The disruption of the international supply chain: Firm resilience and knowledge preparedness to tackle the COVID-19 outbreak

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ABSTRACT

The lockdowns of several countries due to COVID-19 outbreak resulted in severe economic consequences, among which was the immediate general disruption of the international supply chain, with few exceptions. This article aims to investigate whether some supply chains were resilient or not and why, using a knowledge-based approach and specifically focusing on the role played by supply chain innovation in building resilience to disruptions, thanks to knowledge preparedness. The study is motivated by two main rationales: the unique situation of a global pandemic and the absence of studies providing grounded evidences of supply chain resilience in a worst-case scenario.

The research is based on the assumption that knowledge preparedness introduces logistics/supply chain innovations and enables companies to prevent, detect, and respond to unpredictable negative events.

By using a large-scale sample of European firms' data from the Eurostat and a multivariate regression analysis, the authors cross-study the effects of supply chain knowledge preparedness – based on innovation type and expenditures – on the international trade of goods from January to June 2020. The results confirm that the most resilient supply chains were those that had previously introduced innovations, a factor that strengthens the knowledge preparedness of firms when faced with unforeseeable supply chain disruptions.

1. Introduction

This research aims to study the antecedents of supply chain resilience through a knowledge-based approach, specifically by analysing supply chain innovation and focusing on knowledge preparedness as the antecedent of resilience. The study has two main rationales: the unprecedented situation of the global COVID-19 pandemic, which has resulted in a global supply chain disruption, and the absence of previous research investigating such an extreme situation. Such resounding research gaps have been tackled by providing solid evidence built on extensive analyses conducted on a large-scale dataset.

In January 2020, the COVID-19 outbreak caught the whole world completely off guard. By 9 March 2020, Italy declared an

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epidemic crisis. Within a short period, a tragically long list of other countries followed, forcing the World Health Organization (WHO) to declare a global pandemic. Officially on 1 July 2020 there were 10.357.662 cases worldwide and 508.055 deaths, according to WHO (see the Appendix for more information). In its characteristics and impact, COVID-19 has been the most dreadful and vast threat the world has experienced so far. Due to the pandemic, several countries were forced to declare various lockdown measures. Millions people, firms and organisations were completely locked in for about three months or longer. The lockdown caused a sharp plunge in all business activities, among other major disruptions and complications. Notably, the pandemic negatively affected global economic growth. According to updated estimates (October 2020) the virus cut global economic growth at rate of between −4.5% and − 6.0% in 2020, with a partial recovery of a rate of 2.5% to 5.2% in 2021, depending whether or not countries were able to slow down or stop the diffusion of the virus. Consequently, global trade fell by an annual amount of 9.2%, depending on the depth and extent of the global economic downturn (Weiss et al., 2020). Among EU member states, the impact of COVID-19 was largest in France and Italy (−5.3%), followed by Spain and Slovakia (−5.2%) (according to data published on 20 July 2020; Eurostat, 2020). Only Bulgaria, Romania and Ireland had positive growth rates (in Ireland this growth was related to activities of multinational enterprises). The latest World Economic Outlook Growth Projections have estimated a growth of 4.8% for 2021 in advanced economies (United States, Euro Area, Japan, United Kingdom, Japan and others) and 5.9% for emerging markets and developing economies (International Monetary Fund, 2020). Other studies have evaluated the impact of COVID-19 on labour demand, decreased in terms of working hours by 16.24% due to travel restrictions and firm shutdowns (Nikolopoulos et al., 2020).

