The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/1754-2731.htm

Digital technologies and circular economy practices: vital enablers to support sustainable and resilient supply chain management in the post-COVID-19 era

Received 26 December 2021
Revised 1 April 2022
7 June 2022
12 August 2022
Accepted 17 August 2022

Anass Cherrafi
Cadi Ayyad University, Marrakech, Morocco
Andrea Chiarini
Department of Business Administration, University of Verona, Verona, Italy
Amine Belhadi
Rabat Business School, International university of Rabat, Rabat, Morocco
Jamal El Baz
Ibn Zohr University, Agadir, Morocco, and
Abla Chaouni Benabdellah
Rabat Business School, International university of Rabat, Rabat, Morocco

Abstract

Purpose – The COVID-19 pandemic has caused major disruptions and revealed the fragilities in supply chains. This crisis has re-opened the debate on supply chain resilience and sustainability. This paper aims to investigate distinct impacts of COVID-19 on supply chains. It identifies both short- and medium-to-long-term measures taken to mitigate the different effects of the pandemic and highlights potential transformations and their impacts on supply chain sustainability and resilience.

Design/methodology/approach – To address the purpose of the study, a qualitative research approach based on case studies and semi-structured interviews with 15 practitioners from various supply chain types and sectors was conducted. Studied organizations included necessary and non-necessary supply chain sectors, which are differently impacted by the COVID-19 pandemic.

Findings – This study reveals five main challenges facing supply chains during COVID-19, including uncertain demand and supply, suppliers' concentration in specific regions, globalized supply chains, reduced visibility in the supply network, and limited supplier capacity. To help mitigate these challenges and develop both sustainability and resilience, this paper identifies some mitigating actions focusing on the promotion of the health and wellbeing of employees and supply chain stabilization. Further, in the post-COVID era, sustainable and resilient supply chains should consider regionalization of the supply chain, diversification of the supply network, agility, collaboration, visibility, and transparency; and should accelerate the use of smart technologies and circular economy practices as dynamic capabilities to improve supply chain resilience and sustainability.

Originality/value – This study contributes to exploring the sustainability- and resilience-related challenges posed by the COVID-19 pandemic. Its findings can be used by researchers and supply chains decision-makers to limit disruptions and improve responsiveness, resilience, sustainability, and restoration of supply chains.

© Anass Cherrafi, Andrea Chiarini, Amine Belhadi, Jamal El Baz and Abla Chaouni Benabdellah. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at http://creativecommons.org/licences/by/4.0/legalcode

The TQM Journal
Vol. 34 No. 7, 2022
pp. 179-202
Emerald Publishing Limited
1754-2731
DOI 10.1108/TQM-12-2021-0374

The results support benchmarking through sharing of the best practices and organizations can also integrate the different capabilities discussed in this study into the processes of selection and auditing of their suppliers.

Keywords Circular economy, COVID-19, Digital technologies, Supply chain management, Sustainability, Dynamic capabilities

Paper type Research paper

1. Introduction

The ongoing SARS-CoV-2 pandemic that began in 2019 (COVID-19) has been one of the most impactful pandemics faced by human civilization in modern history (Remko, 2020; Sarkis *et al.*, 2020). It has paralyzed the world and affected all areas of societies and economies, causing the worst economic crisis since the Great Depression (International Monetary Fund, 2020; Linton and Vakil, 2020; Paul and Chowdhury, 2020). In this context, according to Karunathilake (2020), the Covid-19 crisis will directly impact all of the Sustainable Development Goals defined to be achieved by 2030.

Because of COVID-19-related supply chain disruptions, the world has experienced unprecedented problems, highlighting the fact that supply chains function as the "veins" of our economy and society (Karmaker *et al.*, 2020). In fact, according to Fortune (2020), more than 94% of Fortune 1,000 organizations have faced supply chain disruption because of COVID-19. High uncertainty, long-term disruption, and ripple effect propagation are among the main risks facing supply chains (Ivanov, 2020b; Karmaker *et al.*, 2020). Supply chain management (SCM) has had considerable difficulty dealing with unexpected demand for particular items when simultaneous travel and production limitations are imposed. In addition, different elements of supply chains, including manufacturing, distribution centers, logistics, and markets are still experiencing important fluctuations in demand, and disruptions to order quantities and lead times.

In this context, this pandemic highlights the urgent need for resilient and sustainable supply chain studies (Cavalcante *et al.*, 2019; Ivanov and Dolgui, 2021; Chaouni Benabdellah *et al.*, 2021; Khanuja and Jain, 2021; Umar *et al.*, 2022) and has put them to the test (Ivanov and Dolgui, 2020, 2021). Resilience has been recognized as a dynamic capacity that allows organizations to increase unexpected and unquantifiable incidents (Yu *et al.*, 2019). Moreover, it is essential to build new processes or reconfigure existing capabilities to enhance an organization's sustainability (Eisenhardt and Martin, 2000; Chaouni Benabdellah *et al.*, 2021). Thus, the challenge for organizations in this scenario is to satisfy the needs of their stakeholders by generating positive economic results and seeking an appropriate balance between the triple bottom line (TBL) and sustainability (Garza-Reyes, 2015; Cherrafi *et al.*, 2018).

The impact of COVID-19 on supply chains has gained the attention of many researchers (Frederico *et al.*, 2021; Joshi and Sharma, 2022; Paul *et al.*, 2021). According to procurement market intelligence service Beroe (2020), only 49% of organizations have developed a business continuity plan for COVID-19 and only 57% have identified critical suppliers and supplies. Supply chain managers, governments, researchers, and policymakers are searching for adequate solutions to limit various impacts on supply chain performance and cope with the pandemic-induced situation (Chowdhury *et al.*, 2020). The World Economic Forum has highlighted the need for organizations to adapt and redesign their supply chains to manage future disruptions. In the same context, Ivanov and Dolgui (2021) called for more studies on supply chain robustness and resilience to help organizations face COVID-19 challenges.

Research has identified digital and circular economy (CE) opportunities for supply chain performance. According to Sarkis *et al.* (2020), CE practices can serve as a driver of change to increase sustainability, leading to resilience (Bag *et al.*, 2019). Digital technologies such as 3D printing, the internet of Things (IoT), big data, cloud

computing, and blockchain can also support CE and supply chain resilience (Nandi *et al.*, 2020; Ralston and Blackhurst, 2020).

In a recent study, Bastas and Garza-Reyes (2022) have analyzed the different challenges and response strategies implemented by manufacturing organizations in the northern region of Cyprus; however, this study has focused on the short- and medium-term issues without discussing the long-term response strategies formulated or that will be formulated by organizations. In the same context, Belhadi *et al.* (2021) have studied the impacts and the learnings captured from the airline and automobile supply chain during the COVID-19 crisis. Another study conducted by Okorie *et al.* (2020) has analyzed different enablers and barriers to manufacturing resilience within the context of disruption caused by COVID-19. The majority of these studies have presented interesting perspectives, conceptual models, and viewpoints on the impacts and response strategies to support practitioners across different manufacturing sectors (Bastas and Garza-Reyes, 2022). However, these contributions have focused on short issues in the absence of empirical data. Consequently, the research on the topic of supply chain transformation to manage future disruptions remains at a nascent stage. Moreover, there is a lack of integration of supply chain resilience, sustainability, and digitalization, which are important for long-term viable supply chains (Ivanov, 2020a, b). The literature focuses only on the individual contributions of these three elements. Considering this gap, our study aims to address four main research questions:

(1) What are the different impacts of COVID-19 on sustainable supply chain performance?

(2) What are the short- and long-term measures taken to mitigate the different effects of the COVID-19 crisis?

(3) What future changes are required to simultaneously improve supply chain resilience and sustainability?

(4) How might digital technologies and CE practices, as dynamic capabilities, help to transform supply chains for more sustainability and resilience?

To address these questions, we conducted a qualitative research study via semi-structured interviews with 15 professionals directly involved in SCM to uncover how supply chain players have been responding to the supply chain disruptions presented by COVID-19. The resulting data were interpreted from a dynamic capabilities perspective.

The results of this study contribute to the body of knowledge on supply chain resilience through an exploratory study of the different impacts, response strategies, and the role of digital technologies and CE practices to transform supply chains for greater sustainability and resilience. In this study, insights and learning lessons are captured from different expert interviews and the finding are used to develop an integrative framework to foster supply chain resilience and sustainability to help organizations to achieve competitive advantages by recovering more rapidly and successfully than rivals.

The rest of this paper is organized as follows. Section 2 presents the theoretical background of this study. Section 3 describes the research methodology. Section 4 discusses the findings from the semi-structured interviews and presents an integrative framework to foster supply chain resilience and sustainability. Finally, Section 5 summarizes the most important insights and outlines theoretical and practical implications, as well as a future research agenda.

2. Theoretical background

2.1 COVID-19 and sustainable supply chain resilience

The disruptive effect of COVID-19 has severely impacted the global economy and paralyzed several supply chains (Belhadi *et al.*, 2020, 2021). According to El Baz and Ruel (2021), more

than 94% of the top 1,000 companies have been negatively affected by the outbreak. The impact of COVID-19 varies between business sectors because of differences in their supply and demand patterns. For instance, companies that depend heavily on movement, such as travel, were the first to be affected. Belhadi *et al.* (2020, 2021) indicated that economic losses in automobile and airline supply chains due to COVID-19 likely exceeded 520 and 375 billion USD, respectively, during the period March 2020 to March 2021. This devastating economic impact was largely caused by aspects of so-called "supply" and "demand" shocks. Supply-side shock was due to the closure of non-essential industries and workers not being able to carry out their activities at home (Sarkis, 2020). Demand side shock was caused by people's immediate response to the pandemic, such as panic buying and reduced demand for goods or services whose consumption was likely to place people at risk of infection, such as transportation and tourism.

