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Supply chain resilience as a system quality: survey-based evidence from multiple industries

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Abstract

Purpose – Experiencing more frequent, system-wide disruptions, such as pandemics and geopolitical conflicts, supply chains can be largely destabilized by a lack of materials, services or components. Supply chain resilience (SCRES) constitutes the network ability to recover after and survive during such unexpected events. To enhance the understanding of SCRES as a system-wide quality, this study tests a comprehensive SCRES model with data from multiple industries.

Design/methodology/approach – The study proposes a theoretical framework conceptualizing SCRES as system quality, extending the classical proactive/reactive taxonomy by multiple system states consisting of the supply system properties, behaviors and responses to disruptions. Underlying hypotheses were tested using an online survey. The sample consists of 219 responses from German industries. Maximum likelihood structural equation modeling (ML-SEM) and moderation analysis were used for analyzing the survey data. The study was particularly designed to elaborate on supply chain theory.

Findings – Two pathways of parallel SCRES building were identified: proactive preparedness via anticipation and reactive responsiveness via agility. Both system responses are primarily built simultaneously rather than successively. The present study further provides empirical evidence on the central role of visibility and velocity in achieving comprehensive SCRES, while flexibility only exerts short-term support after a disruption. The study additionally points to potential “spillover effects” such as the vital role of proactive SCRES in achieving reactive responsiveness.

Originality/value – The present study confirms and expands existing theories on SCRES. While stressing the multidimensionality of SCRES, it theorizes the (inter-)temporal evolution of a system and offers practical guidelines for SCRES building in various industrial contexts. It thus supports the transformation toward more resilient and viable supply chains, contributing to the increasing efforts of middle-range theory building to achieve an overarching theory. The study also points to potential future research avenues.

Keywords Supply chain resilience, Supply chain risk management, Viable supply chains, Proactive and reactive resilience, Survey

Paper type Research paper

1. Introduction

Companies find themselves in increasingly unstable and dynamic market environments that frequently expose organizations to supply risks (Fan and Stevenson, 2018). One of the main

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risks is the disruption in the flow of resources triggered by high-impact, low-probability events, such as natural disasters (hurricanes, flooding, tornadoes, earthquakes, tsunamis, pandemics), man-made catastrophes (nuclear power plant disruptions, accidental toxic spills, poisonings, wars, terrorist attacks) or social tensions (legal disputes or strikes) (Ivanov and Dolgui, 2019). These interruptions can have remarkable and unpredictable negative impacts on supply chains, organizations or society, coupled with substantial financial and non-financial damages (Kähkönen *et al.*, 2021). The related adverse effects (material and product shortages as well as delivery delays) may spread throughout the supply chain very quickly, increasing the negative impact on the supply chain performance and the entire industry (Ivanov *et al.*, 2014). As disruptions quickly propagate, organizations often realize their supply chain vulnerability only at the moment they occur (Chervenkova and Ivanov, 2023).

Considering the example of Sony's Play Station, supply chains have been largely destabilized by the COVID-19 pandemic and the semiconductor shortage in 2020. This resulted in sales decreases and product shortages. Only in 2023 Sony declared its Play Station supply chain to be recovered and completely fixed worldwide (BBC, 2023). As such, one key element to coping with supply chain disruptions is building organizational resilience capabilities that ensure performance (Hendry *et al.*, 2018; Ivanov, 2023). Supply chain resilience (SCRES) is defined as the *"adaptive capability of a supply chain to prepare for and/or respond to disruptions, to make a timely and cost-effective recovery, and therefore progress to a post-disruption state of operations—ideally, a better state than prior to the disruption"* (Tukamuhabwa *et al.*, 2015, p. 8). SCRES thus describes the ability to respond to unanticipated disruptions and restore normal operations quickly and effectively (Yu *et al.*, 2022). Indeed, multiple studies indicate that the concept of SCRES includes various theoretical dimensions. For instance, Chowdhury and Quaddus (2017) showed that resilience could be grouped into (1) proactive capabilities, such as flexibility, visibility, redundancy, integration, financial strength or efficiency, and (2) reactive capabilities, such as supply chain responsiveness or recovery.

Accordingly, SCRES is not a single organizational capability but a multidimensional phenomenon that is typically clustered into proactive and reactive SCRES approaches (Dabhilkar *et al.*, 2016; Hohenstein *et al.*, 2015; Tukamuhabwa *et al.*, 2015; Hägele *et al.*, 2023). The proactive SCRES approach is cause-related and aims to reduce the probability of disruption occurring and avoid or minimize related adverse effects (Ali *et al.*, 2017; Hohenstein *et al.*, 2015; Kochan and Nowicki, 2018). The reactive SCRES approach, in contrast, is effect-oriented and aims at counteracting the adverse consequences of incidents. It does not immediately tackle the risks but attempts to captivate the impairment caused by disruptions by applying different SCRES capabilities (Ali *et al.*, 2017; Hohenstein *et al.*, 2015; Kochan and Nowicki, 2018). Applying the proactive/reactive dichotomy follows the linear time dimension implicit in cause-and-effect relationships (pre-, during- and post-disruption activities). It implies that companies may build SCRES as time unfolds. We argue that building SCRES as a system's quality involves an (inter-)temporal evolution of the system incorporating several system states, being iterated multiple times. In other words, SCRES capabilities cannot be clustered according to before, during and after the event without losing essential aspects.

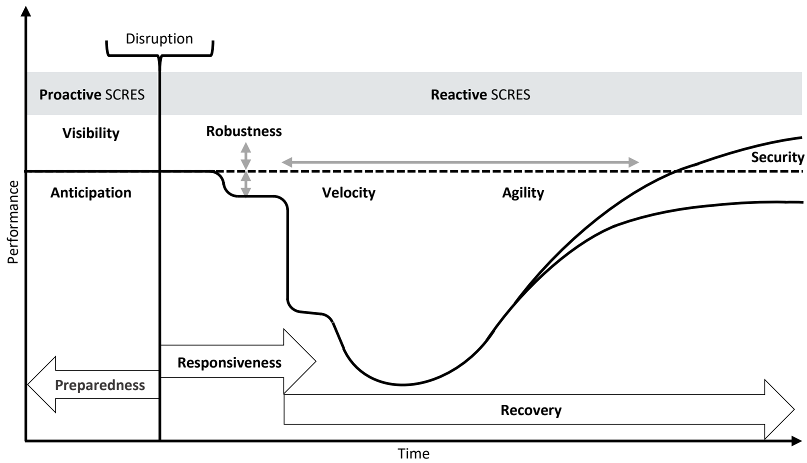
To make more sense of the multidimensional phenomenon of resilience, we therefore apply the adaptation-based view as proposed by Ivanov (2023). Supply chain adaptation and viability is defined as "a behavior-driven property of a system with structural dynamics" by Ivanov and Dolgui (2020). SCRES thereby becomes a part of the business-as-usual operations that are based on structural network variety (i.e. multiple sourcing), redundancy (i.e. inventory pooling) and process flexibility (i.e. reconfigurable manufacturing and logistics systems) (Ivanov, 2023). The originality of our study consequently lies in proposing and testing a comprehensive framework on proactive adaptation, including multiple system states, namely system properties (e.g. preparedness), behaviors (e.g. recovery) and responses (e.g. robustness) to disruptions. The proposed framework operationalizes resilience as a quality of the supply chain by covering a wide range of SCRES constructs and connecting them to the concept of supply chain viability (Ivanov and Dolgui, 2020; Ivanov, 2022). To test the proposed SCRES framework and related hypotheses, an online survey (N = 219) was conducted. Data were analyzed using maximum likelihood structural equation modeling (ML-SEM) and moderation analysis.