Alongside the tragic impact on human health and the chase towards a cure or a vaccine for this deadly virus, COVID-19 caused the worst ever supply chain shortage (*The Guardian*, 20 February 2020), due to disruptions that refer to 'unplanned and unanticipated events that disrupt the normal flow of goods and materials within a supply chain' (Craighead et al., 2007, p. 132). The breadth and depth of the shortage was such that myriad goods were not available, from personal protection equipment – such as facial protective masks – to medical supplies of various kinds (McMahon et al., 2020; Ranney et al., 2020), pharmaceutical (drug) products (Shuman et al., 2020), groceries including food (Cappelli and Cini, 2020; de Paulo Farias and dos Santos Gomes, 2020; Singh et al., 2020), personal hygiene goods, and tech goods. The proportion of the crisis was biblical; 94% of the companies listed in the Fortune 1000 ranking faced supply chain disruptions due to COVID-19 (*Fortune*, 2020; Queiroz et al., 2020). This dystopic scenario provided the rationale and the motivation for this research. Many scholars and professionals (i.e. *Fortune*, Deloitte, etc.) have tried to understand the impacts of COVID-19 on the supply chain and its ripple effect (Choi, 2020; Govindan et al., 2020; Ivanov, 2020a, 2020b; Queiroz et al., 2020; Sarkis et al., 2020). Despite the global disruption, some supply chains have been able to resist the shock. As a proof, firms with a proactive, value-oriented and long-term supply chain management approach prior to COVID-19 – an approach based on a strong collaboration with external stakeholders, common or similar sustainability standards or procurement KPIs (such as quality, lead time and so on), more intensive information exchange, or taking part in sustainability initiatives and industry consortia (e.g. Responsible Business Alliance, Roundtable for Sustainable Palm Oil) – had a proactive detection of early warning signals on deteriorating conditions along their supply chains, even when other physical signals were disrupted (Trautrims et al., 2020). Hence, relational approaches and proactiveness to gain transparency during turbulent times helped to manage supply chain risk (Sodhi and Tang, 2019).

Along this vein, the purpose of this research is to understand what prepared these companies for supply chain resilience against the unpredictable and unprecedented global shocks. The concept of knowledge preparedness has emerged as the most reliable and secure antibody for organisations facing unexpectable and incredibly harsh events. The concept of 'preparedness' was conceived in the field of cognitive psychology (Seligman, 1971) in reference to learning. It refers to the selective learning process that is activated to resist extinction (Seligman et al., 1970). According to Kandel et al. (2020), preparedness is a form of operational readiness or the capability of preventing, detecting and responding to unpredictable and harsh outbreaks.

Despite that this process can also be partially non-cognitive (Seligman, 1971) – at least in the phase of individual motivation and intention – it follows an explicit decision to prepare for disasters (Coombs and Laufer, 2018; Paton, 2003; Paton and Johnston, 2001). Not by chance, the WHO launched a plan for strategic preparedness in response to the COVID-19 outbreak.

Regardless the extreme importance of this concept, managerial literature has been only barely concerned with preparedness. As a matter of fact, so far, preparedness has mostly been seen as a not primary firm's capability for disaster management (Bao et al., 2019). Considering the current importance of the knowledge economy and knowledge management (Ardito et al., 2019; Del Giudice and Maggioni, 2014; Del Giudice et al., 2014), it is quite surprising that scholars have neglected to properly study the role of knowledge preparedness for firm and supply chain resilience thus far. Previously, business resilience was often studied in relationship to strategic agility (Shams et al., 2020; Wieland et al., 2020). Additionally, both themes are extremely new and quite completely underexplored. Therefore, because resilience of the supply chain is described as the capability of handling potential disruptions (Rajesh, 2017) and developing speedy recovery capitals (Todo et al., 2015), resilience is intrinsically tied to readiness of the supply chain (Chowdhury and Quaddus, 2016; Tolonen et al., 2017). Over time, scholars have proposed that innovation is a driver of firm and supply chain resilience (Chowdhury and Quaddus, 2016).

Building on these considerations, we decided to figure out what drove supply chain resilience and international trade during the COVID-19 outbreak. Thus, we aimed to tackle the existing gap in the literature on knowledge preparedness in the supply chain. Furthermore, the study took into account the contribution of supply chain innovation to supply chain resilience by arguing that there is a strong link between innovation and knowledge preparedness. Indeed, supply chain innovation can be defined as 'a combination of information and related technology developments and new marketing and logistic procedures to enhance service effectiveness, improve operational efficiency, increase revenue, and maximise joint profits' (Wong and Ngai, 2019, p. 159). Broadly speaking, thanks to its positive effects on the internal effectiveness and external response to the market, innovation is considered a driver of supply chain resilience and has a direct impact on resilience capability (Parast et al., 2019). For this reason, previous investments in supply chain innovation have prepared companies to resist the pandemic storm. Since knowledge preparedness fosters supply chain resilience, we

originally argued that supply chain innovation is a predictor of knowledge preparedness and resilience.

