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Can the Adoption of Circular Economy Practices Foster Supply Chain Resilience and Performance Improvements?

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ABSTRACT

While a growing literature is showing interest in the circular economy (CE) paradigm, there is still a lack of consensus on whether the adoption of CE practices can help to cope with supply risks arising from an increasingly uncertain business environment in order to increase supply chain resilience (SCRES) and improve a firm's performance. Through a survey of Italian enterprises engaged with CE practices, this study aims to fill this literature gap, investigating whether the adoption of CE practices can initiate a path of increased SCRES, which can lead firms to improve their overall performance, thus proactively responding to environments characterised by high levels of supply risk. This study contributes to the debates about the paths connecting CE practices and firms' performance, especially in the context of vulnerabilities and disturbances, empirically demonstrating how firms might exploit the potential of CE by investing in SCRES. This study sheds light on the relationship between CE and SCRES, particularly underlying the most relevant paths of relationships between CE and those SCRES capabilities that can lead to performance improvements, particularly when the level of supply risk increases.

1 | Introduction

The events of the last few years, such as the COVID-19 pandemic and the recent geopolitical tensions, confirm that one of the main challenges in supply chain management (SCM) is exposure to severe disruptions. These negative events can raise unexpected issues related to raw material shortages and costs, due to the volatility of upstream supply chains, causing strains to relationships with suppliers (Raj et al. 2022; Rajaeifar et al. 2022). As such, identifying, evaluating and managing risks through appropriate strategies represent key aspects that can contribute to increasing supply chain resilience (SCRES) (El Baz and Ruel 2021; Finley and Pettit 2011).

Nowadays, due to the high level of raw material consumption and the subsequent issues in terms of resources' scarcity and supply shortages, governments, institutions and organisations across the globe are investing to cope with these risks, also taking on responsibility for how their goods are produced and shipped in terms of their environmental and social costs. As companies respond to calls for sustainability, the concept of circular economy (CE) has gained traction (Bjørnbet et al. 2021). The CE paradigm aims to maintain materials as long as possible in the economic cycle, hence avoiding, wherever possible, the use of virgin resources and trying to decouple economic performance from environmental degradation (Liu 2009). In fact, recent studies recognise the ability of CE practices to improve the environmental and business performance of companies involved in a variety of sectors (ranging from manufacturing to agri-food), minimising the use of raw materials, reuse and closed flow of materials, avoiding energy leaks, reducing emissions, pollution prevention and reduction (Bai et al. 2020; Jabbour et al. 2019). Also, the adoption of CE practices might improve firms' innovation capabilities, thus leading to better financial performances (Lieder and Rashid 2016; Yazdani et al. 2021).

While the literature deeply discusses the use of supply chain finance approaches to cope with supply risks and to improve performance (Carbonara and Pellegrino 2018; Gaudenzi et al. 2021; Guay and Kothari 2003), little attention has been devoted to CE as a way to deal with raw material supply risks, in order to increase supply chain resilience (SCRES) and thus improve a firm's performance in environments characterised by high supply risks.

Several studies have analysed how CE practices might impact a firm's performance, demonstrating that CE implementation may generate economic benefits while protecting the environment and society (Chen and Dagestani 2023; Mora-Contreras et al. 2023). However, fewer studies investigate the underlying mechanisms of the relationship between CE and a firm's performance. For example, Kwarteng et al. (2022) highlighted that the introduction of a new business model, such as Circular Economy, requires a radical rethinking and transformation of the strategies and capabilities. Del Giudice et al. (2021) investigated the role of digital technologies and big data in the relationship between CE and firm performance, demonstrating that big data are certainly worthwhile on the paths connecting CE practices and firm performance.

Despite these first attempts, the academic literature exploring the relationship between CE and firm's performance and their underlying mechanisms is still scarce.

Recently, a new stream of studies focused on how industries and social-ecological systems adapt themselves to cope with disturbances demonstrates the existence of a synergy between CE and SCRES (e.g., de Sousa Jabbour et al. 2023; Silva and Ruel 2022). For example, Gebhardt et al. (2022) underlined how CE practices can be an enabler for SCRES, particularly by diversifying a company's supply base and increasing redundancies through access to alternative sources of raw materials. CE improves the flow of materials and efficiency, while reducing the vulnerability of companies to disruption (Giannetti et al. 2023). In this sense, CE practices might be theorised as factors promoting SCRES towards better firm's performance, especially in those contexts characterised by high supply risks. However, a small part of the literature seems to empirically explore this research gap. In particular, the link between CE and, alternatively, SCRES, supply risk and firms' performance has been only partially investigated. Thus, this study aims to answer the following research questions (RQs):

RQ1. Can the adoption of CE practices positively influence SCRES?

RQ2. How do different levels of exposure of firms to supply risk influence the relationship between CE and SCRES?

RQ3. Can the adoption of CE practices help achieve better performance?

Grounded in the dynamic capabilities view (DCV), this study examines the relationships between CE practices, SCRES and performance. DCV argues that firms sustain competitive advantage by sensing environmental changes, seizing emerging opportunities and transforming their resources to meet turbulent and uncertain environmental conditions (Teece 2007). In this vein, DCV provides a theoretical foundation for analysing how the adoption of CE practices impacts SCRES and performance, particularly in light of the growing recognition of CE practices as a strategic lever for achieving competitive advantage while addressing environmental and resource challenges (Brogi and Menichini 2024; O. Khan et al. 2020).

To address the research questions, a survey was conducted in Italy, a country which, in recent years, has placed a lot of emphasis on the diffusion of CE practices (Ghisellini and Ulgiati 2020; Palombi et al. 2024). As such, this context is particularly pertinent for exploring the relationship between CE, SCRES and firm performance. Specifically, the study targets respondents from companies that have adopted CE practices. The respondents included management-level individuals (e.g., supply chain managers, CEOs) as well as operational-level ones (e.g., product specialists, employees of the sustainability department) who have an adequate level of experience and expertise in the field of CE and SCRES. Given the scope of the analysis and the survey characteristics, structural model analysis was conducted using the partial least squares structural equation modeling (PLS-SEM) method.

This study makes significant contributions to the literature and the practice. First, by empirically investigating the relationships between CE and the firm's performance, it contributes to the debates about the paths connecting CE practices and performance, especially in the context of vulnerabilities and disturbances. It provides useful insights for practitioners to fully exploit the potentials of CE in terms of performance and resilience improvements. Second, this study answers the call to extend empirical research on the link between CE and SCRES. It sheds light on the relationship between CE and SCRES, empirically demonstrating that it becomes particularly apparent when the level of supply risk increases.

The remainder of the paper is organised as follows. Section 2 provides a review of the relevant literature. Section 3 outlines the hypotheses. Section 4 describes the methodology employed for data collection and analysis. Section 5 presents the numerical results, which are discussed in Section 6. Section 7 concludes the paper with the implications of the analysis and limitations.

2 | Review of the Literature

This section is aimed at introducing the readers to the concepts of CE (Section 2.1), SCRES (Section 2.2), supply risk (Section 2.3) and firm performance (Section 2.4).