With respect to social effects, the literature highlights the serious challenges and severe impact of the COVID-19 pandemic on the job security of thousands of workers around the world (Belhadi *et al.*, 2020, 2021; El Baz and Ruel, 2021). Indeed, the economic impact of the pandemic has compelled (or provided excuses for) companies to reduce their number of employees and the level of their social contributions and cancel their ongoing socially-related investments (Sarkis, 2020; Hoek, 2020). Further, disruptions generated by vital supply chains such as those in the agriculture, food, and pharmaceutical sectors threaten the food and health security of millions of people around the world (Hoek, 2020). This calls for special consideration of social sustainability when developing response strategies.

In terms of environmental impacts, the observed effects of the pandemic are rather controversial (Sarkis, 2020). Several studies have highlighted the positive short-term impact of a slowdown in manufacturing activities via the reduction of toxic gas emissions and restoration of ecological systems (Sharma, 2020). However, other studies have emphasized many challenges in the medium and long-term, such as the crisis rebound effect, where society's recovery activities will exclusively focus on economic and social sustainability (Sarkis, 2020), causing infectious and plastic waste accumulation issues (Belhadi *et al.*, 2020, 2021).

2.2 Theories of risks and resilience in sustainable supply chains

Current global supply chains are experiencing increased exposure to risk at different levels (Ghadimi *et al.*, 2019). According to Scheibe and Blackhurst (2017), many supply chain trends and efficiency-focused activities expose supply chains to increased risk and potential spread of disruption. These trends can increase the coupling and interdependence of firms within supply chains. The first trend increasing the exposure of global chains to risk is the recent increased push for integration in SCM (Lavastre *et al.*, 2012). In fact, integrated global supply chains are characterized by close links between a focal firm and their upstream suppliers and downstream customers. Although this high level of interconnection can enhance flexibility, cost reduction, quality improvement, and reduce lead-time, this cannot be achieved without some cost (Belhadi *et al.*, 2020, 2021). Indeed, outsourcing of their core business activity leads firms to increasingly lose visibility of the entire supply chain and operations. In addition, the intensive use of approaches such as "lean," "Six Sigma," and "just in time" reduces the robustness and resilience of systems while seeking to reduce waste, stock, and variability; and eradicate safety capacity, lead time, and stock (McDermott *et al.*, 2021). Overall, it is noticeable that these diverse sources of vulnerability (increased integration of the supply chain and introduction of systems such as lean/just in time) weaken supply chain systems and make them highly sensitive to uncertainties arising from the surrounding environment (Chowdhury and Quaddus, 2016; Kamalahmadi and Parast, 2016). It is in this environment that the concept of supply chain resilience has emerged as an integrated system for the identification, management, control, and mitigation of supply chain risk.

Belhadi *et al.* (2020, 2021) and Hendry (2019) have defined supply chain resilience as the ability of a supply chain system to prevent and absorb change and restore the previous level of performance after a disruptive event. These definitions build on the broader resilience theory that emanates from a range of contexts including engineering resilience, ecological resilience, and adaptive resilience (Hendry, 2019). This broader resilience theory stipulates that ensuring the continuous operation of a supply chain in the presence of disruption may require strong action on three levels: readiness (proactive, pre-disruption), response (reactive, within-disruption), and recovery (proactive and reactive, post-disruption). This definition has found a rationale in earlier literature that emphasizes the notion of an equilibrium state that should be regained after an unexpected disruptive event.

The growing interest in consideration of sustainability in the design of resilient supply chains is strongly evident in several studies (Fahimnia and Jabbarzadeh, 2016). According to Jabbarzadeh *et al.* (2018), the combination of sustainability and resilience is shaping the future of SCM under uncertainty through the meticulous establishment of trade-offs in the principles and practice of sustainability and resilience in supply chains. Managers can suitability implement these trade-offs by observing the strategic orientation of a supply chain and considering the needs of their supply chain partners. Theoretical studies have mainly been interested in embedding the TBL—that is, the economic, social, and ecological model—in the design of resilient supply chains (Ghadimi *et al.*, 2019). Further, Touboulic and Walker (2015) highlighted that the most commonly used theory to describe the sustainability issue in supply chain development is the resource-based view (RBV), including the natural resource-based view (NRBV). The RBV of supply chain design implies that a competitive advantage can be gained through unique sustainability-related capabilities in supply chains; this describes a classic view of business performance and power. Markley and Davis (2007) argued that the NRBV is highly compatible with the TBL. This idea finds support in the study of Carter *et al.* (2019), who described how supply chains could take advantage of their resources to generate a sustainable competitive advantage and develop resilience in an uncertain environment.

2.3 Digital capabilities of Industry 4.0 technologies

Industry 4.0 (I4.0) refers to the fourth advancement in the "industrial revolution" of industrial systems (Xu *et al.*, 2018). This industrial revolution involves numerous cutting-edge technological advancements such as big data analytics, IoT, cyber-physical systems, blockchain, and artificial intelligence, which integrate digitalization and automation of the supply chain environment (Manavalan and Jayakrishna, 2019; Dhamija and Bag, 2020; Mastos *et al.*, 2020). Moreover, I4.0 employs a smart manufacturing networking concept, where machines and products operate together without human intervention. To conceptualize the digital capabilities of I4.0 technologies, we adopt the dynamic capability view (DCV) introduced by Teece *et al.* (1997), which prescribes that a firm can sense and adapt to changes in the external environment that will be key to sustainability and competitiveness. Hence, dynamic capabilities promote the continuous renovation of proficient resources, supporting organizations to integrate, build, and reconfigure both internal and external competencies to address potential disruptions in the environment (Teece, 2014). The use of DCV by I4.0 has become increasingly popular since 2012. Beske (2012) and Beske *et al.* (2014) were among the first authors who dealt with dynamic capabilities and SCM. Beske (2012) claimed the general positive synergies of the two concepts, while Beske *et al.* (2014) studied the effects in the food industry. Seifert (2015) investigated the application of capabilities that lead to competitive advantage using a specific case study. The author argued that the behavior of any supply chain is governed by its routines and processes, and that capabilities for information transparency and integration are fundamental in companies' environmental sustainability efforts.

Several attempts to offer some clarity on I4.0 capabilities have recently appeared in the literature. For instance, Witschel *et al.* (2019) employed the conceptualization of Teece (2014) to highlight three categories of I4.0 dynamic capabilities: sensing, seizing, and transforming, where:

(1) Digital sensing capability is the ability of I4.0 technologies to enable a given organization to recognize threats and opportunities that may arise.

(2) Digital seizing capability represents the ability of I4.0 technologies to enable an organization to mobilize required resources to address "sensed" threats and opportunities. I4.0 technologies could address the need to make both timely and accurate decisions (Vanpoucke *et al.*, 2014).

(3) Digital transforming capabilities include reconfiguring both intangible and tangible assets of an organization. This is where I4.0 technologies could support innovation and operational efficiency to respond to threats and challenges within the business environment.

2.4 Circular economy principles

The CE is proposed as a practical approach to the sustainable use of finite natural resources through an increase in resource use efficiency to contribute to an equilibrium between the economy, environment, and society (Aranda-Usón *et al.*, 2020). The CE has replaced traditional industrial practices and introduced new closed-loop economic models entirely centered on balancing the economic, environmental, and societal impacts of products and processes (Elia *et al.*, 2017). Several subsets and principles of CE, such as remanufacturing, repurposing, and recycling, are considered worldwide as powerful tools in supply chains for enhancing longevity of the resources, resulting in both sustainability and resilience of supply chains (Bag *et al.*, 2019).

Some authors (Mastos *et al.*, 2021) have started analyzing relationships between I4.0 solutions and circular SCM highlighting the positive effect of these solutions on circular principles.

2.5 Conceptual framework of the study

There has been strong interest in investigating the link between supply chain sustainability and management of environmental and social issues (TBL) through a NRBV theoretical lens; and the design of resilient supply chains using broad design theory. The digital capabilities of I4.0 along with CE principles may underpin this integration. Figure 1 depicts the basic conceptual framework.