The model hypotheses were tested on a large-scale sample of firms located in the European Union. The temporal factors are among the many motivations that led the authors to focus their attention on this area. After the initial China outbreak, Italy was the first country massively affected by the pandemic, promptly followed by other European countries. Yet, these countries showed a great responsiveness to the threat. The multivariate linear regression confirmed the model's hypotheses: supply chain innovation is a proxy of knowledge preparedness and is inversely related to supply chain disruption. Notably, we distinguished the impact per type of innovation. Inventory management innovation was the most important supply chain innovation that helped firms to resist supply chain disruption.

Also, the most important innovations in the medical supply chain were those related to the identification of products – to readily detect out-of-stock –e-procurement, and reverse logistics. The analysis in this article has several critical implications. At a business level, it demonstrates the importance of knowledge preparedness in order to avoid supply chain disruptions. At a social level, it indicates the pathway to reinforce country systems for generating structural resilience in response to unpredictable events and disasters. The social health level, perhaps, is the most important: the results clearly indicate the kind of innovations that are needed to avoid the out-of-stock of vital medical supplies. The rest of the article is structured as follows: first, we review some of the main literature antecedents; second, we present and discuss the results of the empirical analysis; finally, we explain the implications of the study and suggest a few crucial future research pathways.

2. Literature background and model hypotheses

Due to the COVID-19 outbreak, most organisations faced many strategic challenges in managing their supply chains to honour the delivery of products and service and preserve customer satisfaction. If organisations failed to meet such expectations, society would suffer huge consequences (Mafabi et al., 2012). This catastrophic scenario clearly showed a need for resilience. Supply chain resilience refers to 'the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function' (Ponomarov and Holcomb, 2009, p. 131). Current definitions of resilience have been gleaned from the fields of engineering, psychology, ecology and disaster relief (see Table 1). Three constructs were taken into account in most definitions: the phases of resilience, resilience strategies and the capabilities needed for resilience (Ali et al., 2017). With reference to the formative elements required to build an adaptive capacity for supply chain resilience, the literature provides a number of perspectives focusing on different elements, such as adaptability, creativity, situational awareness, resourcefulness, learning, collaboration, tenacity and trust (Scholten et al., 2019).

For example, Pettit et al. (2010, 2019) tried to understand the interplay between the drivers of disruption (vulnerabilities) and the capabilities required to endure disruptions. This conceptualisation was frequently used to understand adaptation and growth (Alfarsi et al., 2020; Fiksel, 2015; Ribeiro and Barbosa-Povoa, 2018; Zhao et al., 2011). At a conceptual level, scholars distinguish between pre-disruption – preparedness and mitigation – and post-disruption – stabilisation and recovery. Our study aims to provide a clear understanding of factors that are salient for firm survival in the pre-disruption phase. Thus, the study focused on preparedness – proactiveness before an event – and the relevant learning processes that would allow a fast adaptation of routines and procedures for supply chain resilience. In the pre-disruption phase, five essential proactive elements emerged to gauge the level of readiness of a company's supply chain resilience: (1) situation awareness, in terms of understanding supply chain vulnerabilities, planning for such events, ability to discern a possible disruption by sensing and interpreting events; (2) robustness, the ability to resist change and use a proactive anticipation of change; (3) visibility, the warning strategy to align firm capabilities and contain disruptive impact; (4) security, designed in advance to protect the supply chain; and (5) knowledge management and understanding of the supply chain and human resource structures as the building blocks for creating a resilient supply chain (Ali et al., 2017). Therefore, knowledge management in the pre-disruption phase improves supply chain resilience. Not by chance, knowledge preparedness makes companies able to prevent, detect and respond to unpredictable contrary events. Successful knowledge-based and resilient firms are characterised by high performance, high flexibility and adaptiveness (Mafabi et al., 2013). Accordingly, we investigate how organisations use knowledge preparedness to build a global supply chain resilience.