2.1 | Circular Economy

Circular economy (CE) can be defined as 'a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops' (Geissdoerfer et al. 2017).[1] Through several activities such as reusing, remanufacturing, refurbishing and recycling, products, parts or materials can be collected and reintegrated into the value chains (Nussholz 2018). Closing the cycles minimises the number of resources disposed of in the landfill, ceteris paribus. Narrowing resource loops is about reducing the resource use associated with products and production processes, thus increasing the efficiency of manufacturing processes and promoting better asset utilisation, ceteris paribus (Bocken et al. 2016). It is widely understood that CE practices cannot be implemented, in isolation, at a single-firm level, but require inter-firm collaboration (Chavez et al. 2023); as such, in order to operationalise CE principles, it is crucial to involve partners at a supply chain level, going beyond the traditional linear flow of materials from suppliers to customers, also involving new actors such as collectors, sorters, reprocessors and remanufacturers (Bimpizas-Pinis et al. 2022). This requires a radical redesign of SCs, in order to match the financial, operational, technological and institutional requirements for implementing R-imperatives (Bressanelli et al. 2019; Burke et al. 2023).

2.2 | Supply Chain Resilience

All supply chains have to cope with several typologies of adverse events, disruptions and disturbances stemming from the fast-changing business environment (Peters et al. 2023; Sturm et al. 2023). Resilience has been defined and investigated from the perspective of single organisations (Parker and Ameen 2018) and supply chains (Chowdhury et al. 2019) under the lens of supply chain resilience (SCRES), underlining its role in fostering long-term competitive advantage (Ivanov and Dolgui 2020). Resilience is a system's ability to recover and return to its original state after disturbances and to survive in a turbulent environment (Kennedy and Linnenluecke 2022; Suryawanshi and Dutta 2022). Wieland and Durach (2021) described SCRES in terms of dynamic adaptation and transformation of SCs. Coherently, Sturm et al. (2022) defined SCRES as 'the reactive ability to absorb and cope with supply-side disruptions to recover and return to a stable situation faster than competitors and to enhance competitive performance'. The current literature has been linking SCRES to several antecedents, which can influence the effective responses of a SC to disruptive events (Ivanov 2021; Sturm et al. 2023). Several studies focused on key capabilities acting as SCRES enablers such as—for example—agility, information sharing, collaboration and visibility (Soni et al. 2014; Um and Han 2021), analysing the role of such capabilities during the different phases of disruptions (Drozdibob et al. 2023; Gaudenzi et al. 2023). A nascent stream of the literature is investigating the connection between CE adoption and SCRES, recognising that CE adoption might develop some key SCRES capabilities (Giannetti et al. 2023). A link between the adoption of CE practices and a general increase in resilience at a systemic level has been proposed (Kennedy and Linnenluecke 2022); however, no study has empirically tested the adoption of CE practices as a way to increase SCRES. From this perspective, we investigate the possible relationship between CE practices and the adjusted capability of the SC to cope with changes linked to disruptions, offering a quick response and maintaining high visibility (Ambulkar et al. 2015).

2.3 | Supply Risk

Supply Risk involves 'potential deviations in incoming supplies in terms of time, quality, and quantity, and potential disturbances to the flow of products and information from within the network, upstream of the focal firms' (Shekarian and Mellat Parast 2021). Almost all organisations are exposed to different degrees of supply risk, arising from several vulnerability sources, which the literature groups into three main categories: suppliers, supply markets and characteristics associated with extended supply chains that become risk drivers (Zsidisin 2003). High uncertainty and risk surrounding modern SCs underline the importance of SCRES, particularly in industries that might face shortages in supply, lack of reactivity and business interruptions (Ivanov and Dolgui 2020). Hence, there is a need to assess how firms might deploy traditional and innovative SCs adopting strategies to cope with supply risk and ensure SCRES. While the SCRM literature has extensively investigated financial and supply chain approaches to cope with supply risks (Fang et al. 2013), the relationships among the adoption of CE practices, SCRES and supply risk have seldom been examined. Seminal research in the field of CE and SCs has found that the operationalisation of CE practices might generate further uncertainties and risks in a SC context (de Lima et al. 2024; Ethirajan et al. 2021). However, no work has, to date, examined the possibility of adopting CE practices as a way to deal with supply risk and increase SCRES, despite some studies generally hinting to the beneficial impact of such practices towards supply risk mitigation (Gaustad et al. 2018).

2.4 | Firm Performance

A wide range of literature investigates the performance of companies embedded in supply chains. In the past years, how the performance has been affected by supply chain collaboration (e.g., Cao and Zhang 2011), supply chain information systems (e.g., Qrunfleh and Tarafdar 2014), digital technologies (e.g., AlMulhim 2021) and supply chain leadership (e.g., Chen et al. 2021) has been investigated.

Recently, several studies investigated the potential effects that CE practices may have on a firm's business and financial performance, demonstrating that CE implementation may contribute to generating benefits such as—for example—improving reputation, market share, customer satisfaction and financial performance (Walker et al. 2021; Yang et al. 2019). However, some studies underline the lack of relationships between CE and a firm's performance, such as business and financial ones (Zhu et al. 2011). These contrasting results emerging from these studies require a deeper empirical analysis of this complex relationship in order to uncover the intervening factors that can mediate it (Mazzucchelli et al. 2022; Mora-Contreras et al. 2023). In particular, while recent studies are suggesting an intuitive positive link between CE and resilience, which can lead firms to improve their overall performance in an increasingly uncertain business environment, the link between firms' performance and—alternatively—SCRES, CE and risk has been only partially investigated. In particular, those studies that have explored the relationship between CE and a firm's performance have often focused on single performance measures, i.e., environmental (Sahoo et al. 2023), financial (Mazzucchelli et al. 2022) or economic (Testa et al. 2020). In our study, we decided to address the three key performance measures together to offer a more complete picture of this relationship, allowing us to identify any contrasting and compensatory effects that CE may have globally on a firm's performance according to a triple bottom line approach.

3 | Hypotheses Development

3.1 | CE and Firm Performance

The CE paradigm is potentially able to create environmental, economic and social advantages, simultaneously (Korhonen et al. 2018). From an environmental perspective, the implementation of CE practices can reduce the material and energy inputs into the production systems, as well as the production of wastes and emissions; from the economic perspective, CE practices can reduce production costs for companies thanks to better resource efficiency; finally, from the social perspective, CE might be able to create new employment opportunities. From a strategic perspective, the implementation of CE practices can be framed through the lens of the DCV (Teece et al. 1997). For instance, CE practices, such as waste minimisation, resource recovery and product redesign, can be seen as manifestations of firms' dynamic capabilities to reconfigure operational routines and innovate under environmental constraints (Castillo-Ospina et al. 2025; Neri et al. 2023). Another example lies in the firm's ability to adopt closed-loop processes, which reflect its dynamic capability to transform production systems in response to resource scarcity (Ritola et al. 2022). Coherently, a firm must develop, integrate and reconfigure resources to enhance business, environmental and financial performance in response to evolving market and regulatory conditions, as pointed out by Köhler et al. (2022). Several studies in the literature confirm this issue. For instance, in their survey in Ghana, Kwarteng et al. (2022) highlighted that the implementation of CE practices contributes to enhancing the financial efficiency at the company level. Through a survey conducted in Italy, Khan et al. (2022) found that CE also improves competitiveness and corporate reputation. Through an analysis of French, British and Indian companies, Malesios et al. (2018) found that two CE activities (i.e., minimising waste and replanning energy use) are linked to improving efficiency and may lead to greater profitability. Mazzucchelli et al. (2022) found that two CE practices (waste treatment and waste recycling) play an important role in enhancing brand reputation, which in turn positively affects financial performance. Similarly, Rodríguez-González et al. (2022) found that the adoption of CE practices might increase the financial performance of companies. These results are even confirmed by other studies—see, in this regard, the review recently published by Yin et al. (2023). Taken together, these insights suggest that CE practices are not merely an environmental initiative but represent a set of strategic capabilities that enable firms to align resource configurations with turbulent environments and institutional conditions (Santa-Maria et al. 2022). Hence, based on these considerations, we hypothesise that:

H1(a, b, c): CE implementation plays a positive role on the company performance namely, business performance (1a), environmental performance (1b) and financial performance (1c).

