above the mean) – and examined the effect of SCL on SCE Health. As presented in Figure 4, SCL has a stronger positive impact on SCE Health when technology turbulence is high ($\beta = 0.989$, $P < 0.001$) than when it is low ($\beta = 0.463$, $P < 0.001$). According to Figure 5, market turbulence improves the positive association between SCL and SCE Health. SCL has a greater positive impact on SCE Health when market turbulence is high ($\beta = 0.907$, $p < 0.001$) than when it is low ($\beta = 0.599$, $p < 0.001$).

4.2. Further analysis – interview results

To gather insights from the practice on SCM, and acquire support for and understanding of the theoretical framework, this research further conducted open-ended questions in the interviews with the practising managers and experts in the SCM field after the empirical study. We selected five case companies with outstanding industry characteristics in supply chains and rich experience in supply chain services. The case companies were located in the fore of their respective industries and had significant features. They covered traditional and emerging

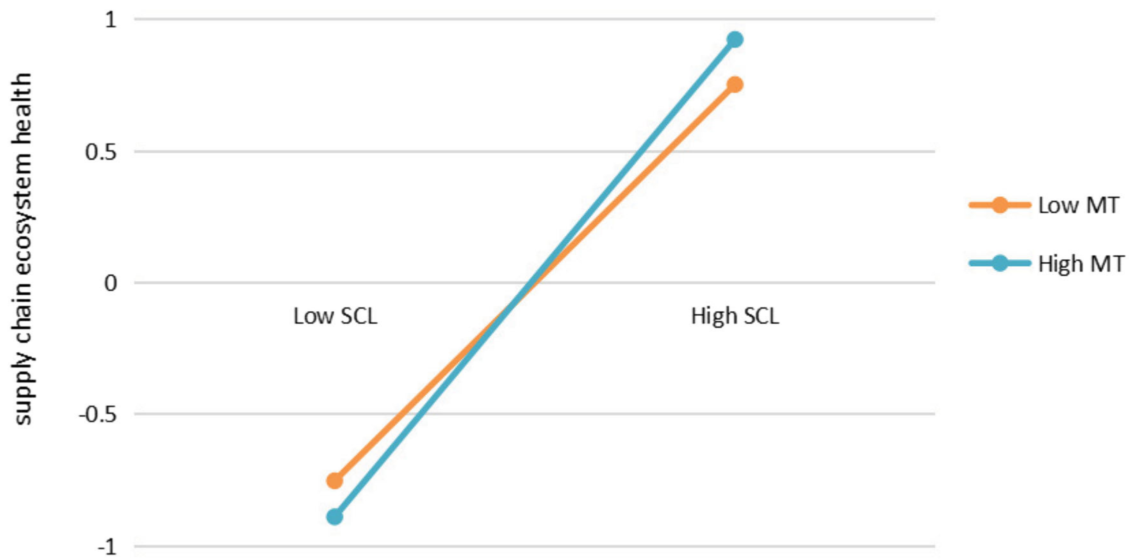

Figure 5. Simple slopes for the interaction effect of SCL and market turbulence on SCE Health.

Table 10. Background information of case companies and interviewees.

Case company	Headquarters	Founded	Industry	Department	Position	Work experience (Yrs)
A	Shandong province	2008	Steel industry	Technical centre	Deputy general manager	16
				Operations management	Deputy general manager	12
B	Beijing	2020	Financial industry	Operations management	Vice president	15
				Operations management	Deputy director	13
				Technical department	Deputy general manager	10
C	Henan province	2014	Consulting service	Operations management	Deputy general manager	13
				Customer department	Accounts manager	7
D	Tianjin	1996	Banking industry	Business department	Deputy general manager	15
				Trading department	Deputy director	10
E	Beijing	1996	Manufacturing industry	Investment department	General manager	32
				Customer department	Deputy director	9

industries at the same time, the future development of the industries being closely related to the SCE. Eleven managers from the five companies participated in the virtual interviews between 27 April 2022 and 7 October 2022 via Tencent Meeting, as travel was restricted due to the COVID-19 pandemic. All participants had rich practical experience of, and unique insights into supply chains. The specific background information of 11 interviewees from the five case companies is shown in Table 10.