2.1. Knowledge preparedness, readiness and time-based competition: the role of innovation for supply chain resilience

The ability to bounce back from disruptive situations, thanks to supply chain resilience, enables organisations to respect their commitments towards the market in terms of service, delivery quality, products availability and time of delivery. Thus, the competitiveness of the supply chain determines the success of the ecosystem. In this context, time advantage is essential for the competitiveness of a supply chain. As a matter of fact, the logistics success mostly depends on the management of the lead-time frontier (Harrison, 2001). The time-based competition is aimed at outperforming competitors by providing products to the end customer in a shorter time than competitors (Christopher, 2000). Speed determines supply chain agility (Agarwal et al., 2007). It therefore follows that a short lead time improves responsiveness to customers when markets are volatile (Christopher, 2000). The focus on speed determines a paradigm shift from the concept of the first-mover advantage to that of the fast-mover advantage (Hawk et al., 2013). However, to achieve such superior performance through time-based competition, the supply chain must develop superior knowledge capabilities (Del Giudice et al., 2017; Mital et al., 2018; Santoro et al., 2019; Sasson et al., 2017). Timely response to customers stems from readiness and high coordination within the entire ecosystem (Cha, 2020; Meschi et al., 2017; Soto-Acosta et al., 2018). Hence, there is a strong link between knowledge and readiness (Rusly et al., 2012). According to Rusly et al. (2012), readiness is a multidimensional construct composed of structural and psychological factors that leverage organisational knowledge management in terms

of knowledge acquisition, creation, and sharing. With reference to the resource-based view, a knowledge-based view of the firm and the dynamic capabilities approach, companies use knowledge resources – collected and recombined over time – in order to generate and implement new organisational structures, processes and competences (Mafabi et al., 2012). The knowledge embedded in human, structural and relational capitals – a key differentiating factor in business (Del Giudice and Maggioni, 2014) – is strongly related to innovation and performance (Cabrilo and Dahms, 2018; Campanella et al., 2014; McDowell et al., 2018; Papa et al., 2018; Subramaniam and Youndt, 2005). Consequently, Holt et al. (2007) suggested that readiness depends on who is involved in the knowledge process, where it is occurring, what is involved and how it is occurring. Yet, knowledge management readiness also depends on socialisation, externalisation, combination and internalisation – SECI processes – of knowledge (Karim et al., 2012; Mehralian et al., 2018). Different from the aforementioned antecedent studies, we assume a technology-based perspective by arguing that innovation is a key determinant of knowledge readiness. Broadly speaking, the innovation capacity – a firm's ability to exploit internal and external knowledge – is deemed to foster knowledge management capacity (Santoro et al., 2018). Yet, the capacity to realise both exploitative (incremental) and explorative (radical) innovations, known as organisational ambidexterity (Caniëls et al., 2017), is also affected by innovation in logistics (Ardito et al., 2018). Ambidexterity is the ability to simultaneously pursue both incremental and discontinuous innovation and change (Dezi et al., 2019). Such capacity affects the firm's adaptation to changes in demand (Ramachandran et al., 2019). Similarly, innovation in logistics influences the mechanisms of knowledge sharing between a firm and its customers or suppliers by creating a common knowledge base for external and internal counterparts that facilitates the use and sharing of relevant knowledge. These sharing mechanisms, in turn, affect ambidexterity and firm performance (Dezi et al., 2019). For instance, the purposive use of disruptive digital technologies affects the way knowledge is managed within organisations, acting as a facilitator (Santoro et al., 2018). Accordingly, innovation emerges as a pre-condition of organisational resilience (Bristow and Healy, 2018; Euchner, 2019; Held et al., 2019; Sabahi and Parast, 2020). In particular, innovativeness is positively associated with global supply chain resilience (Golgeci and Ponomarov, 2013; Kwak et al., 2018). Building on these considerations, we argue that supply chain innovation improves lead time, thus enhancing coordination at a global level. This positive effect is due to improved efficiency and effectiveness. Ultimately, supply chain innovation directly and positively affects knowledge preparedness.

To the best of our knowledge, previous studies have not explicitly considered the relationship between supply chain innovation and knowledge preparedness. We argue that supply chain innovation directly affects a firm's chances of survival, because it creates a sort of knowledge buffer, or knowledge preparedness, that can be deployed to adapt during harsh times. Consequently, we hypothesise the following:

(1) H1: There is a linear and positive relationship between supply chain innovation at an international level and knowledge preparedness.
(2) H2: Supply chain innovation at an international level is a predictor of knowledge preparedness.

2.2. Supply chain disruption and the COVID-19 outbreak

A supply chain disruption is an interruption in the information and material flows of goods due to an unexpected event (Ambulkar et al., 2015; Craighead et al., 2007). Recently, a few studies have tried to explore the effects of the pandemic disease on the disruption of global supply chains through means of simulation models (Ivanov, 2020a). These effects can be synthesised in terms of a severe shortage of medical supplies (Hobbs, 2020; Nikolopoulos et al., 2020; Singh et al., 2020). According to the research, the COVID-19 pandemic will have long-lasting effects on the international supply chain.