3.2 | CE and SCRES

Recent studies extensively question the role that the implementation of CE practices plays for SCRES (de Sousa Jabbour et al., 2023a; Kennedy and Linnenluecke 2022; Le et al. 2023). Several scholars advocate the existence of a synergy between CE and SCRES. According to DCV, it is indeed envisaged that firms must continuously sense, seize and reconfigure their resources to respond effectively to environmental uncertainties and market disruptions. CE practices, such as remanufacturing, recycling and closed-loop supply chains, can be seen as dynamic capabilities that enhance a firm's ability to adapt, recover and remain competitive in times of crisis (de Sousa Jabbour, Latan, Jabbour, & Seles, 2023b; Seles et al. 2022). For instance, Bag et al. (2019) investigated how dynamic remanufacturing capability increases adaptability and flexibility, which play a positive role in SCRES. Similar results are provided by Bressanelli et al. (2022). Furthermore, several scholars agree that the reduced dependency on some raw materials, driven by CE practices, is able to enhance SCRES against disruptions (Baars et al. 2021; Fisher et al. 2020; Gebhardt et al. 2022; Piila and Sarja 2024). Sarkis et al. (2020) and Ibn-Mohammed et al. (2021) argued that the COVID-19 pandemic has highlighted the unsustainability of the current production systems and that CE practices can be used to make these systems more resilient. de Sousa Jabbour et al. (2023) empirically demonstrated a positive influence of CE practices on SCRES, thus supporting the argumentation that CE implementation allows firms to develop capabilities, such as efficiency, flexibility and adaptability, which in turn increase resilience. Firms leveraging these capabilities not only improve performance outcomes but also strengthen their adaptive and responsive capacities in turbulent and uncertain supply environments. This reinforces the argument that CE does not merely represent a shift toward environmental sustainability but also constitutes a strategic enabler for resilience, in alignment with the core principles of the DCV (Chari et al. 2022).

While the majority of studies advocate the existence of a positive direct relationship between CE and SCRES, there are some studies that see a contrast between them, arguing that the optimisation of the business model favoured by CE practices may reduce redundancies, which in turn may negatively impact SCRES (Ivanov et al. 2018). These studies identifying tensions between CE and SCRES remain at the theoretical level, with few papers empirically studying the relationship between CE and SCRES, highlighting the need to investigate this field further. By viewing CE implementation as a dynamic capability, firms leveraging CE not only improve environmental outcomes but also enhance their adaptive and responsive capacity in turbulent supply environments.

Based on this discussion, we hypothesise that:

H2: CE implementation plays a positive role on SCRES.

3.3 | CE, SCRES and Firm Performance

The link between SCRES and firms' performance has been investigated using different lenses and performance measures. From a DCV perspective, SCRES can be understood as a manifestation of capabilities that allow firms to sense disruptions, seize response strategies and transform their operational configurations accordingly (Chari et al. 2022; Pu et al. 2023; Teece 2007). SCRES embodies key dynamic capabilities, such as flexibility, agility, efficiency, visibility and collaboration (Shin and Park 2020), that enable firms to navigate disruptions, maintain operational continuity and achieve superior performance across business, environmental and financial dimensions (Ruiz-Benítez et al. 2018). In this context, Stephens et al. (2022) highlighted the positive role played by SCRES on market performance, particularly in terms of customer satisfaction and loyalty, firm image and market growth. Qader et al. (2022) underscored the positive relationship between SCRES and financial and operational performance, while Sturm et al. (2023) highlighted the positive relationship between SCRES and financial and commercial performance. Authors have explored the relationship between resilience and firm performance through various methods, such as qualitative case studies (Butt 2021; Dohale et al. 2022) and quantitative approaches, for example, interpretive structural modelling (Ruiz-Benítez et al. 2018), Delphi method and structural equation modelling (Birkie et al. 2017; Md Maruf H Chowdhury and Quaddus 2017; El Baz and Ruel 2021; Liu and Lee 2018). Hence, based on these considerations, we hypothesise that:

H3(a, b, c): SCRES plays a positive role in the firm performance namely, business performance (3a), environmental performance (3b), financial performance (3c).

Although SCRES and CE have been largely investigated as separate research topics, scholars highlight the need to cope with new strategic challenges that SCs are facing, with the main aim to develop managerial solutions and dynamic capabilities to address complex environmental challenges (Kennedy and Linnenluecke 2022). In this sense, SCRES and CE share some common foundations. Resilience can help SCs to proactively respond to crises in a dynamically changing environment due to the presence of crucial capabilities as flexibility, agility, efficiency, visibility and collaboration (Shin and Park 2020). Recent studies have analysed how CE practices might positively impact SCRES (Silva and Ruel 2022). For example, Gebhardt et al. (2022) underlined how CE can be an enabler for SCRES, particularly diversifying a company's supply base and increasing redundancies through 'recycling' practices.

Considering the risks that CE poses to companies implementing these practices (De Lima and Seuring 2023), the presence of crucial capabilities of resilience such as flexibility, agility, efficiency, visibility and collaboration (Shin and Park 2020) may help companies to be better prepared to absorb disturbances and thus achieve better performance. In this sense, SCRES, with its foundational capabilities, might act as the underlying mechanism of the relationship between CE and firm performance, especially in complex and highly dynamic environments.

H4(a, b, c): SCRES positively mediates the relationship between CE and firm performance namely, business performance (4a), environmental performance (4b) and financial performance (4c).

3.4 | Supply Risk, SCRES and CE

Supply risk has been defined as 'the potential occurrence of an incident associated with inbound supply from individual supplier failures or the supply market, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety' (Zsidisin 2003). When there is supply scarcity for certain items and sources of supply are constrained, since disruptions in upstream supply chain can have serious negative repercussions for firms, consumers and economies, there is the need for firms to adopt one potential set of mitigation strategies as CE practices (Gaustad et al. 2018). The reliance on CE principles and practices would increase the ability of firms and SCs to proactively respond to crises in turbulent environments due to the presence of crucial capabilities that allow the diversification of material sources, reducing reliance on virgin inputs and promoting closed-loop supply chains (Nandi et al. 2021), thus, from a DCV perspective, seizing opportunities and transforming resources base for adjusting operations and maintaining continuity (Gani et al. 2023). This leads to the following hypothesis:

H5. The greater the supply risk, the greater the positive relationship between CE and SCRES, *ceteris paribus*.