Findings confirm and expand existing middle-range theory (cf. Soltani *et al.*, 2014) on SCRES, presenting empirical evidence that goes beyond the two pathways of proactive and reactive SCRES building. Scrutinizing the multidimensionality of SCRES, the study theorizes the (inter-)temporal evolution of SCRES constructs as properties, behaviors, responses and outcomes of a supply system. The study also responds to the multiple calls for empirical testing of advanced SCRES conceptualizations (i.e. van Hoeck, 2020). From a practical perspective, this study provides practitioners insights into the underlying mechanisms of SCRES supporting their efforts in coping with supply disruptions in volatile market environments. It offers practical guidelines for building SCRES in various industries on the way to viable supply chains (i.e. Ivanov, 2022). The remainder of the paper is structured as follows. Section 2 reviews the literature to provide the theoretical backdrop for developing the SCRES framework in Section 3, where we also outline hypotheses based on the theoretical underpinnings. The research methodology is outlined in Section 4, the results are presented in Section 5 and they are discussed in Section 6. Finally, Section 7 summarizes the research implications and points to limitations and potential future research avenues.

2. Theoretical considerations

Resilience is a universal concept applied in multiple disciplines beyond business research (Castillo, 2023). From an ecological perspective, it describes the ability of a system to absorb changes and retain its essential function in the face of unexpected disruptions (Holling, 1973). In logistics and supply chain management (LSCM), resilience can be developed by identifying a company's supply vulnerabilities and developing corresponding supply chain capabilities (Pettit *et al.*, 2010). The existing literature mostly adopted a risk management perspective to vulnerabilities and focuses on supply chain risk management (SCRM) practices (cf. Browning *et al.*, 2023). Supply chain disruptions, however, force organizations to react, which goes beyond managing supply risks and requires developing new resources, solutions or capabilities (Kähkönen *et al.*, 2021). Thus, SCRES can be seen as the ability to respond to unanticipated disruptions and restore normal operations quickly and effectively (Yu *et al.*, 2022). Such "traditional" conceptualizations handle resilience as performance outcome (Ivanov, 2023). The amplitude of the performance degradation and recovery efforts depends on the disruption severity and the system preparedness for disruptions (Cerabona *et al.*, 2023).

Most authors operationalize SCRES not through a single construct but as consisting of different interconnected ones (Ali *et al.*, 2017; Kochan and Nowicki, 2018). SCRES should be cultivated and maintained by understanding its structure and interconnections (Bhamra *et al.*, 2011; Ponomarov and Holcomb, 2009). The connection between the constructs is typically constructed by time entailed in cause-and-effect relationships: before, during and after the disruptive incident. Some authors consider three phases of resilience, namely (1) a required level of preparedness during the pre-disruption phase, (2) responsiveness and (3) recovery in the post-disruption phase (Chowdhury and Quaddus, 2017; Hohenstein *et al.*, 2015). Chowdhury and Quaddus (2017) particularly highlight the interdependency of the phases since higher preparedness, for instance, enables a quicker response and recovery from the disruption. Similarly, Ali *et al.* (2017) distinguish between three phases of SCRES, namely pre-disruptions, during disruption and post-disruptions (see Figure 1). Such a chronological



Source(s): Adopted from Sheffi and Rice (2005)

Figure 1.
Phase model

perspective on SCRES, however, is not always efficient for timely responses on low probability and even unknown events such as COVID-19 (Sodhi *et al.*, 2023). Current SCRES theory offers only fragmented reference points to address this gap (Castillo, 2023).

While there is a controversial debate on which SCRES capability belongs to which phase (see Table 1), we argue that resilience capabilities do not develop linearly or chronologically but unfold in parallel, constituting an (inter-)temporal evolution. Supply chains need to acquire resilience properties and, at the same time, create an environment in which behavior unfolds in a way that creates the right response (which is a system quality; cf. Ivanov, 2023). Inspired by biology, Ivanov (2023) proposes to conceptualize resilience as the immune system of a supply chain. Immune systems ensure that living creatures survive and perform, indicating it as a quality of the organism. If the supply chain is hit by a disruption (pathogen), an (immune) response is prepared to recover, and the supply chain is adapted, ensuring survival in the event of future disruptions (antibodies) as a quality of the immune system itself (Browning *et al.*, 2023; Ivanov and Dolgui, 2020).

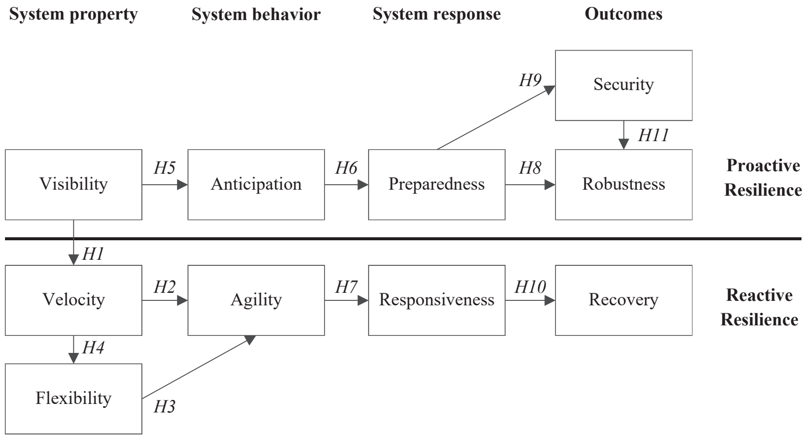
So far, the properties of a supply system are mainly conceptualized from a network perspective, that is, structural properties such as node degree or path length (Basole and Bellamy, 2014; Chowdhury and Quaddus, 2017). Supply chain properties from an (immune) system perspective incorporate the detection of risks (visibility), as well as the capability of a quick and flexible reaction. The behavior of the supply (immune) system is unfolding over time and is contingent on its properties and environmental properties (Sodhi and Tang, 2021). The response of a system encompasses the system's reaction to adapt to the new conditions, turning them into the "new normal" based on its inherent properties and behaviors (Hogan and Coote, 2014). The system response finally determines the outcome. This acquisition of resilience as a quality accordingly may occur before, during or after the disruptive event. We, therefore, argue that perceiving SCRES as a system quality extends the time-based categorization adopted in the literature, providing a more coherent conceptualization of SCRES building that is better aligned with practice.