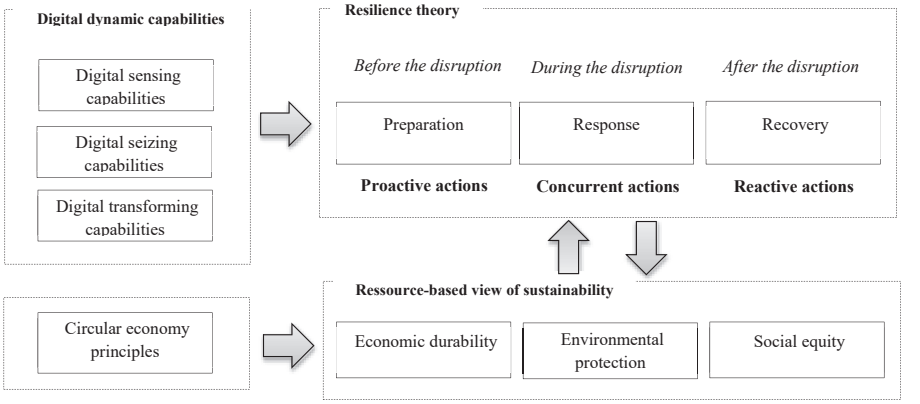


Figure 1.
Conceptual framework of the study

The perspective of the proposed framework for conducting this research fits well with discussion in the sustainability and resilience literature arguing for the need to mobilize the digital capabilities of I4.0 alongside CE principles to effectively recover and learn from a disruptive event while addressing economic, social, and environmental issues related to the disruption (Carter *et al.*, 2019). This use of the DCV, TBL, RBV, circular, and resilience theories results in a "theory matching" approach, as adopted by Hendry (2019). In fact, this solid theoretical approach reinforces the thoroughness and efficiency of this research by including external validity in the design. Moreover, the research approach is highly suitable in the context of the COVID-19 pandemic and uncertain environments in general, where there is fuzziness in how the marketplace will change in the short and long term.

3. Methodology

To address the research questions presented in Section 1, empirical qualitative data are required. Currently, there is no empirical evidence on how the COVID-19 crisis will transform supply chains. The present study is one of the earliest efforts to investigate the "new normal" of supply chains. Thus, an exploratory qualitative method is more appropriate at this stage. According to Yin (2009), qualitative research helps to develop novel insights and in-depth analysis of complex, contemporary, and under-researched topics. Following these arguments, a series of semi-structured interviews were performed with supply chain practitioners over three months based on interview guideline presented in Appendix. We conducted our study following guidelines proposed in the literature to ensure the reliability and validity of our findings (Eisenhardt, 1989; Voss *et al.*, 2002; Yin, 2009). In this context, we have taken into consideration in our study the four precautionary actions proposed by Gibbert *et al.* (2008):

(1) Ensuring internal validity by assessing the causal relationships between digital technologies, circular economy, resilience and sustainability across the existing literature, ensuring construct validity through using a panel of experts to develop and structure questions.

(2) Ensuring external validity through using participants from different sectors to perform a cross-case analysis.

(3) Achieving reliability through the semi-structured interview protocol.

The research questions were answered by applying within-case and cross-case analyses (Eisenhardt, 1989; Miles and Huberman, 1994). Within-case analysis was done by developing a report for each case based on the constructs used in the data collection (Eisenhardt, 1989). A cross-case analysis was then performed to identify common clusters, and patterns, categorizing data as they were collected (Miles and Huberman, 1994). Then, the evidence and results are compared with those in the literature to increase external validity (Yin, 2003).

The unit of analysis used in this study is the company; thus, each case represents a company. We have selected companies that operate in different sectors to ensure that our results are not related to a specific sector and allow alternative explanations to emerge (Eisenhardt and Graebner, 2007). In addition, we have selected companies that have global supply chains. Global presence increases disruptions risk and supply chain fragilities (Belhadi *et al.*, 2020, 2021). Hence, analyzing these companies allowed us to identify cases that "will most likely illuminate" our research questions (Yin, 2009). Figure 2 presents an overview of the adopted methodology, identifying major phases related to the structure of how to collect, structure, and analyze data from these semi-structured interviews.

To ensure the quality, validity, and robustness of the study results, interviewees were selected based on three criteria:

(1) Position and responsibilities: All our selected practitioners are senior executives/managers in SCM.

(2) Experience and knowledge: All our selected practitioners had at least eight years of experience in the field of SCM.

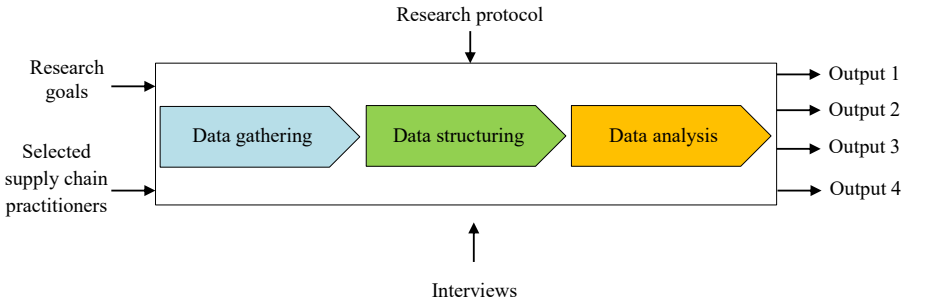
(3) Heterogeneity: We deliberately chose practitioners from different geographical locations, industries, and organizations of different sizes to represent a variety of perspectives, required to achieve a holistic view.

(4) Readiness and time to participate: The interviewees were not remunerated for their participation.

Potential interview participants were identified via different approaches, including through the professional network built over the last decade, contacting known practitioners through LinkedIn, and finally by employing the snowball technique. Based on recommendations for purposive sampling and data saturation (Glaser and Strauss, 2017), a total of 20 interviews were targeted. Data saturation was achieved at the fifteenth interview as no new viewpoints emerged from the interviews. Table 1 presents a general profile of the participants. Participants were anonymized to protect their privacy and each received a unique identity (ID) code. The interviews lasted 60–80 min and were conducted via telephone because of lockdown measures and location constraints. Studies have shown that there is no significant difference between telephone and face-to-face interviews (Kirchherr and Charles, 2018). For data analysis purposes, all interviews were fully recorded and transcribed.

The data were analyzed using the grounded theory approach as an inductive and iterative process that involves coding and grouping of passages into different categories to categorize interviewee responses and find unique insights from different perspectives (Strauss and Corbin, 1990). In this context, all interview transcripts were analyzed and coded using NVivo software. Our coding is deductive in nature, as it is based on the initial theoretical elements developed in Section 2. Based on this, we developed a code book as suggested by Boyatzis (1998). The priori codes are related to the four areas (outputs) presented in Figure 2.

We began our analysis with first-order coding using a line-by-line approach to identify segments of the text that represented a fundamental concept or idea in relation to the research questions. Further, we also performed a step of axial coding to yield more abstracts, as well as



Output 1: Impact of COVID-19 on SCM

Output 2: Measures taken to mitigate the different effects of the COVID-19 crisis

Output 3: Future changes and their impacts on supply chain performance

Outputs 4: Impact of digital technologies and CE practices, as dynamic capabilities, in transforming supply chains for more sustainability and resilience

Figure 2.
Methodology overview

ID	Interviewee position	Years of experience	Sector
E1	Chief executive officer	23	Consultancy
E2	Director	18	Transport and logistics
E3	Head of sales	9	Retail and distribution industry
E4	Supply chain manager	20	Aeronautic industry
E5	Factory manager	26	Automotive
E6	General manager	21	Food industry
E7	Vice president	16	Mechanical industry
E8	Sales-marketing manager	13	Retail and distribution industry
E9	Plant manager	15	Chemical manufacturing
E10	Director of operations	8	Aircraft industry
E11	Engineering manager	10	Textile industry
E12	Project manager	14	Software industry
E13	Supply chain manager	11	Automotive industry
E14	Production manager	9	Electronics industry
E15	General director	19	Pharmaceutical industry

Table 1.
Profiles of the experts interviewed

remove and combine codes (Strauss and Corbin, 1990). At this step, we aimed to connect our inductive codes to the determined constructs collected from the literature (Section 2), such as the impacts of COVID-19 on supply chains, short- and medium-to long-term measures taken to mitigate the different effects of the pandemic and the potential transformations and their impact on supply chain sustainability and resilience.

To ensure the validity and reliability of this coding process, all transcripts were categorized by two researchers (Miles *et al.*, 2018). The categories identified by the two researchers were then compared and revised to achieve convergence in the categorization process. This resulted in 45 codes in eight sub-categories. These sub-categories were subsequently grouped into four main categories: impact of COVID-19 on SCM; measures taken to mitigate the different effects of the COVID-19 crisis; future changes and their impacts on supply chain performance, and impact of digital technologies and circular economy principles on supply chain resilience and sustainability.

4. Results and discussion

The key findings from the interviews are presented and discussed in three sub-sections. The first deals with the challenges and opportunities for digitalization magnified by different impacts of the COVID-19 pandemic on supply chain resilience and sustainability, while the second presents measures taken by organizations to mitigate the various effects of the COVID-19 crisis and discusses future transformations and their impacts on supply chain performance. The third section presents a framework to foster supply chain resilience and sustainability based on the study findings.

4.1 Sensing challenges and opportunities for digitalization

A recent study by the United Nations showed that COVID-19 was impacting virtually all of the Sustainable Development Goals (Karunathilake, 2020). According to most respondents, COVID-19 was affecting both supply and demand sides, creating multiple challenges for supply chain members. This finding is aligned with the results of an international survey performed by the Chartered Institute of Procurement and Supply, which found that more than 86% of supply chains had been impacted by the COVID-19 pandemic (Remko, 2020).

However, some responses from managers interviewed for the current study revealed that not all organizations had been affected equally by the COVID-19 crisis. While some industries

had seen a strong increase in demand, others had seen a decline in demand. For example, Respondent E13 said that, "We have already been impacted by coronavirus. There is a fast reduction in demand for equipment and accessories caused by reduced mobility and various lockdown measures." In contrast, Interviewee E3 reported:

> The impact of COVID-19 is already visible. We see growing demand for our products as a consequence of panic buying. Our centralized strategy, flexibility and inventory control and technologies have helped us to be robust and to prevent product shortages.