Figure 1 shows the conceptual research model and each hypothesis.

4 | Methodology

This section is divided into two subsections: population and data collection instruments (Section 4.1) and data analysis (Section 4.2).

4.1 | Population and Data Collection Instrument

To empirically test the conceptual model (Figure 1), a survey was conducted in Italy, involving respondents of companies that adopted CE practices ranging from management level (e.g., supply chain managers, CEO) to operational level (e.g., product specialists, employee of the sustainability department) serving as exemplar cases of the diffusion of CE practices (Ghisellini and Ulgiati 2020; Palombi et al. 2024). The sample was initially selected from companies that adopted CE practices and listed in the Italian 'Atlas of the Circular Economy[2]'. However, to prevent bias and to reduce the total variance of estimates caused by total non-response, we increased the sample size by adding companies that, although

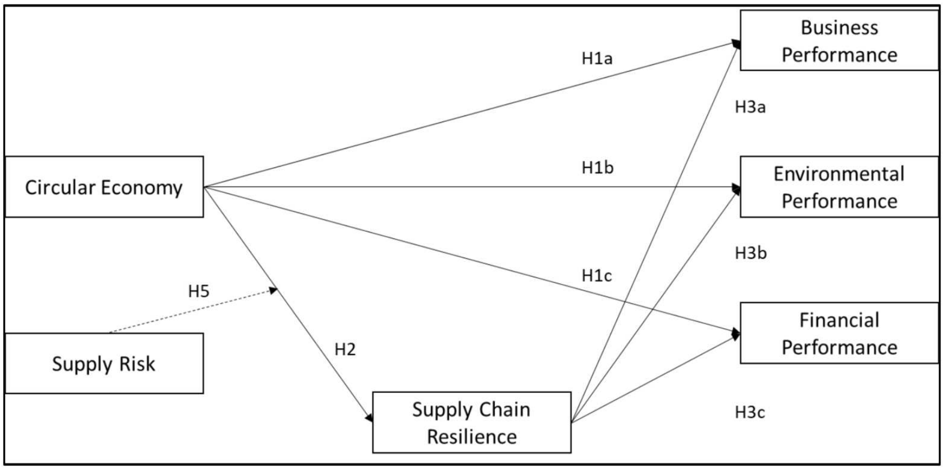

FIGURE 1 | Conceptual research model.

not listed in the Atlas, publicly claimed the adoption of CE practices, achieving a final cohort population of 1071 companies. Their manufacturing affiliation was determined based on their NACE code defined by the European Commission (European Commission 2010). Respondents were selected based on a rigorous analysis of their roles and responsibilities related to the constructs examined in this research.

The questionnaire is composed by a general section for collecting sample features and six main sections, namely, circular economy, supply risk, supply chain resilience, financial performance, business performance and environmental performance. Concerning SCRES, respondents were asked to indicate the level of agreement with several statement (four items adapted from Sturm et al. 2023), through a multi-item 5-point Likert scale ranging from 1 = 'Strongly disagree' to 5 = 'Strongly agree'. Regarding SR, respondents were asked to indicate to what extent they are concerned about several factors related to supply risk (five items from Zsidisin and Wagner 2010), through a multi-item 5-point Likert scale ranging from 1 = 'Not at all' to 5 = 'Extremely'. Concerning CE, respondents were asked to indicate to what extent they have been implementing the several CE practices (five items from Bag et al. 2022) over the last years. Regarding the performances, respondents were asked to indicate the extent of changes in several financial (three items from Sturm et al. 2023), business (four items from Sturm et al. 2023) and environmental (four items from Bag et al. 2022) performances over the last years, through a multi-item 5-point Likert scale ranging from 1 = 'Very much decreased' to 5 = 'Very much increased'. To mitigate the problem of common method variance, we designed and administered the questionnaire applying procedural and statistical remedies (Tehseen et al. 2017). The items for each construct were defined based on an extensive review of existing literature. Then, the questionnaire underwent iterative modifications through author discussions and expert review to validate its clarity and relevance to the research topic. Following revisions, the survey was distributed to participants, with assurances of confidentiality. Responses were collected via email between September and December 2023. Table 1 shows the list of items composing the questionnaire.

4.2 | Data Analysis

Structural model analysis was conducted using the PLS-SEM method, a widely accepted approach for hypotheses validation (Hair Jr. et al., 2021; Nitzl 2016). PLS-SEM evaluates multiple cause-and-effect relationships concurrently among a group of latent variables, each assessed by one or more observed variables. Latent variables represent complex constructs that are not directly measurable but inferred from observable variables serving as indicators of underlying concepts.

One of the key advantages of PLS-SEM is its ability to handle models that incorporate both reflective and formative measurement structures, allowing for greater flexibility when working with heterogeneous constructs (Hair et al. 2019). This feature is especially valuable in research scenarios where traditional covariance-based SEM (CB-SEM) methods may face challenges such as factor indeterminacy or inadmissible solutions. Additionally, PLS-SEM facilitates theory development, especially in exploratory stages, and is well-suited for small samples (Nitzl 2016). Another significant strength of PLS-SEM is its capability to estimate complex moderation effects, overcoming limitations posed by conventional regression-based and factor-based methods (Dash and Paul 2021). PLS-SEM is a valuable analytical tool for predictive research, particularly in supply chain management and related fields (Agyabeng-Mensah et al. 2024), due to its ability to maximise explained variance in endogenous variables and effectively analyse multi-item constructs and interaction effects (Becker et al. 2022). These characteristics make PLS-SEM particularly well-suited for our study, as it effectively handles the complexity of our model and the constraints of our sample size while ensuring robust analytical outcomes.

Preliminary tests were conducted on the data sample to ensure unbiased results, followed by a two-step analysis: (1) assessing the reliability and validity of the model (i.e., measurement model) and (2) examining the structural model. We follow the bootstrap resampling procedure to determine the statistical significance of the results using SmartPLS4.

TABLE 1 | Constructs and items' questionnaire.