Considering the systematic and extremely negative consequences of a disruption in the global supply chain, scholars, firms and institutions, such as the World Economic Forum (Ambulkar et al., 2015), have been paying increasing attention to the creation of resilience mechanisms. Despite the absolute relevance of supply chain resilience for all economies, not much is known about how to build such resilience (Jüttner and Maklan, 2011). Some prior scholars have attempted to explain why innovative firms are more resilient to supply chain and global sourcing disruption (Gunasekaran et al., 2015; Sabahi and Parast, 2020; Wieland et al., 2020). However, to date, the role of knowledge readiness in the face of global supply chain disruptions has been scantly examined.

By and large, relevant prior research suggests that knowledge management and firm innovativeness play a critical role in global supply chain management (Scuotto et al., 2017; Singh et al., 2019).

With the COVID-19 outbreak, the severity of global supply chain disruption led scholars, policymakers and various organisations to focus their attention on building resilient supply chains. Guan et al. (2020, p. 1) argued that 'regardless of the strategy, the complexity of global supply chains will magnify losses beyond the direct effects of COVID-19'. Bridging the gap in the aforementioned studies, we argue that knowledge preparedness allows the mitigation of global supply chain disruption. Thus, we hypothesise the following:

(3) H3: Knowledge preparedness has a linear and negative effect on international supply chain disruption.
(4) H4: International trade is a predictor of international supply chain disruption.

3. Empirical analysis

3.1. Sample and data

This research is focused on member states of the European Union. There are several reasons that led the authors to consider this specific set of countries. First and foremost, Europe, and Italy, in particular, was the first territory to be affected by the pandemic after

the initial COVID-19 outbreak in China. Specifically, the outbreak, which is still ongoing at the time of this writing, had a dramatic impact on society and business because of its fast and large diffusion and the high number of casualties (Saglietto et al., 2020; Yuan et al., 2020). Second, the pandemic severely affected the European supply chain (Ivanov, 2020a).

Data related to the international supply chain have been extracted from the Eurostat website in June 2020 from the specific database that was provided in order to gather a better understanding of the pandemic crisis (https://ec.europa.eu/eurostat/web/science-technology-innovation/data/database). Eurostat is the statistical office of European Union and it gathers and distributes various statistics related to EU member states.

The dataset includes the supply chain innovation of the entire population of European firms, classified by innovation type, which was pertinent because we consider innovation to be a proxy for knowledge preparedness.

We assumed that firms that were prepared to face the global disruption experienced a milder interruption of trades (especially at an international level). Consequently, we investigated what type of supply chain innovation fostered preparedness the most. In doing so, we distinguished companies providing medical supplies from all other goods/services, given the relevance of medical supplies during the pandemic. Moreover, we weighted companies by country. In addition, we also tried to understand whether the sentiment of consumers (in lockdown and frightened by the global situation) or that of other actors affected their purchases/behaviours or not. This is relevant to understand, for instance, if it were the consumers' sentiment that drove the plunge of trades or not. Consequently, we collected the following data: international trade in goods of COVID-19 medical supplies (ITmed), international trade in goods (ITG), balance of payments by country (BPC) and sentiment indicator (SI):

- ITmed refers to COVID-19 test kits/instruments and apparatus used in diagnostic testing, expressed in million euros for the period between December 2019 and May 2020.
- ITG refers to quarterly data of the balance of payments by country, expressed in million euros for the period between December 2019 and May 2020.
- BPC is expressed in million euros and refers to the monthly data of the balance of payments by country for the period between December 2019 and May 2020.
- Sentiment indicator refers to monthly data of the confidence indicator for the period between December 2019 and May 2020. This confidence indicator is the result of a survey of different sectors, calculated as an arithmetic means of answers (seasonally adjusted balances) to a selection of questions related to the reference variable they are supposed to track. These variables are the economic sentiment indicator, industrial confidence indicator, retail confidence indicator, consumer confidence indicator and service confidence indicator. All detailed information can be retrieved from the Eurostat metadata (https://ec.europa.eu/eurostat/cache/metadata/en/ei_bcs_esms.htm).