Figure 2 depicts how this new perspective extends the proactive and reactive perspective of resilience building. Accordingly, we offer a theoretical framework facilitating conceptual development beyond the proactive/reactive dichotomy. It does not only reflect SCRES approaches from a performance outcome perspective but also provides a taxonomy of the

Table 1.
SCRES conceptualizations in extant literature

Source	Visibility	Anticipation	Security	Efficiency	Market strength	Flexibility	Adaptation	Robustness	Redundancy	Responsiveness	Agility	Velocity	Recovery	Preparedness	Knowledge management
Ali *et al.* (2017)	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Chowdhury and Quaddus (2017)				X	X	X				X			X		
Hohenstein *et al.* (2015)	X	X				X			X	X	X	X	X	X	
Ivanov *et al.* (2017)	X					X		X					X	X	
Ivanov *et al.* (2021)									X	X			X	X	
Kilubi and Haasis (2016)	X					X		X	X	X				X	
Kochan and Nowicki (2018)	X	X	X	X	X	X		X	X	X	X	X	X	X	
Karl *et al.* (2018)	X		X			X		X			X				X
Ponis and Ntalla (2016)	X	X									X	X	X		
Sheffi and Rice (2005)										X			X	X	
Wieland and Wallenburg (2013)	X	X						X			X	X		X	
Pre-disruption	X	X	X	X	X	X	X	X	X						
During disruption							X	X	X	X	X				
Post-disruption										X	X	X	X	X	X

Source(s): Authors' own work



Source(s): Authors' own work

Figure 2.
Theoretical framework

main dimensions of SCRES from a viability-based perspective by distinguishing between system properties (inputs), behaviors of a system (dynamic states which a system takes depending on external disturbances and internal properties), system responses (outputs) and the resilience outcomes of security, robustness and recovery. To model system properties, behaviors and responses, we considered visibility, anticipation, preparedness, velocity, flexibility, agility, responsiveness and their mutual interdependencies. The related hypotheses to be tested are developed in the following section. In this vein, the present study also provides more nuanced theoretical insights on SCRES by examining the viability-related hypotheses of multiple dispersed papers in the literature (e.g. Ivanov, 2022), as well as elaborating on the inherent mechanisms of building resilience as a quality.

3. Hypotheses development

According to Sodhi and Tang (2021), supply chains can be conceptualized as socio-ecological systems comprising various elements and their interactions. The characteristics of these system elements and the structure of their interactions result in distinct system properties (Basole and Bellamy, 2014). The subsequent system's behavior refers to actions and responses exhibited by organizations as they interact with the internal and external environment (Hanelt *et al.*, 2021). It encompasses how the system and its constituent elements process, analyze and interpret both internal and external information (Da Veiga *et al.*, 2020). This includes the system's decision-making processes (Bonilla Priego *et al.*, 2011). The behavior of a system, in turn, influences its characteristics and performance, shaping its ability to adapt, innovate and achieve its goals effectively (Ketchen and Hult, 2007). The system response encompasses the reaction to adapt to irregularities or disruptions in its normal operation mode based on its inherent properties and behaviors (Hogan and Coote, 2014). The system response determines the outcome, resulting in security, robustness and recovery.

3.1 System's properties

As the system properties are the foundation for ensuring performance and outcomes (Obuobisa-Darko, 2020), resilient supply chains must prioritize visibility, velocity and flexibility as fundamental properties. *Visibility* describes the system's property of knowing and understanding the current supply chain structural status in a reasonable time (Balakrishnan and Ramanathan, 2021). It enables organizations to generate transparency throughout the supply chain (Hohenstein *et al.*, 2015), revealing the status of operating assets and allowing for risk identification and assessment (Fiksel *et al.*, 2015; Tukamuhabwa *et al.*, 2015). Visibility thus proactively supports warning systems by alerting negative changes or incidents through performance monitoring and, at the same time, reactively enhances the acceleration in risk detection (Ambulkar *et al.*, 2015; Melnyk *et al.*, 2010). Supply chain visibility can be achieved through risk quantification, risk detection and collaboration practices (Ivanov *et al.*, 2021). As a system property itself, it is accordingly grounded in (lower level) SCRM practices.

Velocity describes the property of a system to accelerate actions, enabling organizations to respond to or recover from disruptions quickly (Tukamuhabwa *et al.*, 2015; Wieland and Wallenburg, 2013). As a spillover from proactive visibility, velocity is regarded as a system property, as multiple elements within the system must expedite their actions to enhance the overall system's behavior. Visibility enhances velocity since it serves as a warning system that provides organizations valuable time to coordinate their resources before and speeds up execution after the disruption (Kochan and Nowicki, 2018; Hohenstein *et al.*, 2015). Velocity, in turn, enhances agility, which is a system behavior, as it supports a quick adaption and execution of actions to cope with unexpected changes within the supply chain (Braunscheidel and Suresh, 2009). Furthermore, velocity helps minimize the effects of short- and long-term disruptions due to rapid countermeasure implementation and execution (Balakrishnan and Ramanathan, 2021). Therefore, the following hypotheses are proposed:

H1. Visibility positively affects velocity.

H2. Velocity positively affects agility.

Flexibility describes the property of a system to adapt and reconfigure supply chain resources (Tukamuhabwa *et al.*, 2015) to respond to short-term disruptions and prepare for long-term or even fundamental changes in the market (Parast and Shekarian, 2019; Sheffi and Rice, 2005). Given that flexibility is not a fast-implemented ad hoc system characteristic but necessitates upfront integration and investments within the system (Kamalahmadi *et al.*, 2022), it must be seen as a system's property. It involves the adaptation to unpredictable situations without compromising performance. Flexibility thereby enhances agility by adjusting existing supply chain resources based on the characteristics of the disruption (Sheffi and Rice, 2005). While agility is enhanced by velocity (H2), flexibility consequently moderates this effect. In the literature, flexibility may enhance robustness as it supports the characteristic of supply chain stability under unexpected disruptions or fundamental changes by adjusting existing supply chain resources (Kochan and Nowicki, 2018; Wieland and Wallenburg, 2013). This relationship is not covered by the theoretical reasoning grounded in the viability-based view, pointing to a potential spillover effect from reactive flexibility on proactive robustness. Therefore, solely the following hypotheses are proposed:

H3. Flexibility positively affects agility.

H4. Flexibility moderates the relationship between velocity and agility.

3.2 System's behaviors

As the system behavior eases the subsequent responses to disruptions, resilient supply chains must behave agile and foreseeingly. *Agility* describes the behavior of reconfiguring, managing and adjusting critical supply chain resources (Blackhurst *et al.*, 2011) by accelerating the response time (Braunscheidel and Suresh, 2009; Christopher and Peck, 2004) and by expediting recovery (Tukamuhabwa *et al.*, 2015). Building on flexibility and velocity properties, agility prepares the supply chain within the given system to initiate reconfiguration. Adopting supply chain tactics and operations quickly helps organizations reduce the harmful effects of a disruption in the short- and long-term as the countermeasures are executed quickly, potentially turning them into profitable opportunities (Christopher and Peck, 2004; Stank *et al.*, 2022; Wieland and Wallenburg, 2013).

Meanwhile, *anticipation* describes the behavior of understanding supply chain vulnerabilities and risks to identify and interpret possible disruptions and losses (Pournader *et al.*, 2020). Visibility provides transparency by offering relevant internal or external information, which subsequently enables systems to effectively process, analyze and interpret this data. Enhanced visibility thus plays a crucial role in improving proactive risk anticipation (Ali *et al.*, 2017). Anticipation thus enhances preparedness, which is a system response, as it sharpens alertness by foreseeing disruptions or noticing changes before the functionality of the supply chain is affected to suggest proactive counteractions (Kochan and Nowicki, 2018; Wieland and Wallenburg, 2013). Therefore, the following hypotheses are proposed:

H5. Visibility positively affects anticipation.

H6. Anticipation positively affects preparedness.

3.3 System's response

As the system response determines the outcome, resilient supply chains must respond in a responsive and prepared manner. *Responsiveness* describes the system response that alters behaviors, norms or policies during and right after a disruption hits the organization and its supply chain to achieve a more favorable position and competitive advantage (Richey *et al.*, 2022). Agility contributes to responsiveness by supporting immediate reconfiguration, management and adjustment of critical supply chain resources to minimize the effect of disruptions (Christopher and Peck, 2004; Wieland and Wallenburg, 2013). Responsiveness may also enhance an organization's SCRES reactively right after a disruption occurred (Balakrishnan and Ramanathan, 2021; Ho *et al.*, 2015; Hohenstein *et al.*, 2015; Kochan and Nowicki, 2018; Tukamuhabwa *et al.*, 2015), pointing toward a spillover effect from proactive SCRES on reactive responsiveness. Therefore, the following hypothesis is proposed:

H7. Agility positively affects responsiveness.