The interview results are highly consistent with the SEM results, providing solid theoretical support to the empirical results. All interviewees agreed with the measurement for SCL from the three perspectives of supplier learning, customer learning, and internal learning. The definition of SCE Health also received great support from all interviewees: SCE Health refers to 'a stable and sustainable developing supply chain' (C); 'A system which can achieve incremental gains and continuously develop new customers to make the supply chain longer and wider' (B); 'Not only our own company's well-being in the ecosystem matters, but also that of the whole ecosystem. We all hope that when the ecosystem is healthy, has stable suppliers, and can release more profit space, the price of downstream products increases and the price positioning becomes more accurate' (A); 'Stay active and increase productivity, in addition to achieving vitality, which is to maintain timeliness' (E). All interviewees mentioned key points such as 'stability', 'development', 'productivity', and 'sustainability', which are strongly related to and/or consistent with the measurement of SCE Health from the productivity, robustness, and niche creation perspectives. Our research construct received support from the practitioners and experts in OSCM through multiple interviews.

In general, all case companies recognised that SCL is a very important and necessary ability for companies to achieve their own survival and sustainable development in the post-COVID-19 era. With the development of the supply chain, the transformation from supply chain network to a higher level of SCE is a growing trend. For a company to achieve its own development, it is more important to realise the health of the whole SCE, and this process cannot be separated from SCL. 'Suppliers, core enterprises, and customers can be deeply embedded in the SCE through products to realise true connection, discovering many new value points in the cooperation process and expanding the scope of cooperation, improving product lines, reducing costs, and improving internal process efficiency' (D). Therefore, the underlying rationales of the theoretical framework are reasonable based on the interviews discussed above.

5. The discussion

5.1. Theoretical contributions

By empirically exploring the relationship between SCL and SCE Health, this study provides a new lens into the SCL community and fills an important gap in the SCM literature in the post-COVID-19 era. It contributes to the literature in the following four aspects. First, it proposes a new concept of SCE Health. Learning from previous definitions of business ecosystem health (Iansiti and Levien 2004) and supply chain viability (Ivanov 2022; Münch and Hartmann 2023; Ruel et al. 2021; Sawik 2023), and combining with the characteristics of the SCE (Ketchen, Crook, and Craighead 2014), we define and measure SCE Health from three dimensions – productivity, robustness, and niche creation. To confirm the rationality of this definition, from the theoretical perspective, a science mapping analysis is used to synthesise the keywords of previous research in the supply chain-related fields, which shows the scientificity of our measurement on SCE Health; from the practical perspective, this definition is also discussed through interviews with 11 SCM experts from five case companies, highlighting the uniqueness and importance of SCE Health. These works lay a solid theoretical foundation for our definition and further empirical analyses. The proposal of SCE Health broadens the SCE research, which is no longer limited to the efficient performance of a single company or supply chain viability, but focuses on how to realise and maintain long-term and sustained development of the whole SCE (den Hartigh, Tol, and Visscher 2006; Iansiti and Levien 2004; Kähkönen et al. 2023; Münch and Hartmann 2023). This not only achieves the goal of 'survival' but also those of 'creativity' and 'value', and may even turn crisis and disruption into chances for development.

Second, our research enriches the understanding of the dynamic capabilities theory in the SCL stream by highlighting the significance of internal learning in enhancing external learning under environmental turbulence, which differs from that of previous studies on SCL which focus on the idea that external learning drives internal learning (Huo, Haq, and Gu 2021; Ul Haq 2021). Grounded in the dynamic capabilities theory, our empirical analysis proves that the expansion and development of firms' internal knowledge leads to the demand for more new knowledge, which is not limited to the organisation itself, but expands into a wider scope of learning. In this context, suppliers and customers are suitable learning objects because of interest correlation and sharing. This study presents our direct contributions to the dynamic capabilities theory by explaining how firms perceive lack of knowledge in the process of internal learning (sensing); seek new learning objects and opportunities to make up for shortcomings (seizing); and reconfigure the focus and attention of learning (transforming) to achieve more efficient learning and improved ability (Pavlou and El Sawy 2011).

Third, our study also contributes to the SCL literature by confirming that SCL significantly promotes SCE Health performance. The empirical results show that three different paths of SCL significantly improve the performance of SCE Health. The findings are in line with other research showing that the synthesis of different sources of knowledge leads to competitive superiority, ultimately separating the winners from the losers (Spekman, Spear, and Kamauff 2002). Previous studies placed the foothold of SCL mainly on SCM (Pontrandolfo et al. 2002; Yao, Dong, and Dresner 2012; Zhu, Krikke, and Caniels 2018). We put forward a broader research idea and use empirical research to prove that SCL affects not only the management of production and operations systems, but also the whole SCE, confirming that the three different dimensions of SCL are important paths to realise SCE Health, and emphasising knowledge and learning as unique resources and capabilities which help enterprises to gain a stronger foothold in the ecosystem (Flint, Lusch, and Vargo 2014).