Construct	Item	Indicator	References
Indicate to what extent you have been implementing the following CE practices over the last years (from 1 [not at all] to 5 [extremely])			
Circular economy (CE)	The company is dedicated to reducingy the consumption of raw materials and energy	CE1	Bag et al. 2022
	Company initiatively enhances the energy efficiency of production equipment	CE2	
	Waste produced in the manufacturing process is recycled	CE3	
	Waste products from consumers is recycled	CE4	
	Waste and garbage are used after reprocessing to manufacture new products	CE5	
Indicate to what extent you are concerned about each of the following factors related to supply risk (from 1 [not at all] to 5 [extremely])			
Supply risk (SR)	Ineffective management in the supplier firm	SR1	Zsidisin and Wagner 2010
	Financial instability or financial failure of a supplier	SR2	
	Suppliers incorrectly interpreting our requirements	SR3	
	Incoming product quality problems	SR4	
	Labor/management problems at suppliers	SR5	
Indicate the level of agreement with the following statements (from 1 [strongly disagree] to 5 [strongly agree])			
Supply chain resilience (SCRES)	We are able to cope with changes brought by supply chain disruptions	SCRES1	Sturm et al. 2023
	We are able to adapt to supply chain disruptions easily	SCRES2	
	We are able to provide a quick response to supply chain disruptions	SCRES3	
	We are able to maintain high situational awareness at all times	SCRES4	
Indicate the extent of changes in the following performances over the last years (from 1 [very much decreased] to 5 [very much increased])			
Financial performance (FIN)	Return on investment	FIN1	Sturm et al. 2023
	Profits as percentage of sales	FIN2	
	Labor productivity (sales/employees)	FIN3	
Business performance (BUS)	Sales growth	BUS1	
	Reputation and image	BUS2	
	Customer satisfaction	BUS3	
	Market share (of the main product)	BUS4	

(Continues)

TABLE 1 | (Continued)

Construct	Item	Indicator	References
Environmental performance (ENV)	Our organisation has reduced air emission in the last 3 years	ENV1	Bag et al. 2022
	Our organisation has reduced wastewater in the last 3 years	ENV2	
	Our organisation has reduced solid waste in the last 3 years	ENV3	
	Our organisation has reduced consumption of hazardous/harmful/toxic materials in the last 3 years	ENV4	

5 | Results

5.1 | Data

The survey garnered responses from 292 individuals (27.26%), with 125 questionnaires deemed suitable for analysis. The sample size is deemed adequate for the hypothesised model since it exceeds the minimum requirement of 77 calculated through GPower analysis (parameters: power = 0.8, effect size = 0.15, significance level = 0.05, number of predictors = 3) (Bhadra et al. 2024; Faul et al. 2009). Furthermore, the sample size also surpasses the recommended threshold proposed by Hair Jr. et al. (2021), which suggests a minimum of 110 responses as sufficient to detect a significant effect of magnitude at 80% statistical power, with a minimum R-squared of 0.10 and a 5% significance level. After analysing the respondents' demographics, it is evident that a significant portion of the sample comprises males (72.00%) and individuals holding a master's degree (64.80%), and a majority of respondents are either in a managerial position (43.20%) or middle management (44.00%). At the organisational level, the majority of respondents are employed in manufacturing companies (66.40%) with an annual turnover exceeding 50 million euros (44.00%). Table 2 shows the respondents' demographics.

Before proceeding to assess the quality of the estimated model, we conducted tests for non-response bias and common method bias. To examine non-response bias, we compared early respondents ($N = 60$) with late respondents ($N = 65$) based on the receipt date of the questionnaire. Utilising a t test to analyse the responses of these two sub-samples, we found no significant statistical difference ($p > 0.05$). Hence, we concluded that non-response bias was not a significant concern (Tehseen et al. 2017; Werner et al. 2007).

Furthermore, in line with the methodology outlined earlier and following the procedural remedies suggested by Tehseen et al. (2017) to mitigate the risk of common method bias, we took additional steps to ensure the validity of the dataset. While various procedures exist to assess the risk of common method bias, including Harman's single-factor test—which, though widely used, cannot definitively exclude the presence of such bias—we employed Kock's collinearity test for pathological collinearity (Kock and Lynn 2012).

Pathological collinearity is indicated by variance inflation factors (VIFs) exceeding 3.3, suggesting potential common method bias. However, in our study, all VIFs were found to be below 3.3, as indicated in Table 3, which displays the VIF for each pair of constructs. Based on these results, we concluded that, while common method bias could potentially influence our study due to the use of a single data source, it did not significantly impact our findings according to the statistical test applied.

To enhance the robustness and applicability of our model, we implemented a series of rigorous tests, detailed in Appendix A. Firstly, the PLSpredict test was employed to ensure that the model not only explains the existing data effectively but also possesses robust predictive capabilities (Shmueli et al. 2019). Secondly, to address and understand the diversity within the dataset, we conducted a heterogeneity test consisting of the finite

TABLE 2 | Respondents' demographics.

	Frequency	Percentage (%)
Respondent level		
Gender		
Male	90	72.00
Female	35	28.00
Age		
18–24	2	1.60
25–34	15	12.00
35–44	34	27.20
45–54	37	29.60
55–64	27	21.60
More than 65	> 65	8.00
Level of education		
Middle school or lower	1	0.80
High school	25	20.00
Bachelor's degree	12	9.60
Master's degree	81	64.80
PhD	6	4.80
Respondents position		
Management level	54	43.20
Middle management level	55	44.00
Junior level	14	11.20
Unknown	2	1.60
Organisational level		
Activity sector		
Raw materials	3	2.40%
Manufacturing	83	66.40%
Service	39	31.20%
No. of employees		
0–49	37	29.60
50–249	33	26.40
250–999	25	20.00
1000–4999	12	9.60
> 5000	18	14.40
Turnover (thousands €)		
< 1000	10	8.00
1000–2000	7	5.60
2000–10,000	22	17.60
10,000–50,000	31	24.80
> 50,000	55	44.00

(Continues)

TABLE 2 | (Continued)

mixture partial least squares (FIMIX-PLS) (Hair et al. 2016; Matthews et al. 2016). Finally, in order to identify potential endogeneity issues, we utilised the Gaussian copula approach to detect and correct any correlation between explanatory variables and the error term, which could lead to biased parameter estimates (Eckert and Hohberger 2023; Park and Gupta 2024).

5.2 | Measurement Model

After validating the responses collected through the questionnaire, we proceeded to assess the validity of the model, both at the individual item and at the construct levels. Table 4 summarises the parameters considered to demonstrate the validity of the proposed model. Regarding the items, we evaluated their reliability by examining factor loadings, which should exceed 0.708. This criterion indicates that the construct explains more than 50% of the indicator's variance, according to Hair Jr. et al. (2021). Turning the attention to constructs, we first tested the internal consistency by assessing both Cronbach's Alpha and composite reliability. Since all values exceeded the recommended 0.60 threshold, internal consistency was established (Hair et al. 2017). Secondly, we analysed the average variance extracted (AVE) to ensure convergent validity, considering the 0.50 threshold. This implies that a construct must be able to explain half or more of the indicators' variability (Hair et al. 2019). In this study, the AVE values for all constructs exceeded the suggested threshold, indicating acceptable convergent validity. Thirdly, we confirmed discriminant validity using the Fornell–Larcker criterion and the heterotrait–monotrait ratio (HTMT), which were found to be within the suggested threshold (Hair Jr. et al., 2021), as illustrated in Table 5.

5.3 | Structural Model

After confirming the validity of the items and constructs in the measurement model, we proceeded to examine the relationships in the structural model to address the research questions. The analysis revealed that CE practices had a positive and significant impact only on business performance (H1a, $\beta = 0.289$, p value $= 0.003$), while the relationships with environmental (H1b, $\beta = -0.102$, p value $= 0.202$) and financial performance (H1c, $\beta = 0.100$, p value $= 0.165$) were not significant. The relationship between CE practices and supply chain resilience was found to be positive and significant (H2, $\beta = 0.214$, p value $= 0.026$). Regarding hypothesis 3, SCRES demonstrated a positive effect on all performance measures: business (H3a, $\beta = 0.187$, p value $= 0.047$), environmental (H3b, $\beta = -0.147$, p value $= 0.069$) and financial (H3c, $\beta = 0.272$, p value $= 0.003$). The moderator

TABLE 3 | Variance inflation factors.