Yet other organizations had been forced to shut down or provisionally suspend their operations due to many factors. In this context, Interviewee E4 reported, "COVID-19 has caused the suspension of our assembly line because we can't get parts from our suppliers in Asia." Similarly, Interviewee E14 noted:

> We have shut down more than 50% of our factories in the world and we are not functioning at full capacity in the other factories. Our industry is very labor intensive and depends on highly qualified employees, making us vulnerable to employee absenteeism.

The analysis of the interview responses revealed a critical factor in the interruption of the supply chain; that is, is cost-killing strategies. To achieve cost reductions, organizations adopt many strategies, including "just in time", outsourcing, and offshoring. These strategies make supply chains more profitable and efficient but have also significantly increased supply chain risk. Many complex global supply chains have failed to guarantee a reliable supply. The majority of the interviewees recognized that they did not have any idea of their Tier 2 or Tier 3 suppliers. In addition, some supply chains are highly concentrated in a single location. In this context, Interviewee E15 stated:

> In our company, all raw materials and active ingredients are imported from China and that creates vulnerability. I think that there is a need to diversify our operations and implement a multi-sourcing strategy . . . this is a very complex situation and will take time.

Similarly, Ivanov (2020b) indicated that being globalized and lean, the supply chains of many organizations have become particularly prone to coronavirus outbreaks. Remko (2020) indicated that making SCM decisions on the basis of supplier reduction for better procurement negotiation, and creating specialized plants to achieve economies of scale, increase the risk of disruption.

Several interviewees shared that they had experienced insufficient liquidity. For example, Interviewee E11 noted that:

> Buyers are asking to cancel their shipment of clothes that have already been produced, and deferring payments. We need the cash flow to pay our raw material suppliers. We were not prepared to manage this financial distress, which places our company at economic risk.

It is very clear that COVID-19 has revealed vulnerability in many supply chains. The various impacts of this vulnerability are easily seen in the economic and financial sides of supply chains. However, it is important to also consider the hidden effects that the COVID-19 crisis may be having on environmental and social issues related to supply chains. Disruptions in global supply chains have exposed employees to the risk of contracting the coronavirus, and generated chronic stress and significant job insecurity for many workers.

Data from the interviews indicate that some organizations were able to keep and pay their employees during interruptions to their operations, while many others had to lay off workers or reduce staff working hours temporarily or permanently. Interviewees also reported many changes in consumer behavior that had impacted the traditional offline business model. Demand has moved to online channels as many consumers try to avoid crowded places because of fear of infection. Interviewee E3 pointed out that, "We have signed an agreement

with the largest eCommerce player in Africa to ensure that our customers have access to our variety of products and can have them delivered directly to their homes." However, without effective intervention, this shift can substantially increase the use of packaging, urban congestion, and air pollution.

In terms of opportunities for improved supply chain resilience and sustainably, two interviewees explained the importance of digital technologies in their remaining operations during the COVID-19 outbreak. For example, Interviewee E8 stated that:

> Smart supply chain demand planning and forecasting tools have helped our organization to detect potential supply risks and consequently to take preemptive measures in collaboration with suppliers to ensure different products and daily necessities. These tools have helped us to notify supply networks and to move inventories from regional distribution centers to the local warehouses to be much closer to the customer.

Further, Interviewee E5 indicated that:

> During the COVID-19 crisis, advanced track and trace technologies have allowed our company to have acceptable control and visibility of supply chains by identifying the past and current location of products, delivery dates from suppliers and suppliers' manufacturing program and status.

In summary, organizations with well-developed digital capabilities are better prepared than others to efficiently mitigate the different impacts of supply chain disruptions. The benefits of transparency, collaboration, agility, and visibility for better supply chain resilience and sustainability are limited to organizations that are well on their way to digital transformation.

4.2 Actions to mitigate supply chain disruptions due to COVID-19

In response to the challenges as identified in the previous section, several efforts had been taken by interviewees to improve supply chain resilience and mitigate various risks. The analysis of the interview responses shows that actions taken to mitigate supply chain disruption from COVID-19 can be grouped into two categories:

(1) *Promotion of the health and wellbeing of employees:* All interviewees said that their organizations had put in place many protocols to protect their employees from contracting the virus. For example, interviewee E6 noted that:

> We have developed several actions including, but not limited to, the development of a hygiene program, education about COVID-19 symptoms and prevention, providing workers with protective equipment, and reducing physical distance by encouraging teleworking.

Interviewees also highlighted that many actions had been performed to actively monitor employees' morale and support their mental health and wellness. For example, E8 stated, "Our CEO [chief executive officer] encouraged, in an internal note, top management to listen to their teams and to establish communication channels with employees in order to support their mental health and emotional needs in these challenging times."

(2) *Stabilization of the supply chain:* Of the 15 respondents, 12 indicated that their organizations had created a response team to make rapid decisions to stabilize their supply chain. Interviewees E9 and E10 noted:

> We have established a COVID-19 response team that includes different functions, especially supply chain managers, supply chain analysts, production managers, procurement director, quality, health and safety, and an environmental systems manager to make rapid and accurate decisions in collaboration with our different stakeholders.

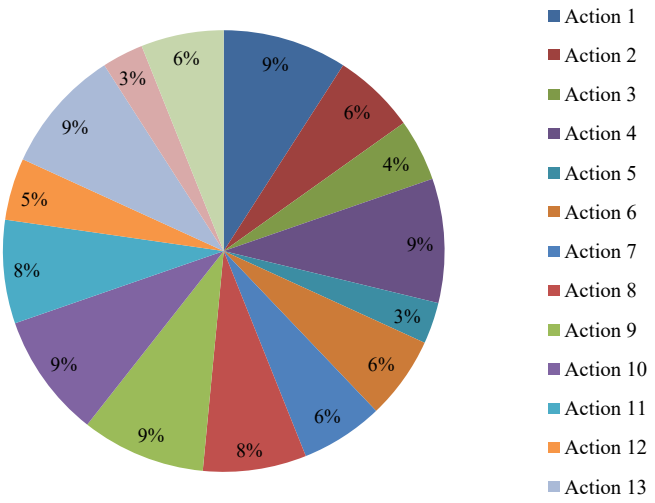
This finding supports the recommendation of De Sousa Jabbour *et al.* (2020) to form a response team made up of supply chain members to collect data and identify problems, opportunities to innovate, and solutions to manage the continuity of supply.

Table 2 provides an overview of the different actions taken by these response teams, according to our interviewees.

Figure 3 shows that Actions 1, 4, 9, 10, and 13 were each confirmed by six interviewees, representing 9% of participants. Actions 8 and 11 were each confirmed by five interviewees (8%). Actions 2, 5, 6, 7, and 15 were each confirmed by four interviewees (6%). Actions 3, and 12, and Actions 5 and 14 respectively were confirmed by three (4%) and two (3%) of the interviewees (see Figure 3). In addition, the analysis in Table 2 shows that actions developed by organizations to mitigate supply chain disruption from COVID-19 focused on the sourcing, manufacturing, and supply chain points of view to ensure business continuity. The deployed efforts focused on mitigating supplier disruption, protecting workers' safety, confirming customer demand, and adjusting manufacturing capacity. However, these actions were

Label	Action	Interviewees
Action 1	Identifying existing inventory in the supply chain—particularly key items—and building an inventory plan to avoid disruptions and keep production running with efficiency based on ERP applications, cloud computing, and big data analytics . . .	E4; E5; E7; E10; E13; E15
Action 2	Mapping a list of critical components, determining the origin of supply, and finding backup suppliers for critical items	E4; E5; E10; E14
Action 3	Analyzing bills of materials and identifying elements that could cause production stoppages or delays based on ERP applications	E5; E7; E15
Action 4	Identifying, analyzing, and developing mitigation strategies (e.g. inventory relocation, design substitution, alternate sourcing) for different risks in supply and demand	E4; E6; E9; E10; E14; E15
Action 5	Making decisions by performing scenario simulations and using artificial intelligence and analytics techniques	E10; E13
Action 6	Communicating with all relevant stakeholders to co-develop plans and rapid solutions (e.g. managing the level of safety stock, working with suppliers to solve bottlenecks, finding alternative sources) by using cloud computing and ERP applications . . .	E5; E6; E9; E11
Action 7	Optimizing production and distribution capacity to satisfy demand (e.g. shifting production to alternative sites) based on simulation and big data analytics . . .	E3; E4; E7; E15
Action 8	Developing an effective strategy to gain priority from key suppliers and identifying new suppliers for critical components	E6; E9; E11; E13; E15
Action 9	Identifying and mitigating different risks in supply and demand based on digital technologies (simulation, big data analytics, 3D printing, digital twins . . .)	E2; E3; E4; E8; E10; E15
Action 10	Planning for mismatches in supply and demand by using different monitoring devices, such as RFIDs, GPS, wireless sensors, barcode scanners . . .	E4; E5; E7; E8; E11; E14
Action 11	Developing a system of metrics and key performance indicators to support operational control	E2; E5; E8; E9; E13
Action 12	Prioritizing and executing corrective and preventive actions	E5; E6; E15
Action 13	Enabling and supporting operations teams (e.g. procurement, manufacturing, logistics, quality, engineering) to safeguard immediate supply, and develop sustainable solutions	E4; E5; E6; E7; E10; E15
Action 14	Implementing digital SCM solutions and tools to trace supply chain visibility and for more transparency	E4; E13
Action 15	Managing cash and net working capital	E4; E5; E11; E15

Table 2.
Mitigating actions



Note(s): See Table 2

Figure 3.
Mitigating actions with interviewee classifications

naturally short-term tactics. Long-term strategies are required to improve supply chain resilience and guard against future supply chain disruptions.