Preparedness describes the response of acting before disruptions hit the organization by creating a level of knowingness and awareness to either reduce or avoid the likelihood of events upfront and/or to withstand or mitigate the negative effects disruptions may have on an organization (Pettit *et al.*, 2010; Ponomarov and Holcomb, 2009). Preparedness itself is operationalized as a disruption prediction (i.e. anticipation capabilities) and is designed for expected disruption scenarios (so-called known-known uncertainties) (Hosseini *et al.*, 2020). Preparedness, as a system's response, involves the adaptive adjustment of the system resources to proactively enhance an organization's robustness and security, which are outcomes, against supply chain irregularities prior to the occurrence of disruptions. Therefore, the following hypotheses are proposed:

H8. Preparedness positively affects robustness.

H9. Preparedness positively affects security.

3.4 Outcomes

As an inherent quality of the system, it may withstand the disruption and answer with continuity (Durach *et al.*, 2015; Ivanov, 2023). Secondly, the system secures its performance

(Hogan and Coote, 2014). *Recovery* as a system's performance outcome (Iborra *et al.*, 2020) describes the state after a disruption hit the organization to bounce back from it and reach at least the pre-disruption performance level (Ali *et al.*, 2017; Jüttner and Maklan, 2011). It is directly enhanced by reactive responsiveness, which allows for quick supply chain reconfigurations that expedite recovery, enabling organizations to reduce the negative effects of disruptions long-term as the countermeasures are executed very fast (Tukamuhabwa *et al.*, 2015). Responsiveness thus plays a crucial role in the recovery of the system's characteristics and its performance reactively, enabling it to effectively navigate and overcome challenges or changes in its environment, which often involve significant alterations in the structure of the supply chain (Wieland *et al.*, 2023). Therefore, the following hypothesis is proposed:

H10. Responsiveness positively affects recovery.

Security as a status of the system's outcome (Iborra *et al.*, 2020) describes the stability to resist deliberate attacks such as theft, terrorism and the infiltration of counterfeits, and it helps to ensure freight and cybersecurity (Stevenson and Busby, 2015). It tries to bounce back disruption effects with implemented countermeasures in advance, enhancing preparedness (Stevenson and Busby, 2015). *Robustness* as a status (Iborra *et al.*, 2020) similarly describes the stability to ensure supply functionality in the case of disruptions (Colicchia and Strozzi, 2012; Klibi *et al.*, 2010) and to remain effective (Meepetchdee and Shah, 2007; Durach *et al.*, 2015). It requires proactive actions before the disruption occurs (Craighead *et al.*, 2007). Security and robustness are directly enhanced by preparedness (H8, H9) to resist adverse disruption effects by stabilizing the situation right after a shock appears (Min, 2019). Security may further moderate the relationship between preparedness and robustness. Therefore, the following hypothesis is proposed:

H11. Security moderates the relationship between preparedness and robustness.

3.5 Originality of the study

Research on SCRES constructs has attracted immense research interest in the past, which means some of the proposed hypotheses have already been empirically tested applying a "traditional" theoretical stance (see Table A1). Previous studies often distinguish between the proactive and reactive SCRES approaches (e.g. Chowdhury and Quaddus, 2017) but did not apply an overarching theoretical framework that seeks to extend this inherent dichotomy. An overarching theoretical understanding of the SCRES phenomenon thus still needs to be developed (Castillo, 2023). The originality of our study is the proposal and the test of a comprehensive framework on SCRES that is theory-driven and consistent with the viability-based view proposed by Ivanov (2023). Nonetheless, we also tested an additional model that includes potential "spillover effects" between proactive and reactive SCRES building (see Figure A1 and Table A2). This second model, however, features hypotheses that are not significant and lower model fit indices, which supports our model.

4. Research methodology

To collect the required data for testing the proposed hypotheses, an online survey with a self-administrative questionnaire was conducted. The research unit was the individual company and its supply chain. The authors strategically collected and analyzed primary data from processing and manufacturing companies located in North Rhine-Westphalia, Germany.

4.1 Data collection

The data collection took place in 2022. The authors randomly sampled the companies mentioned by the Ministry of Economic Affairs, Industry, Climate Action and Energy in

North Rhine-Westphalia, which covers a broad set of industries, including automotive, electronics, chemicals, food and so forth. The study targeted management concerned with operations and supply chain management in the selected companies that received the online questionnaire. To ensure high quality of the responses, incomplete and invalid responses were deleted. After eliminating the severely lacking data sets, a total of 219 valid responses were collected, resulting in a response rate of 14%. The remaining data sets showed no response gaps. Table 2 gives an overview of the sample and the respondents' profiles. Most respondents worked in purchasing and supply chain management positions (N = 148; 67.58%) and had worked in their current positions for more than 5 years (N = 112; 51.13%). Most of the sample comprised respondents working within the automotive industry (N = 35; 15.98%). In line with this, most respondents work in companies with more than 1,000 employees (N = 148; 67.58%).

4.2 Survey design

The central SCRES dimensions of the theoretical framework presented in Figure 2 are operationalized with reflective, multi-item constructs, where the items are based on previous studies and tested scales. Participants self-reported answers on a five-point Likert scale (1 = "strongly disagree" to 5 = "strongly agree"). The first part of the questionnaire collected basic information about the companies, while the subsequent parts asked about the single SCRES dimensions. To avoid social desirability bias, the survey design granted participants anonymity and confidentiality (King and Brunner, 2000), ensuring that answers remained private. Besides assuring privacy, questions were framed in a way that no personal information could be retrieved. The questionnaire was administered in German. The back-translation technique was used (Malhotra *et al.*, 2012), that is, the questions were first translated and then re-translated. In addition, the researchers conducted a pretest to ensure that the questionnaire was readable, understandable, answerable and not too complicated. According to the pretest, items with low scores were deleted, and the remaining items with unclear meanings were revised. Further items were excluded from the exploratory factor analysis (EFA) to create a more robust measurement model. The remaining 40 items are listed in Table 3.

4.3 Data analyses and quality assurance

ML-SEM was used to find relationships between the study variables as "it permits statistical significance testing of factor loadings and correlations among factors and the computation of confidence intervals for these parameters" (Fabrigar *et al.*, 1999, p. 277). ML-SEM has become a quasi-standard in business research to analyze the relations between latent constructs (Hair *et al.*, 2013). This is also supported by the increasing number of studies in LSCM and SCRES using SEM (Shah and Goldstein, 2006; Eryarsoy *et al.*, 2022). Several quality measures considering reliability and validity were obtained before testing the proposed hypotheses, including scale reliability, convergent validity and discriminant validity. The Statistical Package for Social Sciences (SPSS, including Hayes PROCESS) and the R software package were used for conducting the analyses.