Broadly speaking, we tested whether supply chain innovation is a proxy (predictor) of supply chain knowledge preparedness or not. We also explored how European innovative supply chains performed during the lockdown and the resulting global disruption. Data related to disruption specifically refer to the lockdown period. When companies performed fairly (mild reductions in trades), it means they were resilient, thanks to the supply chain innovation previously introduced, which we classified by innovation type. When company performance was poor, it means they were not resilient. Thus, we argue that poor performance indicates a lack of knowledge preparedness.

Data related to supply chain innovation are drawn from the Community Innovation Survey (CIS). These data refer to the CIS 2016 version, as updated in February 2020. We use these data to estimate knowledge preparedness of the supply chain and to understand how previous innovation could be used as a buffer against unexpected disruptions due to environmental shocks. Clearly, preparedness was built in advance through gathering innovative knowledge and technologies.

Retrieved data refer to enterprises that either introduced innovation in logistics by type of innovation or not and enterprises with expenditures for innovation in logistics. Enterprises are clustered by size (small, medium and large firms depending on the number of employee) and class of expenditures (expressed in euros). Innovation in logistics and supply chain is classified as innovations in logistics, other innovations in logistics, redesign of shipment, inventory management systems, digital supply chain management, e-procurement, unique and automatic identification of products within the whole supply chain, reverse logistics and new delivery models, including the use of alternatively fuelled vehicles or multimodal logistics. All values are expressed in numbers. This classification is the result of a survey conducted by the European Union. Detailed information on the survey and variables are available on the Eurostat website (https://ec.europa.eu/eurostat/web/science-technology-innovation/data/database).

The use of Eurostat data, and CIS in particular, is solidly grounded in prior research (Bakhshi and McVittie, 2009; Hofman et al., 2020). Most important, the use of such a source is strongly encouraged at this moment as a means to create a solid knowledge basis through replicable analyses and open-source data.

3.2. Methodology and model

Given the general intent to understand whether supply chain innovation is a predictor (proxy) of knowledge preparedness, we used a predictive model to verify our hypotheses. Specifically, a multivariate linear regression analysis was performed to test the model's hypotheses, along with descriptive statistics on the sample.

This method has been largely adopted in the field of study (Hong et al., 2019; Wang and Hu, 2020; Wijaya et al., 2019) and enables understanding the degree at which the set of independent variables is a predictor of the chosen dependent variables, which are called responses (Imai, 2011). The general equation is the following:

$$Y = XB + \Xi \tag{1}$$

where Y identifies the n × p matrix of dependent variables, X is the n x (q + 1) matrix of q predictors, B is the (q + 1) matrix of fixed parameters and Ξ is an n × p matrix such that the matrix is a multivariate normally distributed with a covariance matrix Σ.

We used this model to simultaneously test the different hypotheses of our model, which is aimed at verifying whether innovation in supply chain is a proxy of knowledge preparedness, useful in buffering firms from the international supply chain disruption caused by the COVID-19 outbreak or not. The general representation of the model is shown in Fig. 1.

We used the mean value during the examined period for each of the variables. The few missing values were excluded from the sample. The final dataset included the following countries: Belgium, Bulgaria, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, North Macedonia, Poland, Portugal, Romania, Serbia, Slovenia, Slovakia, Spain, and Sweden.

3.3. Variables

The variables and abbreviations are reported in Table 2. We originally tested whether supply chain innovation is a proxy of supply chain knowledge preparedness. Based on the model, we considered enterprises that introduced innovation in logistics by type of innovation and enterprises with expenditures for innovation in logistics as our independent variables. We also assumed such innovations are a proxy of knowledge preparedness. The response variables are international trade (before the pandemic), international trade in goods of COVID-19 medical supplies and international trade in goods during the pandemic. The two different international trades in goods are needed to evaluate whether there was a plunge of trades or not and how intense it was.

Previous studies have used similar measures in terms of international trade to evaluate supply chain performance (Gereffi, 1999; Gunasekaran et al., 2001; Mann, 2012), so we adopted these variables as a proxy of international supply chain disruption.

We also employed different control variables. In addition to firm size and class, the sample was also controlled for balance of payments by country (Janus and Riera-Crichton, 2013) and sentiment indicator (Johnson and Watson, 2011).