The findings also indicate that this crisis has provided an excellent opportunity to implement more digital technologies in supply chain processes. Organizations are beginning to seize this opportunity to strengthen the resilience of their supply chains.

4.3 Changes and their impacts on supply chain resilience and sustainability

The COVID-19 pandemic is likely to accelerate the structural transformation of the global supply chain. Overall, the interviewees believed that fundamental changes were inevitable. For example, Interviewee E1 said, "I think that the COVID-19 pandemic will lead to a structural change in the global supply chain; however, this change will take time, effort, and investment to build greater supply chain resilience and sustainability." Similarly, Interviewee E4 noted, "The pandemic is a crisis moment, but this could catalyze efforts deployed by organizations to better analyze the vulnerabilities of their network supply to respond more effectively to future disruptions." This is consistent with the literature: according to Remko (2020), there is a need to explore new ways that can help supply chains to resist future global disruptions. Supply chain managers need to adopt new strategies and practices that lead to extra-resilient strategic supply chain approaches (De Sousa Jabbour *et al.*, 2020). The analysis of the interview response shows that future changes can be grouped into three categories as outlined below.

Diversification of supplier networks: The diversification of a logistics network is likely to be the "new normal". The majority of our interviewees agreed that diversification in supply chains and implementation of a multi-sourcing strategy will be important to ensure the viability and survival of organizations by minimizing the risk of future disruptions. For example, Respondent E15 indicated that, "organizations have realized the risk of relying on a single supplier or a single geography. The production of many products is concentrated in one country—sometimes in one city or one organization—and that makes supply chains extremely vulnerable."

In a survey of 1,142 firms conducted by DNV GL, 56% of respondents had faced supply chain disruption related to COVID-19. As a result, 57% were planning to diversify their supply chains to mitigate risks generated by single sourcing.

Identification, evaluation, and contraction with new suppliers is a long process. In this context, some interviewees indicated that blockchain technology offers access to verifiable and trusted information that can be used by organizations to quickly bring new suppliers on board. Further, Interviewee E13 indicated that, "supply chain concentration in countries with lower labor and production costs and environmental standards is a result of focusing on scale economies in manufacturing ... This is a big challenge that will take time to correct."

This finding is in agreement with earlier studies such as that of Zhu *et al.* (2020), which indicated that diversification efforts may take a long time and may not be favorable for some organizations. Practitioner E11 believed that, "governments must help organizations to diversify their supply chains and minimize the risk of sourcing from specific regions or countries." For example, Japan has provided an incentive program to encourage Japanese organizations to move production out of China and back to Japan or other countries (Bermingham *et al.*, 2020).

Localization of supply chains: In recent years, supply chains have become large, global, and integrated to minimize costs, reduce inventories, and benefit from economies of scale. However, these cost-cutting strategies can rapidly imperil a business. The majority of interviewed experts believed that over the next few years, we can anticipate a shift to micro supply chains to improve flexibility, sustainability, and resilience. For example, Interviewee E7 noted that, "organizations will try to build local resilience and reduce multi-stage and globalized supply chains. Value chains are likely to become more localized to boost resilience and sustainability. Micro supply chains are more secure, resilient, and less vulnerable". However, according to Nandi *et al.* (2020), the opportunity to localize sourcing depends on the presence of resources in each area.

Most experts agreed that digital technologies such as the IoT, industrial communication networks supported by big data, 3D printing, autonomous mobile robots, and collaborative robots could contribute to enabling localization, especially in developed countries. In addition, this shift may be an opportunity to promote sustainability transitions in the context of supply chains. Respondent E2 described how localization can contribute to achieving sustainability, as follows: "I think that localization of supply chains will have a positive impact on the environment by reducing the energy required for transport, storage, and shipping as a major emitter of greenhouse gases." In the same context, Interviewee E13 noted that: "additive manufacturing will help to produce components and modules anywhere in the supply chain contributing to reduce suppliers, transportation risks."

However, one interviewee indicated:

> Global supply chains continue to be necessary in order to ensure many raw materials sourcing at least until that circular economy replaces the current linear production systems. The materials recovered from products that have reached the end of their useful life can be an alternative and can be also used as feedstock for additive manufacturing.

Similarly, Interviewee E14 said, "I think that circular economy principles can reinforce localization capabilities." This finding supports the suggestion by Nandi *et al.* (2020) that CE practices have helped to reinforce materials and establish closed resource loops to enhance localization efforts.

Smart technologies: COVID-19 has uncovered many challenges in supply chains including complexity and uncertainty. Most interviewees (12 of 14) believed that the COVID-19 crisis will accelerate supply chain digital transformation. For example, Interviewee E12 noted, "Different supply chain players are looking to invest in digital solutions to move to a more flexible, fluid, and profitable supply chain." All the interviewees acknowledged the potential benefits of digital transformation in supply chains supported by artificial intelligence,

blockchain technology, big data, cloud technology, and the IoT. Practitioner E4 stated, "Automation and robotics will help organizations to reduce operation costs of onshore production and decrease the risk of dependence on humans." Similarly, Interviewee E12 indicated that:

> Machine learning, big data analytics, and cloud computing will help organizations to perform real-time scenario analysis, improve forecast accuracy, and suggest better allocation and replenishment strategies by extracting critical internal and external data at every step of the supply chain. This allows organizations to be in action rather than reaction.

Further, Interviewee E4 noted, "Several technologies including digital twin, blockchain and Internet of Things will provide supply chain players with visibility, precision and control of their supply chain. This enables real-time tracking and visibility to improve resilience, sustainability and responsiveness of supply chain." This was also noted by Interviewee E13: "These solutions allow firms to map and see the entire value chain and take appropriate actions to improve agility, sustainability, and collaboration between supply chain players to secure the supply chain in case of any risk." However, Respondent E11 indicated that, "The implementation of Industry 4.0 technologies requires data quality as well as a skilled workforce and financial resources. I think that policymakers and governments could support and accelerate supply chain digitalization."

Smart technologies seem to have a certain impact on environmental sustainability in the supply chain, improving CE efforts. E5, for instance, stated: "Smart sensors and RFID tags are helping us in identifying and tracking down components of the products which could be recycled and/or reused when the product reaches its end of life". This was also discussed by Interviewee E11; however, Respondent E11 highlighted how this kind of implementation could increase the cost of the final product and it is not so viable for small components and components subjected to mechanical and thermal stress.

Table 3 summarizes the impacts of the most common smart technologies on supply chain resilience and sustainability.

4.4 An integrative framework to foster supply chain resilience and sustainability

Based on our findings, we propose an integrative framework to improve supply chain resilience and sustainability. Figure 4 illustrates the proposed framework.

Four pillars are required to build supply chain resilience and sustainability: (1) agility and collaboration; (2) localization; (3) diversification; and (4) visibility and transparency. In this framework, agility and collaboration are considered as one pillar because agility is considered an element that includes velocity to react to new environmental conditions in the context of disruptions (Hohenstein *et al.*, 2015). The speed of reaction requires information sharing and collaboration to mitigate risks (Nandi *et al.*, 2020).

The four pillars are supported by a strong foundation of two key enablers: digital technologies and CE practices that are in interaction. Digital technologies can strengthen circular economy practices and consequently play an important role in transforming supply chains to achieve resilient and sustainable supply chains.

In addition, clearly defined governance and control mechanisms can produce specific recommendations, implement policies, and execute processes that contribute to preparing supply chain partners for future shocks and making networks more resilient and sustainable.

It is important to indicate that the impact of these two enablers has been confirmed by many respondents. The digitalization and circular economy principles can help to develop agility and collaboration, localization, diversification, visibility and transparency (see Tables 2 and 3). These pillars form dynamic capabilities to support organizations and their supply chains to counter different disruptions.