Construct	SCRES	SR	CE	FIN	BUS	ENV
Supply chain resilience (SCRES)		—	—	—	—	—
Supply risk (SR)	1.069	—	—	—	—	—
Circular economy (CE)	1.102	—	—	—	—	—
Financial performance (FIN)	1.012	—	1.012	—	—	—
Business performance (BUS)	1.012	—	1.012	—	—	—
Environmental performance (ENV)	1.012	—	1.012	—	—	—

TABLE 4 | Parameters model summary.

Construct	Items	Loadings	Composite reliability (CR)	Cronbach's alpha	Average variance extracted (AVE)
Supply chain resilience	SCRES1	0.729	0.865	0.806	0.617
	SCRES2	0.769			
	SCRES3	0.841			
	SCRES4	0.799			
Supply risk	SR1	0.754	0.904	0.867	0.653
	SR2	0.825			
	SR3	0.838			
	SR4	0.851			
	SR5	0.768			
Circular economy	CE1	0.775	0.839	0.759	0.569
	CE2	0.858			
	CE3	0.727			
	CE4	0.641			
Financial performance	FIN1	0.802	0.830	0.733	0.622
	FIN2	0.674			
	FIN3	0.876			
Business performance	BUS1	0.692	0.846	0.757	0.579
	BUS2	0.847			
	BUS3	0.741			
	BUS4	0.755			
Environmental performance	ENV1	0.826	0.913	0.874	0.725
	ENV2	0.875			
	ENV3	0.882			
	ENV4	0.822			

effect of supply risk on the relationship between CE practices and SCRES was observed (H5, $\beta = 0.126$, p value $= 0.085$). Finally, the mediating effect of SCRES was found to be positive and significant in the relationship between CE practices and financial performance (H4c, $\beta = 0.058$, p value $= 0.065$), while it was not significant in business (H4a, $\beta = 0.040$, p value $= 0.126$) and environmental performance (H4b, $\beta = -0.031$, p value $= 0.144$). In detail, SCRES acts as a full mediator in the relationship between the implementation of CE principles and financial performance. This underscores the pivotal role of an organisation's supply

TABLE 5 | Discriminant validity.

Construct	SCRES	SR	CE	FIN	BUS	ENV
Fornell–Larcker criterion						
Supply chain resilience (SCRES)	0.786					
Supply risk (SR)	−0.269	0.808				
Circular economy (CE)	0.107	0.253	0.754			
Financial performance (FIN)	0.283	0.107	0.129	0.789		
Business performance (BUS)	0.218	0.061	0.309	0.521	0.761	
Environmental performance (ENV)	−0.158	0.300	−0.118	0.152	0.032	0.852
Heterotrait–monotrait ratio (HTMT)						
Supply chain resilience (SCRES)	—					
Supply risk (SR)	0.302	—				
Circular economy (CE)	0.195	0.307	—			
Financial performance (FIN)	0.290	0.131	0.154	—		
Business performance (BUS)	0.260	0.112	0.370	0.750	—	
Environmental performance (ENV)	0.174	0.338	0.163	0.215	0.100	—

TABLE 6 | Structural model summary.

Hypothesis	Path coefficients	Standard deviation	T values	*ps*	Result
Direct effects					
H1a: CE—> **BUS**	0.289	0.104	2.783	0.003***	Supported
H1b: CE—> **ENV**	−0.102	0.122	0.836	0.202	Not Supported
H1c: CE -> **FIN**	0.100	0.102	0.974	0.165	Not Supported
H2: CE -> **SCRES**	0.214	0.110	1.943	0.026**	Supported
H3a: SCRES -> BUS	0.187	0.112	1.671	0.047**	Supported
H3b: SCRES -> ENV	−0.147	0.099	1.480	0.069*	Not Supported
H3c: SCRES -> FIN	0.272	0.100	2.722	0.003***	Supported
H5: SR x CE -> **SCRES**	0.126	0.092	1.374	0.085*	Supported
INDIRECT EFFECTS					
H4a: CE -> **SCRES -> BUS**	0.040	0.035	1.148	0.126	Not Supported
H4b: CE -> **SCRES -> ENV**	−0.031	0.030	1.065	0.144	Not Supported
H4c: CE -> **SCRES -> FIN**	0.058	0.039	1.512	0.065*	Supported

chain resilience in determining the extent to which CE practices positively impact financial performance. The results of the analyses are summarised in Table 6 and illustrated in Figure 2.

6 | Discussion

The data of this study are gathered from companies that are based in Italy, which represents a country that has placed a lot of emphasis on the diffusion CE practices, being therefore an exemplar case for other national contexts (Ghisellini and Ulgiati 2020; Palombi et al. 2024) when exploring the relationship between CE, SCRES and firm's performance.

With regard to RQ1 (Can the adoption of CE practices positively influence SCRES?), our study suggests how implementing CE practices can enhance SCRES (H2). Indeed, companies adopting CE practices are more able to cope with changes brought by supply chain disruptions, adapt easily and quickly to these disruptions, and maintain high situational awareness at all times. This result is consistent with several studies which initially investigated the link between sustainability and resilience

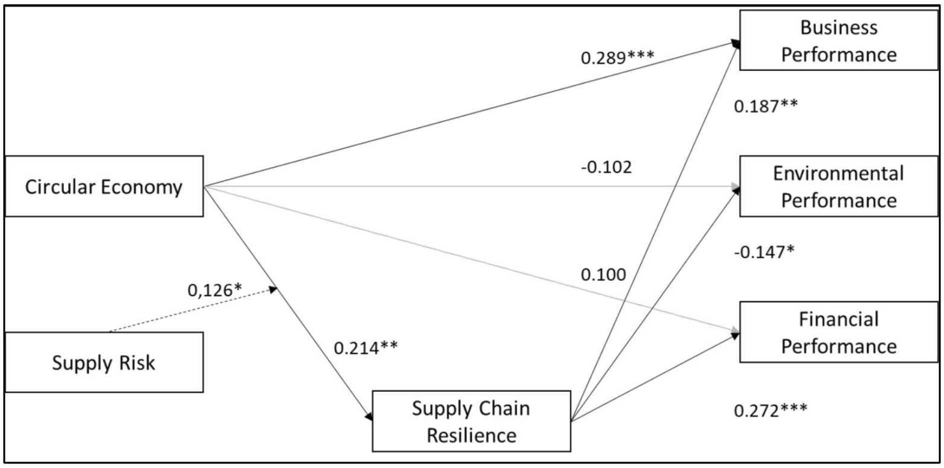

FIGURE 2 | Conceptual research model results.

(Cotta et al. 2023; Ivanov 2017) and then the link between CE and SCRES (Bag et al. 2019; Le et al. 2023).