Given that our study is based on self-reported data, Harman's one-factor test was applied to avoid common method bias by loading all items into an EFA (Podsakoff *et al.*, 2003). Since the one-factor model explained just 27.16% of the variable's total variance, common method bias can confidently be rejected (Fuller *et al.*, 2015). A full collinearity test was further employed to control for common method variance, corroborating that common method variance is not present in the data (Kock, 2015). The sampling adequacy of the data set was assessed with the Kaiser-Meyer-Olkin (KMO) test as the goodness of fit criterion (Hair *et al.*, 2013), which for this study's data is 0.889. Along with the KMO test, Bartlett's test of

	Item	Frequency	Percentage
Gender	Male	137	62.56
	Female	79	36.07
	Diverse	3	1.37
Position	Consulting	1	0.45
	R&D	1	0.45
	IT	3	1.37
	Management	13	5.94
	Operations	18	8.22
	Purchasing	76	34.70
	Sales	26	11.87
	Supply chain/Logistics	72	23.88
	Others	9	4.11
Experience in current position	<5 years	104	47.48
	>5 years <10 years	61	27.85
	>10 years	51	23.28
	Not specified	3	1.37
Company affiliation	<5 years	100	45.66
	>5 years <10 years	54	24.65
	>10 years	59	26.94
	Not specified	6	2.74
Company size	>1,000	148	67.58
	1–50	13	5.94
	201–500	24	10.96
	501–100	13	5.94
	51–200	17	7.76
	Not specified	4	1.83
Business area	Automotive industry	35	15.98
	Chemical industry	22	10.05
	Computer and electronics industry	7	3.20
	Construction industry	4	1.83
	Consulting	3	1.37
	Consumer goods industry	26	11.87
	Distribution/Wholesale/Retail	33	15.07
	Energy	1	0.45
	Finance	1	0.45
	Food and beverages industry	22	10.05
	Health care provider (e.g. Hospital)	3	1.37
	Insurance	1	0.45
	IT	1	0.45
	Logistics service providers	31	14.16
	Mechanical engineering industry	15	6.84
	Oil industry	1	0.45
	Pharmaceutical/Medical industry	2	0.91
	Recycling	1	0.45
	Others	10	4.57

Source(s): Authors' own work

Table 2.
Respondents

sphericity was performed, which yielded an approximative χ^2 of 3965.21, significant $p < 0.001$, showing that correlations between items are sufficiently distinct.

A confirmatory factor analysis (CFA) was then conducted to purify the used scales. All retained items could be assigned to the constructs associated with the theoretical framework. To test the scales' internal consistency, Cronbach's alpha was employed. All scales show good reliabilities with $\alpha > 0.6$ and <0.9 (Cronbach and Meehl, 1955). The descriptive statistics

	Items	Code	Source
Visibility	Our supply chain members have real-time information for monitoring and changing operations strategy	VIS1	Mandal *et al.* (2016)
	Our supply chain members have access to inventory and order status information for forecasting	VIS2	
	Our supply chain members have the necessary information system for tracking goods and products	VIS3	
Anticipation	We effectively use demand forecasting methods	ANT1	Zouari *et al.* (2021)
	We have a formal risk identification and prioritization process	ANT2	
	We closely monitor deviations and risks from normal operations, including near misses	ANT3	
	We quickly recognize early warning signals of possible disruptions	ANT4	
	We have detailed contingency plans and regularly conduct preparedness exercises and readiness inspections	ANT5	
Flexibility	We have flexibility in production regarding the volume of orders and production schedules	FLE1	Chowdhury and Quaddus (2017)
	We produce different types of products to meet customer requirements	FLE2	
	We have a multi-skilled workforce to continue production	FLE3	
Velocity	Our supply chain can rapidly deal with threats in our environment	VEL1	Mandal *et al.* (2016)
	Our supply chain can quickly respond to changes in the business environment	VEL2	
	Our supply chain can rapidly address opportunities in our environment	VEL3	
Security	We employ layered defenses and do not depend on a single type of security measure	SEC1	Zouari *et al.* (2021)
	We use stringent restrictions for access to facilities and equipment	SEC2	
	We have active security awareness programs that involve all personnel (trainings)	SEC3	
	We effectively collaborate with government agencies to improve security	SEC4	
	We have a high level of information systems security to resist attacks	SEC5	
	We use a variety of personnel security programs, such as awareness briefings, travel restrictions and threat assessments	SEC6	
Robustness	We have reliable backup utilities (electricity, water, communications, etc.) to ensure supply functionality	ROB1	Zouari *et al.* (2021)
	We maintain access to duplicate or redundant facilities and equipment	ROB2	
	We have a significant excess capacity of materials, equipment and labor to boost output if needed quickly	ROB3	
Agility	We use strategic gaming and simulations to design more adaptable processes	AGI2	Zouari *et al.* (2021)
	We develop innovative technologies to improve operations	AGI4	
	We continually strive to reduce lead times for our products	AGI5	
	We effectively employ continuous improvement programs	AGI6	

(*continued*)

Table 3.
Survey items after EFA

	Items	Code	Source
Preparedness	We are capable to recognize supply chain disruptions quickly	PRE1	Chowdhury and Quaddus (2017)
	We have readiness training for overcoming a crisis	PRE2	
	We have resources to get ready during a crisis	PRE3	
	We have early warning signals	PRE4	
	We have forecastings for meeting demand disruptions	PRE5	
Recovery	We can quickly organize a formal response team of key personnel on-site and at the corporate level	REC1	Zouari *et al.* (2021)
	We have an effective strategy for communication in a variety of extraordinary situations	REC2	
	We successfully deal with crises, including addressing public relations issues	REC3	
	We take immediate action to mitigate the effects of disruptions despite the short-term costs	REC4	
Responsiveness	We can respond quickly to disruptions	RES1	Chowdhury and Quaddus (2017)
	We can undertake adequate responses to the crisis	RES2	
	We have a response team for mitigating a crisis	RES3	

Table 3. **Source(s):** Authors' own work

(mean, standard deviation, kurtosis and skewness), item loadings and their degree of validity are presented in Table 4. Further tests regarding construct validity and factor reliability were conducted on the confirmatory measurement model. We computed the scores for the composite reliability (CR) and the average variance extracted (AVE). Following Fornell and Larcker (1981), however, the AVE is a more conservative measure, and the conventional thresholds may be too strict. If the AVE value is below the usual limits of 0.5, but the CR reaches a higher value above 0.6, the conditions for subsequent examinations can also be reached (Fornell and Larcker, 1981).

The square root of the respective AVE is taken to test for discriminant validity. If the AVE's square root of the construct is greater than the correlations of the construct with that of other constructs, discriminant validity is achieved (Garson, 2016). The final values for discriminant validity after eliminating selected items are shown in Table 5. The hypotheses of the study were then tested with ML-SEM. Because almost all items lay within acceptable ranges of kurtosis and skewness (i.e. a threshold of ± 1, respectively, see Table 4), the normal-theory-based ML test statistic for multilevel structural equation modeling can be applied (Ryu, 2011). The model fit indices of the structural model are evaluated with the minimum discrepancy (chi-square/df = 1.585), Tucker–Lewis index (TLI = 0.894), comparative fit index (CFI = 0.880), root mean square residual (SRMR = 0.060) and root mean square of approximation (RMSEA = 0.052) values. The indices confirm that the data fit of the model is acceptable for this complex model, acknowledging that TLI and CFI are only close to the recommended thresholds (Hair *et al.*, 2013). Finally, we checked the mediations of the constructs (Baron and Kenny, 1986).