3.4. Findings

Descriptive statistics are reported in Table 3. Interestingly, Table 3 signals that there is a great volatility in the sample. Such volatility is generally deemed a proxy for risk (Chen and Petkova, 2012). So, the first result that emerged from the analysis is a presence of huge business risk. In addition, Table 3 shows the descriptive statistics by type of supply chain innovation: redesign of shipment, inventory management systems, digital supply chain management, e-procurement, unique and automatic identification of products within the whole supply chain, reverse logistics and new delivery models, including the use of alternatively fuelled vehicles or multi-modal logistics.

Each of these innovations relate to components of the global supply chain. For instance, the redesign of shipment relates to the redesign of the packaging – for example, using recyclable materials – in order to reduce the space needed for the storage of goods, alternative delivery methods and so forth.

The inventory management system is a core component of an efficient and effective supply chain. Singh and Verma (2018, p. 3867) define it as 'the part of supply chain management that plans, implements and controls the efficient, effective, forward, and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customer's requirements'. Introducing an innovation in inventory management systems directly impacts on time-based competition, as well as on end user satisfaction.

Digital supply chain management refers to the digital knowledge management of the supply chain (Scuotto et al., 2017). The current massive digitisation, accelerated by the global pandemic, along with the dominance of the knowledge paradigm, put digital supply chain management at the centre of scholar and practitioner conversations.

E-procurement refers to the digital information systems related to the acquisition of supply. This aspect may play a discriminant role in global supply chain and during disruptions, such as the one caused by the global pandemic.

Reverse logistics is becoming increasingly important in terms of sustainability of supply chains (Rogers and Tibben-Lembke, 2001). Reverse logistics is 'the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal' (Rogers and Tibben-Lembke, 1999, p. 2).

Table 4 shows the results of the multivariate analysis. Interestingly, the variable LogExp seems to be nonsignificant, whilst, by contrast, LogINN has a high level of statistical significance. In brief, supply chain innovation is a proxy of knowledge preparedness. Such a proxy is measured in terms of supply chain innovations introduced by firms before the COVID-19 outbreak. Therefore, the hypotheses of the model are confirmed. Table 5 shows results grouped by type of innovation. Supply chain innovations had a differentiated effect on disruption (supplies that are not delivered). For instance, in the medical supply chain, the innovations that were buffered from global disruption were those related to shipment, e-procurement, reverse logistics and unique and automatic identification of products. In general, inventory management innovations are the most important to avoid supply chain disruption. We also included the label 'other innovation', which refers to the survey questionnaire CIS, question 14.1. The respondents were asked to answer the question 'During the three years from 2014 to 2016 did your enterprise introduce any of the following innovations in logistics?' by choosing yes or no for each of the seven listed types of supply chain innovation. As an eighth item, 'other', was added when respondents introduced other types of supply chain innovations that were not listed among the choices. Finally, it is interesting to

note that the control variable 'sentiment' had a poor effect on the supply chain, as explained by the two R-squared values, about 0,1 for both dependent variables, as shown in Table 6.

3.5. Discussion

This study originally examined the impact of knowledge preparedness on global supply chain disruption during the COVID-19 outbreak, achieving extremely important results.

Originally, the authors aimed at providing grounded evidence that supply chain resilience springs from knowledge preparedness, which is driven by innovation. The results show that the authors' hypotheses were largely confirmed. First, the results originally indicated that supply chain innovation is a proxy for supply chain knowledge preparedness at a level of extremely high statistical significance: F = 32,911 > Fsign = 0,000, and F = 138,688 > Fsign = 0,000.

This study extended the existing knowledge by unveiling the role of knowledge preparedness and innovation in building resilient supply chains (Sabahi & Parast, 2019). Second, we found that supply chain innovation is a proxy for supply chain preparedness. In other words, knowledge management confirmed its paramount role for building firm resilience (Ali et al., 2017) through implementing continuous innovative processes based on knowledge acquisition, creation and sharing. Knowledge acquisition capabilities, knowledge generation capabilities and knowledge combination capabilities represent three relevant dimensions of knowledge-based dynamic capabilities (Del Giudice et al., 2017; Mital et al., 2018; Santoro et al., 2019; Sasson et al., 2017; Zheng et al., 2011). Taking inspiration from these categories, the results confirmed the impact of knowledge acquisition capabilities and knowledge combination capabilities on knowledge preparedness as a new form of knowledge (not just operational) affecting readiness and the ability to prevent, detect and respond to unpredictable and harsh outbreaks. Combination capabilities are vital for sensing and reacting to disruptive events (Likoum et al., 2018). In addition, using, recombining and sharing stocks of knowledge foster supply chain innovation. Thus, knowledge preparedness buffers firms from supply chain disruptions indeed.