Smart technology	Impacts on supply chain resilience and sustainability	Source
Big data	Can help supply chain actors to perform better sale forecasts to optimize inventory levels and avoid the "bullwhip" effect, which saves resources	E3; E6; E8; E10; E15
	Can help organizations to monitor environmental indicators (e.g. CO_2 emissions, air pollutants)	E5; E7; E9
	Can aid in understanding environmental impacts on supply chains and consequently develop more precise environmental impact assessments	E1; E5; E10
	Can be used to promote ethical behavior among supply chain actors by providing higher transparency and traceability, which may positively influence commitment to sustainable business practices	E3; E8; E9
	Can assist in ensuring suppliers' cooperation in applying sustainable (social and environmental) practices	E1; E5; E11
	Can help in decision-making as it plays a key role in supply chain strategic and operational planning. In strategic planning, big data can aid in decisions regarding sourcing, network design, product design, and development. In operational planning, it can help improve forecasting, procurement, production, and logistics	E4; E9; E10; E12; E15
	Can help in the smart selection of environmentally friendly raw materials for production	E4; E7; E14
IoT	Can help to minimize delivery errors, waiting times, and damaged products. This helps reduce resource consumption and carbon emissions	E2; E3; E10; E15
	Can assist in improving resource utilization (e.g. energy, raw materials, employees) in supply chain processes	E4; E6; E9; E11
Blockchain technologies	Can assist in reducing product rework and recall because of its tracking capabilities	E2; E7; E9; E15
	Can help to improve supply chain transparency and traceability, and avoid unethical behavior	E2; E7; E12
	Can assist in governance disruption and information sharing including environmental and social aspects. It makes it easy to trace the footprint of products and reduce fraud	E2; E7; E8
	Can help to ensure trust among partners and smart-contract transactions, and reduce lead times	E2; E5; E6; E12
Digital twins	Can be used to model and simulate supply chains based on real-time data, allowing for complete end-to-end supply chain visibility	E4; E9; E13; E15
	Can be used in planning and real-time control decisions including prediction of demand spikes and supply shocks, and making recommendations on required actions to ensure preparedness and resiliency	E4; E5; E8; E13

Table 3.
Changes and their impacts on supply chain resilience and sustainability

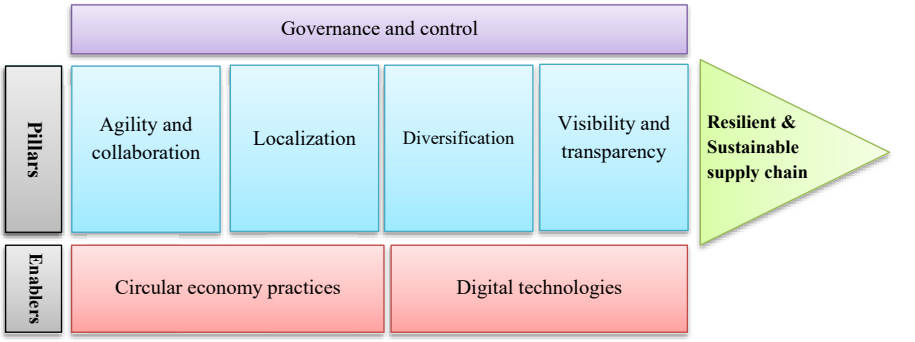


Figure 4.
Conceptual framework to foster supply chain resilience and sustainability

5. Conclusions

The COVID-19 outbreak has exposed supply chain fragility and shown that pandemic crises can seriously affect economies on a large scale. In this context, assessing COVID-19 impacts on supply chain performance, identifying the measures taken to mitigate the various effects of the pandemic, and exploring future supply chain transformation are very important elements to help supply chain decision-makers. This paper is an attempt to contribute to the supply chain resilience and sustainability literature and responds to calls from several academics for more studies in the context of the COVID-19 crisis (Ivanov, 2020a; Ivanov and Dolgui, 2021; Remko, 2020). Our study enriches the literature on supply chain resilience and sustainability. It also contributes to the literature on dynamic capabilities by highlighting the potential role of digital technologies in the sensing, seizing, and transforming of supply chains in the post-COVID-19 era. In this context, the NRBV and TBL are useful frameworks for better understanding the relationship between supply chain resilience, sustainability and organization resources.

This study has revealed five main challenges facing supply chains during the COVID-19 pandemic. These are uncertainty in demand and supply; supplier concentration in specific regions; globalized supply chains; less visibility in supply networks; and limited supplier capacity. This paper also outlines several mitigating actions for restoring supply chains, which focus on the promotion of the health and wellbeing of employees and supply chain stabilization. The future of the supply chain in a post-COVID world was also explored. To minimize the impacts of future disruptions, supply chain players can employ several strategies, including regionalization of the supply chain, diversification of the supply network, and acceleration of the use of smart technologies and CE practices to improve supply chain resilience and sustainability through visibility, connectivity, precision, and control in real-time.

From a management point of view, supply chain actors can objectively use our proposed theoretical framework as a roadmap to identify and develop the capabilities needed to improve supply chain resilience and sustainability. This study has the following implications for supply chain decision-makers:

(1) Supply chain players must rethink their strategies to be prepared for any future pandemic situation.

(2) Organizations should adopt and accelerate the use of smart technologies and automation to improve supply chain resilience, sustainability, and robustness through visibility, connectivity, precision, and control in real-time.

(3) Localization, diversification, and regionalization of the supply chain could be deployed by organizations to reduce supply chain vulnerability.

(4) The transition to a new normal will require collaboration and cooperation with governments and different stakeholders.

(5) Digitalization and CE practices as dynamic capabilities can help to sense, seize, and reconfigure supply chains by rendering them more resilient and sustainable.

(6) Organizations should take this crisis as an opportunity for experimentation, innovation, and improvement in the area of digitalization and CE to generate positive capabilities and ultimately a competitive advantage.

Finally, the findings of this study may help supply chain actors to develop and prioritize short- and long-term investment strategies to effectively build their dynamic capability to avoid disruptions in crises like the COVID-19 pandemic. Moreover, the results support benchmarking through sharing of best practices; organizations can integrate the different

capabilities discussed in this study into the processes of selection and auditing of their suppliers.

6. Limitations and future research

This research has some limitations that highlight potential directions for future research. First, as is common in qualitative research, our study is based on the subjective opinions of participants and the findings are dependent on researcher interpretations and biases. Second, although our study reached theoretical saturation, the small number of interviews could limit the generalizability of our findings. Consequently, further empirical studies are required to validate our research findings. These studies should focus on the adoption of digital technologies, CE practices, localization, and diversification of supply chains, to contribute to enhancing the "3Rs" (responsiveness, resilience, and restoration) during a crisis. Further studies should focus on best practices and mitigating actions for restoring manufacturing and service capacity in highly complex and uncertain scenarios.

References

Aranda-Usón, A., Portillo-Tarragona, P., Scarpellini, S. and Llena-Macarulla, F. (2020), "The progressive adoption of a circular economy by businesses for cleaner production: an approach from a regional study in Spain", *Journal of Cleaner Production*, Vol. 247, doi: 10.1016/j.jclepro.2019.119648.

Bag, S., Gupta, S. and Foropon, C. (2019), "Examining the role of dynamic remanufacturing capability on supply chain resilience in circular economy", *Management Decision*, Vol. 57 No. 4, pp. 863-885.

Bastas, A. and Garza-Reyes, J.A. (2022), "Impact of the COVID-19 pandemic on manufacturing operations and supply chain resilience: effects and response strategies", *Journal of Manufacturing Technology Management*, Vol. 33 No. 5, pp. 962-985, doi: 10.1108/JMTM-09-2021-0357.

Belhadi, A., Kamble, S., Jabbour, C.J.C., Gunasekaran, A., Ndubisi, N.O. and Venkatesh, M. (2021), "Manufacturing and service supply chain resilience to the COVID-19 outbreak: lessons learned from the automobile and airline industries", *Technological Forecasting and Social Change*, Vol. 163, 120447, doi: 10.1016/j.techfore.2020.120447.

Belhadi, A., Kamble, S.S., Khan, S.A.R., Touriki, F.E. and Kumar, D.M. (2020), "Infectious waste management strategy during COVID-19 pandemic in Africa: an integrated decision-making framework for selecting sustainable technologies", *Environmental Management*, Vol. 66, pp. 1085-1104.

Bermingham, F., Magnier, M. and Leng, S. (2020), "Coronavirus: China faces fight to hang onto foreign manufacturers as US, Japan, EU make COVID-19 exit plans. South China Morning Post", available at: https://www.scmp.com/economy/china-economy/article/3081415/coron avirus-china-faces-fight-hang-forei gn-manuf actur ers-us.

Beroe (2020), "Latest Insights from Beroe", available at: https://www.beroeinc.com/insights/ (accessed 18 June 2021).

Beske, P. (2012), "Dynamic capabilities and sustainable supply chain management", *International Journal of Physical Distribution and Logistics Management*, Vol. 42 No. 4, pp. 372-387.

Beske, P., Land, A. and Seuring, S. (2014), "Sustainable supply chain management practices and dynamic capabilities in the food industry: a critical analysis of the literature", *International Journal of Production Economics*, Vol. 152, pp. 131-143.

Boyatzis, R.E. (1998), *Transforming Qualitative Information: Thematic Analysis and code Development*, SAGE Publications, Thousand Oaks.

Carter, C.R., Hatton, M.R., Wu, C. and Chen, X. (2019), "Sustainable supply chain management: continuing evolution and future directions", *International Journal of Physical Distribution and Logistics Management*, Vol. 50 No. 1, pp. 122-146.

Cavalcante, I.M., Frazzon, E.M., Forcellini, F.A. and Ivanov, D. (2019), "A supervised machine learning approach to data-driven simulation of resilient supplier selection in digital manufacturing", *International Journal of Information Management*, Vol. 49, pp. 86-97.

Chaouni Benabdellah, A., Zekhnini, K. and Cherrafi, A. (2021), "Sustainable and resilience improvement through the design for circular digital supply chain", *IFIP International Conference on Advances in Production Management Systems*, Cham, Springer, pp. 550-559.

Cherrafi, A., Garza-Reyes, J.A., Kumar, V., Mishra, N., Ghobadian, A. and Elfezazi, S. (2018), "Lean, green practices and process innovation: a model for green supply chain performance", *International Journal of Production Economics*, Vol. 206, pp. 79-92.

Chowdhury, M.M.H. and Quaddus, M. (2016), "Supply chain readiness, response and recovery for resilience", *Supply Chain Management: An International Journal*, Vol. 21 No. 6, pp. 709-731.