5. Findings

This section assesses each research hypothesis separately to test the single constructs. We thereby provide several models: one for reactive SCRES, one for proactive SCRES, one general model (see Table A3) and one model testing the "spillover effects" (see Figure A1 and Table A2). The first model focused on proactive resilience and assumed a positive relationship between visibility and anticipation (H5) as well as between anticipation and

Constructs	Mean	Std. deviation	Skewness	Kurtosis	Std. loadings	Cronbach's α	CR	AVE
Visibility	2.478	0.994				0.778	0.759	0.515
VIS1			0.492	0.014	0.785			
VIS2			0.515	−0.291	0.742			
VIS3			0.543	0.033	0.615			
Anticipation	2.692	1.017				0.799	0.800	0.447
ANT1			0.467	0.081	0.582			
ANT2			0.395	−0.560	0.632			
ANT3			0.471	−0.226	0.670			
ANT4			0.167	−0.557	0.672			
ANT5			−0.082	−0.628	0.772			
Flexibility	2.198	0.968				0.709	0.674	0.412
FLE1			0.516	0.362	0.535			
FLE2			0.313	0.653	0.644			
FLE3			0.820	0.838	0.732			
Velocity	2.747	0.841				0.805	0.719	0.465
VEL1			0.407	−0.288	0.806			
VEL2			0.110	−0.130	0.652			
VEL3			0.391	0.520	0.566			
Security	2.256	0.961				0.864	0.843	0.472
SEC1			0.572	0.247	0.666			
SEC2			0.804	0.615	0.666			
SEC3			0.975	1.032	0.646			
SEC4			0.147	−0.586	0.722			
SEC5			0.805	0.482	0.710			
SEC6			0.605	0.034	0.708			
Robustness	2.912	0.971				0.685	0.645	0.381
ROB1			0.132	−0.246	0.639			
ROB2			0.313	−0.231	0.698			
ROB3			−0.210	−0.364	0.498			
Agility	2.537	1.034				0.700	0.675	0.349
AGI2			−0.311	−0.053	0.447			
AGI4			0.556	0.297	0.636			
AGI5			0.735	0.301	0.513			
AGI6			0.847	1.054	0.727			
Preparedness	2.820	0.976				0.816	0.752	0.378
PRE1			0.559	0.575	0.628			
PRE2			−0.226	−0.661	0.650			
PRE3			−0.028	−0.456	0.571			
PRE4			0.261	−0.711	0.628			
PRE5			0.278	−0.366	0.593			
Recovery	2.385	0.907				0.798	0.731	0.406
REC1			0.579	0.226	0.670			
REC2			0.630	0.224	0.623			
REC3			0.598	0.103	0.689			
REC4			0.011	0.256	0.558			
Responsiveness	2.563	0.915				0.739	0.663	0.400
RES1			0.547	0.344	0.741			
RES2			0.528	0.442	0.544			
RES3			0.347	−0.580	0.596			

Note(s): Thresholds: Cronbach's $\alpha \geq 0.7$; composite reliability ≥0.6; average variance extracted ≥0.5
Source(s): Authors' own work

Table 4. Psychometric properties

Table 5. Discriminant validity: Fornell-Larcker criterion

Construct	1	2	3	4	5	6	7	8	9	10
1. Visibility	*0.718*									
2. Anticipation	0.482	*0.669*								
3. Flexibility	0.242	0.379	*0.642*							
4. Velocity	0.376	0.435	0.181	*0.682*						
5. Security	0.306	0.429	0.247	0.252	*0.687*					
6. Robustness	0.240	0.371	0.184	0.409	0.415	*0.617*				
7. Agility	0.200	0.409	0.255	0.272	0.359	0.441	*0.591*			
8. Preparedness	0.364	0.567	0.273	0.428	0.474	0.439	0.444	*0.615*		
9. Recovery	0.409	0.415	0.286	0.312	0.513	0.419	0.392	0.556	*0.637*	
10. Responsiveness	0.365	0.522	0.289	0.492	0.426	0.455	0.452	0.593	0.628	*0.633*

Note(s): The square root of the AVE for each variable (values on the diagonal) is higher than any of the bivariate correlations between the latent variables (values under the diagonal)
Source(s): Authors' own work

preparedness (H6). Subsequently, the relationships between preparedness and robustness (H8), as well as security (H9), are tested. Lastly, the (mutual) relationship of security and robustness (H11) is evaluated. The path coefficients of the research hypotheses are shown in Table 6, including the explained variance in the model. The results reveal significant positive effects for all the tested hypotheses H5, H6, H8, H9 and H11. The second model, which focuses on reactive resilience, assumed a positive relationship between visibility and velocity (H1). Subsequently, the relationships between velocity and agility (H2), flexibility on agility (H3), as well as velocity on flexibility (H4), are tested. Moreover, the effect of agility on responsiveness (H7) and responsiveness on recovery (H10) are analyzed. The path coefficients of the research hypotheses are shown in Table 7, including the explained variance. The results reveal significant positive effects for the tested hypotheses. Hypotheses H1, H2, H3, H4, H7 and H10 are therefore supported.

Hayes' PROCESS macro version 4.0 was used to analyze possible mediation effects (Hayes, 2013). Bootstrapping with 5,000 samples and a confidence interval of 95% was used to evaluate the effects following established guidelines. Effects were considered significant if the 95% bias-corrected and accelerated confidence intervals (BCa CI) did not include zero (Hayes and Rockwood, 2017). Model 4 was selected for the mediation effects hypothesized in this study with one proposed mediator (Hayes, 2013). A standardized significant indirect effect between velocity and agility through the mediator flexibility is found (H4), which is

Table 6. Path coefficients of the ML-SEM for proactive resilience

Hypothesized relationship	Hypotheses	Estimate	z-value	*p*-value	Result
Visibility → anticipation	H5	0.549	6.825	<0.01***	Supported
Anticipation → preparedness	H6	0.721	6.324	<0.01***	Supported
Preparedness → robustness	H8	0.442	3.399	<0.01***	Supported
Preparedness → security	H9	0.651	5.905	<0.01***	Supported
Security → robustness	H11	0.317	2.923	<0.01***	Supported
Variance explained in the endogenous variables					
Anticipation	$R^2 = 0.559$				
Robustness	$R^2 = 0.353$				
Preparedness	$R^2 = 0.548$				
Security	$R^2 = 0.325$				

Source(s): Authors' own work

Hypothesized relationship	Hypotheses	Estimate	z-value	p-value	Result
Visibility → velocity	H1	0.511	6.446	<0.01***	Supported
Velocity → agility	H2	0.262	3.913	<0.01***	Supported
Flexibility → agility	H3	0.315	3.209	<0.01***	Supported
Velocity → flexibility	H4	0.172	2.694	<0.01***	Supported
Agility → responsiveness	H7	0.945	5.255	<0.01***	Supported
Responsiveness → recovery	H10	0.702	7.917	<0.01***	Supported
Variance explained in the endogenous variables					
Velocity	$R^2 = 0.300$				
Agility	$R^2 = 0.326$				
Flexibility	$R^2 = 0.059$				
Responsiveness	$R^2 = 0.468$				
Recovery	$R^2 = 0.607$				

Source(s): Authors' own work

Table 7. Path coefficients of the ML-SEM for reactive resilience

relatively small with B = 0.033, 95% BCa CI [0.000 to 0.097]. Likewise, a highly significant but small indirect effect between preparedness and robustness through security is present (H11) with B = 0.113, 95% BCa CI [0.047 to 0.204]. Accordingly, all mediation hypotheses are supported; however, these are relatively small and can be neglected.