With regard to RQ2 (How do different levels of exposure of firms to supply risk influence the relationship between CE and SCRES?), we found that the positive impact that CE practices have on SCRES is particularly apparent when the level of supply risk is higher (H5). This result, which confirms the importance of the external environment for the effectiveness of the CE practices, aligns with several studies e.g., (Fraccascia and Yazan 2018; Massari and Giannoccaro 2024; Nandi et al. 2021), and contributes to fill the existing gap regarding the relationship between SCRES, CE and sustainability practices, and performance, as underlined by Negri et al. (2021). Specifically, the outcome of this study is consistent with recent studies attributing the synergies between CE and SCRES to the ability of CE practices to create organisational capabilities that help firms mitigate supply risks. These capabilities include the flexibility to diversify sources of raw materials by using renewable or recycled materials (Borms et al. 2023; de Sousa Jabbour et al., 2023a). Additionally, recent examples of firms transitioning towards closed-loop supply chains, such as IKEA and Decathlon, demonstrate that the redundancy created by recovering post-consumption products for reuse and recycling can help firms manage raw material shortages and fluctuations in supply and demand (Gebhardt et al. 2022).

With regard to RQ3 (Can the adoption of CE practices help achieve better performance?), this research highlights how implementing CE practices can impact the performance of companies both directly (H1) and indirectly (H4).

With reference to the direct effects, the companies in our sample report how, after the adoption of CE practices, their business performance has increased in terms of sales growth, reputation and image and customer satisfaction, compared to the main competitors in the last few years. This result is deepening existing studies in the literature (Schöggl et al. 2024), which analyse the relationship between CE and performance in different countries, such as Spain (Triguero et al. 2023), Italy (Mazzucchelli et al. 2022), China (Guo and Tsinopoulos 2023), Vietnam (Le et al. 2023), India (Nudurupati et al. 2022) and Ghana (Kwarteng et al. 2022). In line with our study, which highlighted the key performance of sales growth, reputation and customer satisfaction, the research conducted by Yin et al. (2023) underscores a robust positive correlation between CE practices and sales and market share expansion. However, in our study, no direct impact seems to exist between CE practices and environmental and financial performance. This can be related to the fact that companies immediately perceive the positive impacts of CE practices on their relationships with customers, enhancing competitive growth, while environmental and financial performances are perceived as achievable in a long-term period since most of the CE practices are expected to reach their targets within a 10-year timeframe. From a financial standpoint, in fact, implementing CE practices often requires high upfront investments in new equipment, infrastructure and new competencies development, which can be offset by benefits gained in medium/long-term horizons (Mazzucchelli et al. 2022).

Nevertheless, we found that implementing CE practices can indirectly impact the firm's performance because it contributes to enhancing SCRES, which in turn can have a positive impact on the firm's performance. In this regard, our results indicate that all aspects of a firm's performance can be significantly affected by SCRES. Notably, the impact on business and financial performance is positive, aligning with recent studies by El Baz and Ruel (2021), Liu and Lee (2018), Qader et al. (2022), Stephens et al. (2022) and Sturm et al. (2023). However, the impact of SCRES on environmental performance seems to be negative. This result is unexpected and denies our hypothesis. In this regard, there is a wide literature discussing the negative impact of increased resilience on natural ecosystems (e.g., Goerner et al. 2009; Ulanowicz et al. 2009). In the supply chain context, for example, Fahimnia et al. (2018) acknowledged that while a positive relationship between SCRES and environmental performance is often assumed, instances exist where a negative correlation between SCRES and environmental sustainability can occur.

Specifically, we found that SCRES fully mediates the relationship between CE practices and financial performance. This result is in line with the literature that emphasises that risks and uncertainties associated with CE practices may hinder the full potential of CE, if they are not well managed (De Lima and Seuring 2023). Hence, our results confirm that only those firms investing in SCRES, along with CE, may obtain better financial performance from CE implementation, being better prepared to absorb disturbances that CE may cause and being able to withstand disruptions during crises and normal times without incurring significant costs (Yu et al. 2019). Our study, in fact, is an original contribution to understanding the wide picture of the relationships between CE, SCRES and firm's performance.

7 | Implications, Future Research Directions and Conclusions

This study offers several implications for academics and practitioners. The strong effect of CE practices on business performance, as previously described, underlines the strategic role of CE in enhancing the company performance. Moving a step forward from the study of Schöggl et al. (2024), our study in particular underlines the link between CE practices and the performance related to sales, reputation and customer satisfaction, confirming the strategic importance of investing in CE practices.

In addition, CE practices are positively related to SCRES, demonstrating how CE allows firms to be more prepared to cope with disruptions and to respond quickly to unfavourable events. Interestingly, SCRES impacts financial performance due to the strong benefits of SCRES on cost performance, according to Jabbarzadeh et al. (2018). SCRES also mediates the relationship between CE and financial performance. It means managers can improve financial performance by investing in CE practices and SCRES, confirming and developing the evidence of Hohenstein et al. (2015). While, in fact, CE is mainly inspired by business goals, since there is a positive relationship between CE practices and business performance, the relationship between CE practices and SCRES offers a strong positive impact on financial performance, such as labour productivity, profits and ROI.

These findings are particularly relevant for those firms that seek to improve CE practices and their resilience, as well as for those firms that are required to develop CE and SCRES as a pressure imposed by key stakeholders.

Similarly, the study offers some theoretical implications which are worth further investigation. As mentioned, the study reveals that CE practices might have a positive direct impact on SCRES levels. Such evidence, despite being rather intuitive due to the activation of alternative supply networks aimed at supporting CE practices, had just been suggested from a conceptual point of view in the literature (see, for instance, Kennedy and Linnenluecke 2022). As such, the empirical results offered in this paper call for further testing in different contexts in order to shed further light on the capability of CE practices to foster resilience.

In addition to this, the absence of a direct link between the adoption of CE practices and environmental performance is another aspect that deserves further investigation. The literature has already pointed out the issue that CE practices, especially if linked to lower R-imperatives, might not produce significant results from an environmental point of view, and even lead to counterintuitive rebound effects, where the inability to displace primary production might also lead to unsustainable circularity (Boldoczki et al. 2021; Lowe et al. 2024). While the study has not investigated in detail the type of CE practices adopted by the surveyed firms, it still offers an important reflection on the fact that the adoption of CE practices, per se, might not improve sustainability performance. Coupled with the previously discussed significance of CE practices for the increase of SCRES levels and on general business performance, these findings might reveal some new rationale behind the adoption of CE practices by firms, which deserves some further investigation, openly questioning the more techno-enthusiastic CE narratives that promise the possibility of decoupling economic growth from environmental degradation (Genovese and Pansera 2021). Finally, the study offers policy-making implications.

Finally, our findings carry some important policy implications. While governmental initiatives that promote and support the adoption of CE practices are recommended—especially in turbulent and uncertain environments—it is crucial that such policies are designed with a proper and critical understanding of CE's diverse impacts. Rather than assuming inherent environmental benefits, policy frameworks should encourage the implementation of high-impact, systemic CE practices, while also encouraging their monitoring to avoid unintended consequences, such as rebound effects or forms of circularity which might have negative environmental impacts. By doing so, policymakers can more effectively support firms in enhancing business performance and SCRES, while also ensuring that CE initiatives contribute meaningfully to broader sustainability goals.