Fourth, under the environmental turbulence driven by geopolitical instability and COVID-19, this research also explores the moderation effect of environmental turbulence on the relationship between SCL and SCE Health. Environmental turbulence is regarded as a chance for the development and performance of enterprises. Wang et al. (2015) find that market turbulence positively moderates the enabling effects of innovation and information capabilities. Hanvanich, Sivakumar, and Hult (2006) confirm that environmental turbulence strengthens the relationship between learning and organisational performance. Consistent with this trend, our research provides empirical evidence that environmental turbulence promotes the impact of SCL on SCE Health, indicating that, under an increasingly complex environment, particularly when technological developments and market changes are difficult to predict, efficient implementation of SCL can help firms to establish advantages in these seemingly unfavourable conditions (Li, Wang, and Zhao 2018). In addition to maintaining the development of the enterprise itself, SCL can also drive the whole SCE to make progress in a healthier direction.

5.2. Managerial implications

This research draws attention to the significance of SCE Health and confirms its importance and scientificity. Particularly following the severe impact of the global epidemic, it is hard to survive by relying on the power of an enterprise independently; even collaboration with the upstream and downstream cannot satisfy the demand for development. Therefore, it is necessary to pay attention to the SCE from a more macro and comprehensive perspective, which includes not only the enterprise and its supply chain partners, but also the supply chain partners' partners, competitors' partners, as well as various supply chain relationships in other industries. Managers and decision-makers also need to find potential opportunities from logistics flows, capital flows, and information flows to seek better development opportunities and achieve a win–win outcome with the SCE members, aiming at the ultimate goal of SCE Health. Supply chain professionals may also find our validated SCE Health measurement scale useful from the 'productivity', 'robustness' and 'niche creation' dimensions, while SCE Health can be taken as one of the important indicators to measure the future development of enterprises and the trend of the whole industry.

Another important finding from a practitioner perspective is the positive and significant link between SCL and SCE Health. SCL does not happen overnight, but requires a process; hence, business leaders must be patient and make a commitment to fully comprehend the significance, difficulties, and needs of SCL and convey this commitment to all employees through various channels and strategies. Only in this way can a formal pattern of learning emerge, and dynamic capabilities be built through active knowledge collection and sharing in multiple channels.

More importantly, SCE Health should not only be a measurement indicator, but also a guide to all SCE members. Driven by the goal of SCE Health, it is clear that SCL is a clever choice, because information and knowledge sharing is related to the establishment and maintenance of relationships, while the formation of closer cooperation and tighter binding with the SCE members profoundly impacts the efficiency of SCL and the realisation of SCE Health. In the current post-COVID-19 era, environmental turbulence is inevitable. However, business leaders should not regard it simply as a factor hindering development, but as an opportunity. They should value the construction of dynamic capabilities and the chance to form the firm's own unique competitive advantage through SCL to maintain robustness, realise the promotion of productivity, and achieve innovation and value co-creation, thereby driving the whole SCE to become healthier.

6. Conclusions

This study presents a new concept of SCE Health and empirically investigates the relationship between SCL and SCE Health, grounded in the dynamic capabilities theory and the data from 208 questionnaires. The positive moderation effects of environmental turbulence are also analysed. First, we investigated the relationships between the three dimensions of SCL and found that internal learning improves external learning (supplier and customer learning). Second, we found that SCL plays a significantly positive role in SCE Health. Third, we identified that both technological turbulence and market turbulence positively moderate the relationship between SCL and SCE Health. These findings contribute to the SCL literature and offer a new view based on SCE for the development of SCM.