6. Discussion

To better understand the nature of SCRES building, the present study tests a comprehensive model with empirical evidence that extends the classical conceptualizations. The proposed theoretical framework operationalizes resilience as a supply chain quality by covering a wide range of theoretical constructs (Ivanov and Dolgui, 2020; Ivanov, 2022). The study thereby builds on previous research of several scholars who show that SCRES supports organizations to better cope with disruptions and helps them to gain a competitive advantage in turbulent environments (e.g. Hendry *et al.*, 2018). While many studies focused on selected constructs (see Table A1), specific industries (Balakrishnan and Ramanathan, 2021) or specific events (e.g. the COVID-19 pandemic) (Kähkönen *et al.*, 2021), this study attempts to provide more general and cross-sector empirical evidence. By applying a robust and theory-driven research design, our research adds to the theory development efforts in the field.

6.1 Theoretical implications

To the best of our knowledge, this is the first study investigating both SCRES perspectives delineated by Ivanov (2023), the performance outcome-driven view and the viability-driven view, encompassing the construction of parameters related to system properties, system behavior, system responses and outcomes to operationalize SCRES as a quality of the supply chain. The findings confirm two proactive or reactive SCRES pathways with their central constructs – preparedness, responsiveness and recovery – explaining more than 50% of the variance in the (performance-driven) model (cf. Sheffi and Rice, 2005). In addition, the authors found that proactive and reactive resilience can be built simultaneously as inter-temporal evolution of the system. This supports the criticism of the classical categorization of SCRES constructs along time phases (see Table 1) and supports the argument put forward in this paper that SCRES phases must be developed simultaneously as the single phases overlap. Future research needs to promote mutual SCRES building and ways to evaluate trade-offs between proactive and reactive resilience strategies.

Furthermore, we found supporting evidence for the importance of visibility for SCRES (Hohenstein *et al.*, 2015; Dolgui and Ivanov, 2023). Visibility as a system property must be considered the starting point for building SCRES (Ali *et al.*, 2017; Balakrishnan and Ramanathan, 2021; Pournader *et al.*, 2020; Ho *et al.*, 2015), as it explains 55.9% of the variance of anticipation and 30.0% of the variance of velocity. In other words, organizations may only be able to build subsequent SCRES with visibility. Supply systems require visibility and velocity as inherent property of the system to allow for proactive adaptation (MacCarthy *et al.*, 2022; Wieland and Durach, 2021). This implies that adaptation has a proactive and reactive nature when theorized from a viability-based view (Ivanov and Dolgui, 2020). Hence, our framework does not consider adaptation as a single construct to be either proactive or reactive, but on a meta-level through the supply system's behavior and response. The dual nature of adaptation (and resilience) implies the existence of "spillover effects" in its evolution.

Our study accordingly tests spillovers, such as the role of proactive SCRES in achieving responsiveness, as argued by Ali *et al.* (2017), Hohenstein *et al.* (2015) as well as Kochan and Nowicki (2018). Here, the empirical data confirm the positive direct effect of robustness on responsiveness ($p < 0.01$***, see Table A2). Although the study found empirical evidence for the proposed hypotheses and the roles of anticipation and agility as "connectors" for enhanced proactive and reactive SCRES, only weak support for flexibility as a moderator of the relationship between velocity and agility (H4) was found. Hence, we wonder if flexibility as a central resilience construct may help organizations to proactively withstand a disruption in the long term. The sole reconfiguration of existing resources may only exert an effect as a short-term response (Tukamuhabwa *et al.*, 2015). Long-term preparedness, in turn, can only be achieved through adaptable and reconfigurable structures and processes (Ivanov, 2023). In this vein, the present study only partially confirms Richey *et al.*'s (2022) conceptualization of agility as an essential dimension of responsiveness, while flexibility plays a minor role.

Answering multiple calls for more empirical support (Hohenstein *et al.*, 2015; Ivanov *et al.*, 2017; Kochan and Nowicki, 2018), this study presents a theoretically and empirically grounded SCRES framework tested through reliable empirical data. The present study contributes to the increasing efforts of middle-range theory building in LSCM (Stank *et al.*, 2017). Acknowledging the multiple efforts in theorizing particular dimensions of SCRES, such as the responsiveness view proposed by Richey *et al.*'s (2022) or the adaptation-based view proposed by Ivanov (2023), this study attempts to provide an empirically driven, holistic perspective on this recent SCRES theory. In this vein, the present study theorizes the inter-temporal evolution of SCRES building. While there are overlaps and iterations in the evolution of single SCRES capabilities, the proposed framework elaborates on the diachronic sequence of proactive and reactive SCRES pointing to potential spillovers. Our framework thereby articulates how different SCRES dimensions reinforce one another or serve as prerequisites. Finally, and in addition to its explorative nature, this study builds upon previous research and validates several hypotheses that have been previously examined.

6.2 Practical implications

The COVID-19 pandemic unveiled deficiencies in the state of preparedness within numerous supply chains (van Hoeck, 2020; Rozhkov *et al.*, 2022). This lack became evident in the 2020 semiconductor shortage, during which numerous companies in the semiconductor consumer and automotive sector encountered challenges in the assembly of their products due to the unavailability of microelectronics stemming from a combination of lockdown-related disruptions and the erratic fluctuations in demand (Frieske and Stieler, 2022). While most industries applied standard measures, such as production capacity reduction, factory shutdowns and product mix changes, proactive adaptation through stockpiling, product mix flexibility and even the production of their own chips were missing (MacCarthy *et al.*, 2022). Due to this long-term disruption, the public encountered, and still encounters, shortages in the supply of everyday necessities, attributed to an absence of proactive adaptation and preparedness measures. Based on the study's mean and standard deviation values, we can conclude that the SCRES performance of companies is still at low to medium levels.

Our SCRES framework offers a roadmap for decision-makers to steer transformative processes towards higher levels of SCRES. They can strategically develop their organizations to enhance resilience by gaining a holistic perspective on SCRES dimensions and their interrelationships. Considering the very recent conflicts in Ukraine and Israel, for instance, companies need to acknowledge that the severity, complexity and duration of such disruptions are becoming the "new normal." Here, the resilience of the supply chain includes the simultaneous response to the current event and preparation for future disruptions. Such adaptive cycles are linked across different systems, namely the supply system, political-economical system and social-ecological system (Wieland and Durach, 2021). To survive such long-term disruptions, companies may focus on more than just visibility through real-time information and data analytics but also proactively adapt the supply network.

Notably, our study transcends the confines of specific industries or crises, such as the COVID-19 pandemic, rendering it applicable to various business sectors or private contexts. One of the general findings is that organizations should not only focus on establishing visibility in their supply chains but also leverage the inherent properties of the supply system through appropriate behavior (Ivanov *et al.*, 2021; Yu *et al.*, 2022). This entails clear decision rules, which need to be developed and adapted over time. Another finding is the option to independently focus on either the proactive or reactive SCRES once visibility and velocity as system properties have been achieved. This allows organizations to prioritize their SCRES efforts in line with available resources (e.g. labor or funding). Although the full potential of SCRES can only be realized by creating synergies and the right portfolio of proactive and reactive SCRES (Aldrighetti *et al.*, 2023), this strategic flexibility enables organizations to realize immediate benefits and stepwise unlock synergies within the organization's portfolio.