There are some limitations to this study, offering opportunities for future research. This paper aims to investigate the broad and complex relationships between the adoption of CE practices, SCRES, supply risk and performance. To consolidate these preliminary results in this novel field, future studies should aim to enlarge the sample, with the scope to enhance the model and further confirm its viability. Second, since this study is cross-sectional, further investigations are recommended on industrial differences, as well as on the development of longitudinal research. Given the complexity of the model, the future development of multimethod approaches can consolidate the evidence of this study. Coherently with survey-based methodology, this study relied on managers' perceptions to assess SCRES as well as the firm's performance, through key stages of disruption such as preparation, response and recovery. While useful, perception-based measures may not fully capture how resilience develops in practice. Therefore, future research should combine these with metrics or secondary data to better reflect resilience over time. Moreover, this research has not examined the association between CE and broader categories of risks. In addition, the research did not investigate the potential opposite relationship between SCRES investments and CE investments, analysing when and how SCRES can influence CE. The relationship between SCRES and environmental performance could be further investigated, given the results of this study and the lack of consensus across existing research. Additionally, considering that SCRES is built through different practices and capabilities whose importance and utilisation vary according to the phase of the disruption (Drozdibob et al. 2023; Gaudenzi et al. 2023), further research can be devoted to investigating how these key practices and capabilities act in the relationship between CE, SCRES and performance. Finally, we treated risk and disruption broadly as any event interrupting normal operations. This approach may overlook important differences between frequent, smaller risks and rare, high-impact events. Future studies should distinguish between types of risks and disruptions to better understand how CE practices might impact resilience in specific uncertain and risk conditions.

Author Contributions

Roberta Pellegrino: conceptualisation, data curation, formal analysis, funding acquisition, methodology, writing, final review and editing. **Barbara Gaudenzi:** conceptualisation, methodology, writing, final review and editing. **Luca Fraccascia:** conceptualisation, methodology, writing, final review and editing. **Andrea Genovese**: methodology, writing, final review and editing. **Luigi Jesus Basile**: formal analysis, methodology, writing, final review and editing.

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Endnotes

[1] Readers interested to deepen other definitions of circular economy are referred to the reviews by Kirchherr et al. (2017, 2023).

[2] Atlas of the Circular Economy | Atlante, 2024. Economia Circolare. URL https://economiacircolare.com/atlante/ (accessed 5.18.24).

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Appendix

A.1 | Predictive Power

Following Shmueli et al. (2019), the predictive validity of the model was tested using the PLSpredict algorithm on SmartPLS, with settings including 10 folds and 10 repetitions. The assessment confirmed that most of the Q2 values were positive, and excluding the ENV1 indicator, the root mean square error (RMSE) for all indicators was lower than that of the corresponding linear regression model, demonstrating the model's predictive validity. Table A.1 shows the results of the predictive power test.

TABLE A.1 | Predictive validity test.

Items	Q^2predict	PLS-SEM_RMSE	LM_RMSE
BUS1	0.021	0.865	0.877
BUS2	0.058	0.707	0.737
BUS3	0.010	0.758	0.791
BUS4	0.041	0.672	0.706
ENV1	0.009	0.884	0.862
ENV2	0.010	0.767	0.770
ENV3	0.016	0.806	0.817
ENV4	0.007	0.829	0.842
FIN1	−0.017	0.746	0.787
FIN2	−0.017	0.830	0.861
FIN3	−0.012	0.782	0.810
SCRES1	−0.021	0.845	0.860
SCRES2	0.045	0.909	0.939
SCRES3	0.003	0.828	0.865
SCRES4	0.078	0.837	0.882

A.2 | Endogeneity

Following the confirmation of non-normality through rigorous statistical tests, namely the Kolmogorov–Smirnov test with Lilliefors correction and Shapiro–Wilk test as outlined by Sarstedt and Mooi (2014), on the latent variable scores, we proceeded with the utilisation of Park and Gupta (2024) Gaussian copula approach. This methodology, facilitated through Smart PLS 4, was employed to address potential endogeneity concerns. The analysis involved estimating the model utilizing the PLS algorithm and evaluating the significance of the selected Gaussian copula paths through bootstrapping techniques, employing a subsample of 5000 and constructing percentile bootstrap confidence intervals for a two-tailed test with α set at 0.1. The examination of the results, as presented in Table A.2, indicates that none of the paths reached statistical significance ($p > 0.1$). Consequently, it can be inferred that no discernible endogeneity issues were detected, thus affirming the robustness of the model, in line with the observations made by Hult et al. (2018).

A.3 | Heterogeneity

Heterogeneity in structural model analysis refers to the varying behaviors and structures of individuals and organisations used as sample groups. Traditional models, such as PLS-SEM, are often viewed as oversimplifications and can compromise the integrity of results (Sarstedt 2008). To assess heterogeneity, the FIMIX-PLS module within SmartPLS 4.0.9.9 was used, adhering to Matthews et al. (2016) methodology. Table A.3 shows the heterogeneity analysis results. The results were derived from a dataset of 125 respondents, with a G-power analysis establishing a minimal sample size of 55. The analysis explored one and two segment configurations, adhering to parameters like 5000 iterations, a stopping criterion of 1×10^{-9}, and 10 repetitions. The one-segment model was found to be the most robust, while the two-segment model showed a normed entropy statistic below the threshold of 0.5, indicating inadequate differentiation between segments (Hair et al. 2016). Thus, the data do not exhibit significant heterogeneity (Hair et al. 2016; Sarstedt 2008).

TABLE A.2 | Endogeneity test results.

	Non normality test			
	Kolmogorov–Smirnov		Shapiro–Wilk	
	Coefficient	***ps***	**Coefficient**	***ps***
CE	0.105	0.002	0.962	0.002
SCRES	0.135	0.000	0.933	0.000
	Gaussian copula approach			
	Coefficient	**Standard deviation**	**T statistics**	***p***
GC (CE) **-> FIN**	0.738	0.774	0.954	0.340
GC (CE) -> BUS	−0.398	0.739	0.539	0.590
GC (CE) -> ENV	−0.212	0.808	0.262	0.793
GC (SCRES) -> FIN	−0.172	0.470	0.367	0.714
GC (SCRES) -> BUS	0.689	0.481	1.432	0.152
GC (SCRES) -> ENV	−0.614	0.476	1.289	0.198

Abbreviations: BUS, business performance; CE, circular economy; GC, Gaussian copula; ENV, environmental performance; FIN, financial performance; SCRES, supply chain resilience.

TABLE A.3 | FIMIX-PLS analysis for unobserved heterogeneity.

Criteria	Number of segments 1	2
AIC	1.394.515	**1.380.163**
AIC3	1.407.515	**1.407.163**
AIC4	**1.420.515**	1.434.163
BIC	**1.431.283**	1.456.528
CAIC	**1.444.283**	1.483.528
HQ	**1.409.452**	1.411.186
MDL5	**1.682.356**	1.977.986
LnL	**−684.258**	−663.082
EN	**0.000**	0.467
No. of segments	**1**	**2**
2	82 out of 125 (65.70%)	43 out of 125 (34.30%)