Although the present study is very beneficial to the research on SCL, it is not free from limitations, and prospects exist to extend the work in the future. First, the measurement for SCL is not limited to internal learning, supplier learning, and customer learning; future researchers might expand the learning entities in the SCE (Batista et al. 2019; Viswanadham and Samvedi 2013). Second, SCL and its impacts on SCE Health were tested empirically with data collected only from firms in China. Future studies could collect data from more firms in more countries and regions to enhance the generalisability of the findings, exhibiting the lingering effects of COVID-19 from multiple perspectives (Batista et al. 2019; Willis, Genchev, and Chen 2016). Third, our study uses only cross-sectional data and the findings are static. The dynamic relationship between SCL and SCE Health could be supplemented by longitudinal data studies in the future to further deepen the research findings (Yao, Dong, and Dresner 2012). Fourth, the definition of SCE Health, design of the framework, and identification and finalisation of key indicators are mainly based on the relevant experts' interviews and the literature review; future studies might expand on potential opinions and improve them further.

Disclosure statement

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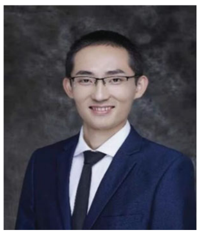
Notes on contributors



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Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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Appendix

Appendix A. Questionnaire and measurement items

Construct			Item	Items sources
Supplier Learning		SL1	Our company acquires substantial production information from our major supplier.	Huo, Haq, and Gu (2019)
		SL2	Our major supplier provides us with critical and useful information for product innovation.	
		SL3	As a part of product development, our company learns a great deal from our major supplier.	
		SL4	Our company applies the knowledge learned from our major supplier in new technology adoption.	
Internal Learning		IL1	Internal functions communicate a lot of innovation information to each other.	
		IL2	Internal functions learn a lot of useful things from each other.	
		IL3	Knowledge communication among internal functions promotes adoption of new technology.	
		IL4	Internal functions evaluate whether they have applied product knowledge from other functions.	
Customer Learning		CL1	Our major customer provides us with critical information for product innovation.	
		CL2	Our company acquires information on supply chain operation and various financial activities from our major customer.	
		CL3	Our company has systematic checks to ensure that the knowledge from our major customer is utilised.	
SCE Health	Productivity	P1(product quality)	Our company offers reliable products of high quality that meet customer needs.	Liu, Liu, and Gu (2021)
			Our company produces consistent quality products that meet specification requirements.	
			Our company ensures high product design quality.	
		P2(product cost)	Our company produces products with low production costs.	
			Our company produces products with low purchasing costs.	
			Our company sells products with low sales costs.	
		P3(product creation)	We are the first within the industry to introduce new products.	
			We frequently introduce products that are radically different from established products in the industry.	
			Our new product introduction has increased over the last 5 years.	
	Robustness		Our supply chain and logistics networks can:	Kwak, Seo, and Mason (2018)
		R1	Remain effective and sustainable even when internal/ external disruptions occur.	
		R2	Avoid or minimise risk occurrence by anticipating and preparing for them.	
		R3	Absorb a significant level of negative impacts from recurrent risks.	
		R4	Have sufficient time to consider most effective reactions.	
	Niche creation	Var(variety)	Our company can provide a wide range of products and services.	Iansiti and Levien (2004)
			Our company's products and services cover many industries and scenarios.	
			Through the integration and cooperation with the whole supply chain, our company has the opportunity to reach a richer and broader market.	
		SV(supplier value)	In order to better create supplier value, our company takes the following measures:	Jayaram, Kannan, and Tan (2004)
			Scope of resources under the control of suppliers.	
			Willingness of suppliers to share confidential information.	
			Willingness of suppliers to integrate with supply chain.	
			Emphasizing quality instead of price in the selection of suppliers.	
		IV(internal value)	In order to create better internal process value, our company uses operations practices for:	
			Reducing lot sizes.	
			Reducing the number of suppliers.	
			Increasing the frequency of deliveries.	
			Reducing the levels of inventory.	
		CV(customer value)	In order to create better customer value, our company takes the following measures:	
			Determination of future customer expectations.	
			Employing a customer satisfaction measurement system.	
			Determination of key factors for improving customer satisfaction.	
			Understanding how your customers use your products and services.	
Technological Turbulence		TT1	It was very difficult to forecast technology developments in our industry.	Hung and Chou (2013)
		TT2	The technology environment was highly uncertain.	
		TT3	Technological developments were highly unpredictable.	
		TT4	Technologically, our industry, was a very complex environment.	
Market Turbulence		MT1	It was very difficult to forecast market developments in our industry.	
		MT2	Customer needs and product preferences changed quite rapidly.	
		MT3	It was difficult to predict changes in customer needs and preferences.	
		MT4	Market competitive conditions were highly unpredictable.	