Chowdhury, M.T., Sarkar, A., Saha, P.K. and Anik, R.H. (2020), "Enhancing supply resilience in the COVID-19 pandemic: a case study on beauty and personal care retailers", *Modern Supply Chain Research and Applications*, Vol. 2 No. 3, pp. 143-159.

De Sousa Jabbour, A.B.L., Jabbour, C.J.C., Hingley, M., Vilalta-Perdomo, E.L., Ramsden, G. and Twigg, D. (2020), "Sustainability of supply chains in the wake of the coronavirus (COVID-19/SARS-CoV-2) pandemic: lessons and trends", *Modern Supply Chain Research and Applications*, Vol. 2 No. 3, pp. 117-122, doi: 10.1108/MSCRA-05-2020-0011.

Dhamija, P. and Bag, S. (2020), "Role of artificial intelligence in operations environment: a review and bibliometric analysis", *The TQM Journal*, Vol. 32 No. 4, pp. 869-896.

Eisenhardt, K.M. (1989), "Building theories from case study research", *Academy of Management Review*, Vol. 14 No. 4, pp. 532-550.

Eisenhardt, K.M. and Graebner, M.E. (2007), "Theory building from cases: opportunities and challenges", *Academy of Management Journal*, Vol. 50 No. 1, pp. 25-32.

Eisenhardt, K.M. and Martin, J.A. (2000), "Dynamic capabilities: what are they?", *Strategic Management Journal*, Vol. 21 Nos 10-11, pp. 1105-1121.

El Baz, J. and Ruel, S. (2021), "Can supply chain risk management practices mitigate the disruption impacts on supply chains' resilience and robustness? Evidence from an empirical survey in a COVID-19 outbreak era", *International Journal of Production Economics*, Vol. 233, 107972, doi: 10.1016/j.ijpe.2020.107972.

Elia, V., Gnoni, M.G. and Tornese, F. (2017), "Measuring circular economy strategies through index methods: a critical analysis", *Journal of Cleaner Production*, Vol. 142 No. 4, pp. 2741-2751.

Fahimnia, B. and Jabbarzadeh, A. (2016), "Marrying supply chain sustainability and resilience: a match made in heaven", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 91, pp. 306-324.

Fortune (2020), available at: https://fortune.com/2020/02/21/fortune-1000-coronavirus-china-supply-chain-impact/ (accessed 1 September 2021).

Frederico, G.F., Kumar, V., Garza-Reyes, J.A., Kumar, A. and Agrawal, R. (2021), "Impact of I4.0 technologies and their interoperability on performance: future pathways for supply chain resilience post-COVID-19", *The International Journal of Logistics Management*, Vol. ahead-of-print No. ahead-of-print, doi: 10.1108/IJLM-03-2021-0181.

Garza-Reyes, J.A. (2015), "Lean and green–a systematic review of the state-of-the-art literature", *Journal of Cleaner Production*, Vol. 102, pp. 18-29.

Ghadimi, P., Wang, C. and Lim, M.K. (2019), "Sustainable supply chain modeling and analysis: past debate, present problems and future challenges", *Resources, Conservation and Recycling*, Vol. 140, pp. 72-84.

Gibbert, M., Ruigrok, W. and Wicki, B. (2008), "What passes as a rigorous case study?", *Strategic Management Journal*, Vol. 29 No. 13, pp. 1465-1474.

Glaser, B.G. and Strauss, A.L. (2017), "Theoretical sampling", *in Sociological Methods*, Routledge, pp. 105-114.

Hendry, L.C. (2019), "Local food supply chain resilience to constitutional change: the Brexit effect", *International Journal of Operations and Production Management*, Vol. 39 No. 3, pp. 429-453.

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

Hohenstein, N.-O., Feisel, E., Hartmann, E. and Giunipero, L. (2015), "Research on the phenomenon of supply chain resilience: a systematic review and paths for further investigation", *International Journal of Physical Distribution and Logistics Management*, Vol. 45 Nos 1-2, pp. 90-117, doi: 10.1108/IJPDLM-05-2013-0128.

International Monetary Fund (2020), "The great lockdown: worst economic downturn since the great depression", available at: https://blogs.imf.org/2020/04/14/the-great-lockdown-worst-economicdownturn-since-the-great-depression/ (accessed 4 May 2021).

Ivanov, D. (2020a), "Predicting the impact of epidemic outbreaks on the global supply chains: a simulation-based analysis on the example of coronavirus (COVID-19/SARSCoV-2) case", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 136, 101922, doi: 10.1016/j.tre.2020.101922.

Ivanov, D. (2020b), "Viable supply chain model: integrating agility, resilience and sustainability perspectives—lessons from and thinking beyond the COVID-19 pandemic", *Annals of Operations Research*, pp. 1-21.

Ivanov, D. and Dolgui, A. (2020), "Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak", *International Journal of Production Research*, Vol. 58 No. 10, pp. 2904-2915.

Ivanov, D. and Dolgui, A. (2021), "OR-methods for coping with the ripple effect in supply chains during COVID-19 pandemic: managerial insights and research implications", *International Journal of Production Economics*, Vol. 232, 107921.

Jabbarzadeh, A., Fahimnia, B. and Sabouhi, F. (2018), "Resilient and sustainable supply chain design: sustainability analysis under disruption risks", *International Journal of Production Research*, Vol. 56 No. 17, pp. 5945-5968.

Joshi, S. and Sharma, M. (2022), "Digital technologies (DT) adoption in agri-food supply chains amidst COVID-19: an approach towards food security concerns in developing countries", *Journal of Global Operations and Strategic Sourcing*, Vol. 15 No. 2, pp. 262-282, doi: 10.1108/JGOSS-02-2021-0014.

Kamalahmadi, M. and Parast, M.M. (2016), "A review of the literature on the principles of enterprise and supply chain resilience: major findings and directions for future research", *International Journal of Production Economics*, Vol. 171, pp. 116-133.

Karmaker, C.L., Ahmed, T., Ahmed, S., Ali, S.M., Moktadir, M.A. and Kabir, G. (2020), "Improving supply chain sustainability in the context of COVID-19 pandemic in an emerging economy: exploring drivers using an integrated model", *Sustainable Production and Consumption*, Vol. 26, pp. 411-427.

Karunathilake, K. (2020), "Positive and negative impacts of COVID-19, an analysis with special reference to challenges on the supply chain in South Asian countries", *Journal of Social and Economic Development*, Vol. 23, pp. 568-581.

Khanuja, A. and Jain, R.K. (2021), "The conceptual framework on integrated flexibility: an evolution to data-driven supply chain management", *The TQM Journal*, Vol. ahead-of-print No. ahead-of-print, doi: 10.1108/TQM-03-2020-0045.

Kirchherr, J. and Charles, K. (2018), "Enhancing the sample diversity of snowball samples: recommendations from a research project on anti-dam movements in Southeast Asia", *PloS One*, Vol. 13 No. 8, e0201710.

Lavastre, O., Gunasekaran, A. and Spalanzani, A. (2012), "Supply chain risk management in French companies", *Decision Support Systems*, Vol. 52 No. 4, pp. 828-838.

Linton, T. and Vakil, B. (2020), "Coronavirus is proving we need more resilient supply chains", *Harvard Business Review*, available at: https://hbr.org/2020/03/coronavirus-is-proving-that-weneed- more-resilient-supply-chains (accessed 20 November 2020).

Manavalan, E. and Jayakrishna, K. (2019), "A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements", *Computers and Industrial Engineering*, Vol. 127, pp. 925-953.

Markley, M.J. and Davis, L. (2007), "Exploring future competitive advantage through sustainable supply chains", *International Journal of Physical Distribution and Logistics Management*, Vol. 37 No. 9, pp. 763-774.

Mastos, T.D., Nizamis, A., Vafeiadis, T., Alexopoulos, N., Ntinas, C., Gkortzis, D. and Tzovaras, D. (2020), "Industry 4.0 sustainable supply chains: an application of an IoT enabled scrap metal management solution", *Journal of Cleaner Production*, Vol. 269, pp. 122-127.

Mastos, T.D., Nizamis, A., Terzi, S., Gkortzis, D., Papadopoulos, A., Tsagkalidis, N. and Tzovaras, D. (2021), "Introducing an application of an industry 4.0 solution for circular supply chain management", *Journal of Cleaner Production*, Vol. 300, 126886.

McDermott, O., Antony, J. and Douglas, J. (2021), "Exploring the use of operational excellence methodologies in the era of COVID-19: perspectives from leading academics and practitioners", *The TQM Journal*, Vol. 33 No. 8, pp. 1647-1665.

Miles, M.B. and Huberman, A.M. (1994), *Qualitative Data Analysis – An Expanded Source Book*, Sage Publications, Thousand Oaks, CA.

Miles, M.B., Huberman, A.M. and Saldana, J. (2018), *Qualitative Data Analysis: A Methods Sourcebook*, Sage Publications, Thousand Oaks, CA.

Nandi, S., Sarkis, J., Hervani, A. and Helms, M. (2020), "Do blockchain and circular economy practices improve post COVID-19 supply chains? A resource-based and resource dependence perspective", *Industrial Management and Data Systems*, Vol. 121 No. 2, pp. 333-363.