7. Conclusion

SCRES is an increasingly important concept that, despite extensive research attention, needs to be better understood. The main reason is that SCRES is a multidimensional and inter-temporal phenomenon with complex interactions. In response, this study answered multiple calls on advanced middle-range SCRES theory to disentangle its underlying concepts. For this, it first redefined SCRES as a system quality and subdivided the main dimensions of SCRES by distinguishing between system properties, behaviors of a system, system responses and resilience outcomes. Second, we extended the traditional, chronological conceptualization of SCRES by operationalizing the intertemporal evolution of SCRES capabilities. Thereby, the study provides novel insights into the interaction of multiple SCRES constructs and the underlying mechanisms of building as a systems quality. Third, the study points to potential spillover effects, such as the positive direct effect of robustness on responsiveness.

In sum, the results provide a valuable contribution to practitioners and academics as it, on the one hand, supports theory testing and elaboration in LSCM and, on the other hand, yields sufficient reliability and validity measures to support the consistency of the proposed model. The study opens a broad spectrum for future research, which may focus on the selection of practices or tools to support the SCRES evolution, including the use of digital technologies, for example, to assist forecasting or product design (Browning *et al.*, 2023). Further research may build on the idea of non-linear relationships between single SCRES constructs, which arise from the existence of spillovers. Remarkably, the non-significant, direct effect of flexibility on robustness can be explained through different types of relationships, such as inverted U-shaped patterns. Quantifying potential synergies between simultaneous SCRES evolution and losses through prioritizing one phase over another also provides an opportunity for future studies.

The present study features some limitations. A main limitation was that not all SCRES theoretical dimensions available in the literature could be tested. The antecedence of SCRES building, such as resilience culture (cf. Ho *et al.*, 2015; Tukamuhabwa *et al.*, 2015), or outcomes of SCRES, such as efficiency or an advanced market position (Kochan and Nowicki, 2018; Tukamuhabwa *et al.*, 2015), was not considered to avoid complexity and ambiguity in our analysis. Meanwhile, readiness as an important SCRES capability of taking action before a disruption hits the organization was not included due to its similarity with preparedness (Hohenstein *et al.*, 2015; Ivanov *et al.*, 2017; Kilubi and Haasis, 2016). The same holds for adaptability and improvisation, other important capabilities that were not included given their similarity with flexibility (cf. Richey *et al.*, 2022). Testing these constructs provides another potential venue for future empirical research.

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Further reading

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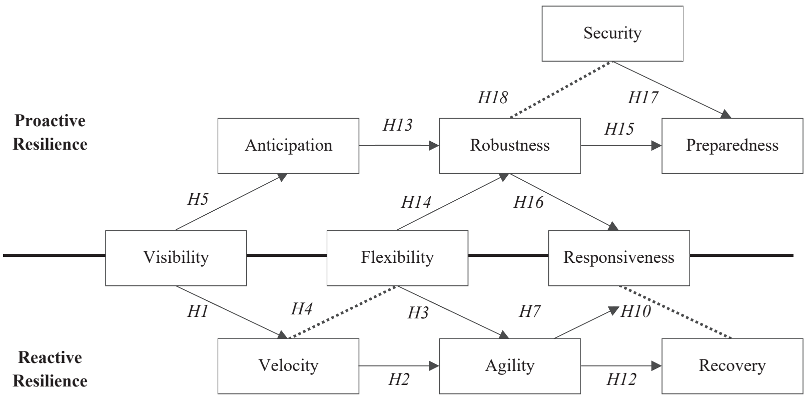
Appendix

Hypotheses		Tested	Source
Visibility positively affects velocity	H1	✓	Ahimbisibwe *et al.* (2016)
Velocity positively affects agility	H2	✓	Huma and Ahmed (2022)
Flexibility positively affects agility	H3	✓	Kazancoglu *et al.* (2022)
Flexibility moderates the relationship between velocity and agility	H4	✓	Mandal *et al.* (2016)
Visibility positively affects anticipation	H5	✓	Jain *et al.* (2017)
Anticipation positively affects preparedness	H6	✗	
Agility positively affects responsiveness	H7	✓	Kazancoglu *et al.* (2022)
Preparedness positively affects robustness	H8	✗	
Preparedness positively affects security	H9	✗	
Responsiveness positively affects recovery	H10	✗	
Security moderates the relationship between preparedness and robustness	H11	✗	
Agility positively affects recovery	H12	✗	
Anticipation positively affects robustness	H13	✗	
Flexibility positively affects robustness	H14	✗	
Robustness positively affects preparedness	H15	✗	
Robustness positively affects responsiveness	H16	✗	
Security positively affects preparedness	H17	✗	
Security moderates the relationship between robustness and preparedness	H18	✗	

Source(s): Authors' own work

Table A1.
Tested hypotheses in extant literature



Source(s): Authors' own work

Figure A1.
Tested spillover effects

Hypothesized relationship	Hypotheses	Standardized coefficient	T-statistics	p-value	Result
Visibility → velocity	H1	0.481	5.693	<0.01***	Supported
Velocity → agility	H2	0.208	3.409	<0.01***	Supported
Flexibility → agility	H3	0.370	3.421	<0.01***	Supported
Visibility → anticipation	H5	0.483	6.181	<0.01***	Supported
Agility → responsiveness	H7	0.730	4.310	<0.01***	Supported
Agility → recovery	H12	0.753	4.376	<0.01***	Supported
Anticipation → robustness	H13	0.518	4.167	<0.01***	Supported
Flexibility → robustness	H14	0.176	1.649	<0.1	Rejected
Robustness → preparedness	H15	0.553	4.266	<0.01***	Supported
Robustness → responsiveness	H16	0.402	3.859	<0.01***	Supported
Security → preparedness	H17	0.385	3.836	<0.01***	Supported
Variance explained in the endogenous variables					
Velocity	R^2 = 0.251				
Agility	R^2 = 0.329				
Responsiveness	R^2 = 0.444				
Recovery	R^2 = 0.343				
Anticipation	R^2 = 0.481				
Robustness	R^2 = 0.303				
Preparedness	R^2 = 0.375				
Responsiveness	R^2 = 0.581				

Note(s): Chi-square/df = 1.767, TLI = 0.818, CFI = 0.832, SRMR = 0.128, RMSEA = 0.062
Source(s): Authors' own work

Table A2.
Path coefficients

Hypothesized relationship	Hypotheses	Estimate	z-value	p-value	Result
Visibility → velocity	H1	0.511	6.446	<0.01***	Supported
Velocity → agility	H2	0.262	3.913	<0.01***	Supported
Flexibility → agility	H3	0.315	3.209	<0.01***	Supported
Velocity → flexibility	H4	0.172	2.694	<0.01***	Supported
Visibility → anticipation	H5	0.478	6.548	<0.01***	Supported
Anticipation → preparedness	H6	0.704	6.248	<0.01***	Supported
Agility → responsiveness	H7	0.945	5.255	<0.01***	Supported
Preparedness → robustness	H8	0.444	3.412	<0.01***	Supported
Preparedness → security	H9	0.649	5.876	<0.01***	Supported
Responsiveness → recovery	H10	0.702	0.702	<0.01***	Supported
Security → robustness	H11	0.326	3.017	<0.01***	Supported
Variance explained in the endogenous variables					
Velocity	R^2 = 0.300				
Agility	R^2 = 0.326				
Flexibility	R^2 = 0.059				
Responsiveness	R^2 = 0.468				
Recovery	R^2 = 0.607				
Anticipation	R^2 = 0.468				
Security	R^2 = 0.322				
Preparedness	R^2 = 0.527				
Robustness	R^2 = 0.359				

Note(s): Chi-square/df = 1.585, TLI = 0.894, CFI = 0.880, SRMR = 0.060, RMSEA = 0.052
Source(s): Authors' own work

Table A3.
Path coefficients of the ML-SEM