Okorie, O., Ramesh, S., Charnley, F., Patsavellas, J., Widdifield, D. and Salonitis, K. (2020), "Manufacturing in the time of COVID-19: an assessment of barriers and enablers", *IEEE Engineering Management Review*, Vol. 48 No. 3, pp. 167-175.

Paul, S.K. and Chowdhury, P. (2020), "A production recovery plan in manufacturing supply chains for a high-demand item during COVID-19", *International Journal of Physical Distribution and Logistics Management*, Vol. 51 No. 2, pp. 104-125.

Paul, S.K., Moktadir, MdA. and Ahsan, K. (2021), "Key supply chain strategies for the post-COVID-19 era: implications for resilience and sustainability", *The International Journal of Logistics Management*. doi: 10.1108/IJLM-04-2021-0238.

Ralston, P. and Blackhurst, J. (2020), "Industry 4.0 and resilience in the supply chain: a driver of capability enhancement or capability loss?", *International Journal of Production Research*, Vol. 58 No. 16, pp. 5006-5019, doi: 10.1080/00207543.2020.1736724.

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

Sarkis, J. (2020), "Supply chain sustainability: learning from the COVID-19 pandemic", *International Journal of Operations and Production Management*, Vol. 41 No. 1, pp. 63-73.

Sarkis, J., Cohen, M.J., Dewick, P. and Schröder, P. (2020), "A brave new world: lessons from the COVID-19 pandemic for transitioning to sustainable supply and production", *Resources, Conservation and Recycling*, Vol. 159, 104894, doi: 10.1016/j.resconrec.2020.104894.

Scheibe, K.P. and Blackhurst, J. (2017), "Supply chain disruption propagation: a systemic risk and normal accident theory perspective", *International Journal of Production Research*, Vol. 56 Nos 1-2, pp. 43-59.

Seifert, R. (2015), "Dynamic capabilities in sustainable supply chain management: a theoretical framework", *Supply Chain Forum: An International Journal*, Vol. 16 No. 4, pp. 2-15.

Sharma, S. (2020), "Effect of restricted emissions during COVID-19 on air quality in India", *Science of the Total Environment*, Vol. 728, doi: 10.1016/j.scitotenv.2020.138878.

Strauss, A. and Corbin, J. (1990), *Basic of Qualitative Research: Grounded Theory Procedures and Techniques*, Sage, Newbury Park, CA.

Teece, D.J. (2014), "The foundations of enterprise performance: dynamic and Ordinary capabilities in an (economic) theory of firms", *Academy of Management Perspectives*, Vol. 28 No. 4, pp. 328-352.

Teece, D.J., Pisano, G. and Shuen, A. (1997), "Dynamic capabilities and strategic management", *Strategic Management Journal*, Vol. 18 No. 7, pp. 509-533.

Touboulic, A. and Walker, H. (2015), "Theories in sustainable supply chain management: a structured literature review", *International Journal of Physical Distribution and Logistics Management*, Vol. 45 Nos 1/2, pp. 16-42.

Umar, M., Khan, S.A.R., Zia-ul-haq, H.M., Yusliza, M.Y. and Farooq, K. (2022), "The role of emerging technologies in implementing green practices to achieve sustainable operations", *The TQM Journal*, Vol. 34 No. 2, pp. 232-249, doi: 10.1108/TQM-06-2021-0172.

Vanpoucke, E., Vereecke, A. and Wetzels, M. (2014), "Developing supplier integration capabilities for sustainable competitive advantage: a dynamic capabilities approach", *Journal of Operations Management*, Vol. 32 Nos 7-8, pp. 446-461.

Voss, C., Tsikriktsis, N. and Frohlich, M. (2002), "Case research in operations management", *International Journal of Operations and Production Management*, Vol. 22 No. 2, pp. 195-219.

Witschel, D., Döhla, A., Kaiser, M., Voigt, K.I. and Pfletschinger, T. (2019), "Riding on the wave of digitization: insights how and under what settings dynamic capabilities facilitate digital-driven business model change", *Journal of Business Economics*, Vol. 89 No. 8, pp. 1023-1095.

Xu, L.D., Xu, E.L. and Li, L. (2018), "Industry 4.0: state of the art and future trends", *International Journal of Production Research*, Vol. 56 No. 8, pp. 2941-2962.

Yin, R. (2003), *Case Study Research: Design and Methods*, 3rd ed., Sage Publishing, Beverly Hills, CA.

Yin, R.K. (2009), *Case Study Research: Design and Methods*, 4th ed., Sage Publications, Thousand Oaks, CA.

Yu, W., Jacobs, M.A., Chavez, R. and Yang, J. (2019), "Dynamism, disruption orientation, and resilience in the supply chain and the impacts on financial performance: a dynamic capabilities perspective", *International Journal of Production Economics*, Vol. 218, pp. 352-362.

Zhu, G., Chou, M.C. and Tsai, C.W. (2020), "Lessons Learned from the COVID-19 pandemic exposing the shortcomings of current supply chain operations: a long-term prescriptive offering", *Sustainability*, Vol. 12 No. 14, doi: 10.3390/su12145858.

Further reading

Aastrup, J. and Halldórsson, Á. (2008), "Epistemological role of case studies in logistics: a critical realist perspective", *International Journal of Physical Distribution and Logistics Management*, Vol. 38 No. 10, pp. 746-763.

Belhadi, A., Touriki, F.E. and Fezazi, S.E. (2018), "Benefits of adopting lean production on green performance of SMEs: a case study", *Production Planning and Control*, Vol. 29 No. 11, pp. 873-894.

Benabdellah, A.C. and Zekhnini, K. (2021), "Sustainable product development: the intersection of design for X, big data and industrial Internet of Things with fuzzy logic theory", *2021 Third International Conference on Transportation and Smart Technologies (TST)*, IEEE, pp. 79-84.

da Mota Pedrosa, A., Näslund, D. and Jasmand, C. (2012), "Logistics case study based research: towards higher quality", *International Journal of Physical Distribution and Logistics Management*, Vol. 42 No. 3, pp. 275-295.

DNV GL (2020), available at: https://www.dnvgl.com/news/companies-pursue-alternative-suppliers-to-spread-supply-chain-risks-and-build-resilience-190723 (accessed 14 August 2021).

Ellram, L.M. (1996), "The use of the case study method in logistics research", *Journal of Business Logistics*, Vol. 17 No. 2, pp. 93-138.

Karunathilake, K. (2021), "Positive and negative impacts of COVID-19, an analysis with special reference to challenges on the supply chain in South Asian countries", *Journal of Social and Economic Development*, Vol. 23 No. 3, pp. 568-581.

Lin, Q., Zhao, S., Gao, D., Lou, Y., Yang, S., Musa, S.S., Maggie, H. and Wang (2020), "A conceptual model for the coronavirus disease 2019 (COVID-19) the outbreak in Wuhan, China with individual reaction and governmental action", *International Journal of Infectious Diseases*, Vol. 93, pp. 211-216.

Näslund, D. (2002), "Logistics needs qualitative research – especially action research", *International Journal of Physical Distribution and Logistics Management*, Vol. 32 No. 5, pp. 321-338.

Seuring, S. (2005), "Case study research in supply chains — an outline and three examples", in Kotzab, H., Seuring, S., Müller, M. and Reiner, G. (Eds), *Research Methodologies in Supply Chain Management*, Physica-Verlag HD, available at: https://doi.org/10.1007/3-7908-1636-1_16 (accessed 2 March 2022).

Strauss, A. and Corbin, J. (1998), *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*, Sage, Thousand Oaks, CA.

Appendix: Interview guideline

Opening

Good morning/afternoon

Thank you for taking time from your busy schedule to do this interview. First, I would like to present the research goals to you. This project aims:

(1) To investigate the different impacts of COVID-19 on the supply chain

(2) To examine both short- and medium-to-long-term measures taken to mitigate the different effects of the pandemic

(3) To highlight potential transformations and their impacts on supply chain performance

(4) To highlight the role of digital technologies and circular economy practices as dynamic capabilities to improve supply chain resilience and sustainability.

The interview contains seven open-ended questions. It will take around 60–80 min.

The results of this interview will be published in an academic journal; however the anonymity and confidentiality of your response will be strictly maintained and your name or the name of your organization will never appear on any public record.

Interview questions:

(1) Please introduce your company/organization and its products/services.

(2) Please describe the social, economic and environmental impacts of the coronavirus crisis on your supply chain.

(3) Please describe the measures (short and long term) that you have taken or are considering taking in your organization to mitigate the social, economic, and environmental effects of the COVID-19 crisis.

(4) The COVID-19 crisis is likely to accelerate fundamental and structural changes to supply chain practices. According to your point of view, what will be these changes and their social, economic, and environmental impacts?

(5) How might digital technologies and circular economy practices help to transform supply chains for more sustainability and resilience.

(6) Do you believe that this COVID-19 crisis presents a supply chain opportunity?

(7) Do you have any additional comments or concerns you would like to share?

Floating prompts

Could you please explain this element in more detail?
That is very important; could you please continue explaining this?
Could you please give a practical example?

Closing

Thank you very much for your participation in this study. We will send you a copy of the papers that are developed from this research, once they are published.

Corresponding author

Andrea Chiarini can be contacted at: andrea.chiarini@chiarini.it

For instructions on how to order reprints of this article, please visit our website:
www.emeraldgrouppublishing.com/licensing/reprints.htm
Or contact us for further details: **permissions@emeraldinsight.com**