According to results, the model's hypotheses were confirmed. Importantly, the results showed that knowledge preparedness mitigated the effects of the global supply chain disruption during the COVID-19 outbreak. Notably, the study showed that some supply chain innovations, such as shipment, e-procurement, identification of products and reverse logistics, are more important than others.

Intuitively, shipment affects the responsiveness to customers, which is an indicator of readiness. During the pandemic, the most essential need was a timely global sourcing of medical equipment, drugs and other goods for individual protection. An efficient and effective global sourcing is inherently tied to inventory management through automatic identification of goods and to e-procurement. Interestingly, reverse logistics – related to recycling and including all logistics activities that enable the return of used products in order to recapture the value or to implement proper disposal (Panjehfouladgaran and Lim, 2020) – also played an important role for global health. Sustainability of the supply chain will assume a paramount importance in forthcoming years.

Finally, sentiment indicators had almost no effect on global supply chain disruption. This last result is of a particular importance because it is counterintuitive and goes beyond expectations. Specifically, it identifies that the supply chain disruption was caused solely by a lack of preparedness because consumers kept demanding goods per usual. In other words, supply chain resilience is exclusively a knowledge matter.

Also, the results of the study confirmed knowledge as the paramount factor creating resilience and buffering firms during difficulties. Only knowledge can help to mitigate the consequences of supply chain disruption.

To the best of our knowledge, there is no prior research that tackled this gap in knowledge to date. Considering that COVID-19 outbreak permanently changed business dynamics, this study has opened up to a whole new panorama whose importance is ascertained by the different calls for solutions launched by organisations worldwide.

3.6. Managerial implications

The impact of the study goes far beyond a mere theoretical contribution. It provides a direct and clear practical answer to managers and policymakers who seek to build resilient systems, as the aforementioned considerations would enable them to respond adequately to international supply chain disruptions. In fact, in an interconnected society, the supply chain has become increasingly global and complex over time. The COVID-19 outbreak showed the weakness of such a system, magnifying exponentially the social and economic repercussions of the global pandemic. Any future supply chain, along with the inherent architecture of economies, must be redesigned in order to exploit the interdependencies, minimising risk, because during harsh events avoiding global supply chain disruption matters in terms of life and death and takes a long time to rebound. For instance, when some of the vaccine supplies were disrupted the delay had a dramatic impact on health and business. Thus, the relevance of knowledge preparedness of the supply chain is unquestionable. To this end, the future supply chain should be thought in terms of system resilience, and continuous innovation may be the only weapon that can be used, as the empirical findings clearly show. Specifically the study underlined that some supply chain innovations, such as shipment, e-procurement, identification of products and reverse logistics, have a greater relevance than others to avoid international supply chain disruptions, increasing readiness, effectiveness and sustainability.

4. Limitations of the research, future perspectives and conclusions

Despite the interesting results at the theoretical and practical levels, this study offers only a cross-sectional perspective of a limited period of time. Nevertheless, the general validity of the analysis and the concept is not affected by the time range. As a matter of fact, the cross-sectional analysis used in this case is well-suited to enabling correlations to emerge between variables, also making the results

consistent and able to provide useful managerial insights in the long run.

Conversely, the theoretical and managerial significance of the study opens up several future perspectives of research. First, future scholars should investigate supply chain disruptions in cases of other global catastrophes, including human-driven ones (i.e. the global financial crisis). In addition, future studies should extend this cross-sectional analysis by adding longitudinal data when available. Finally, it is important to broaden the view of resilience by understanding other dynamics that may influence this variable. For instance, additional analyses should focus specifically on the contribution of digital technologies to the global supply chain during the COVID-19 outbreak. Notably, given the global dimension of current phenomena, a holistic approach to climate resilience should become central to the study.

In a nutshell, even though the dystopic scenario generated by the COVID-19 outbreak provided the rationale for and the motivation to do the current research, the study goes beyond the specific event to restate the critical relevance of the role of knowledge preparedness for firm and supply chain resilience, where supply chain innovation seems to be the primary contributor. In other words, the study clearly indicates the pathway for generating structural resilience in response to unpredictable events at firm and country-system levels, with positive effects on social well-being and global sustainability.
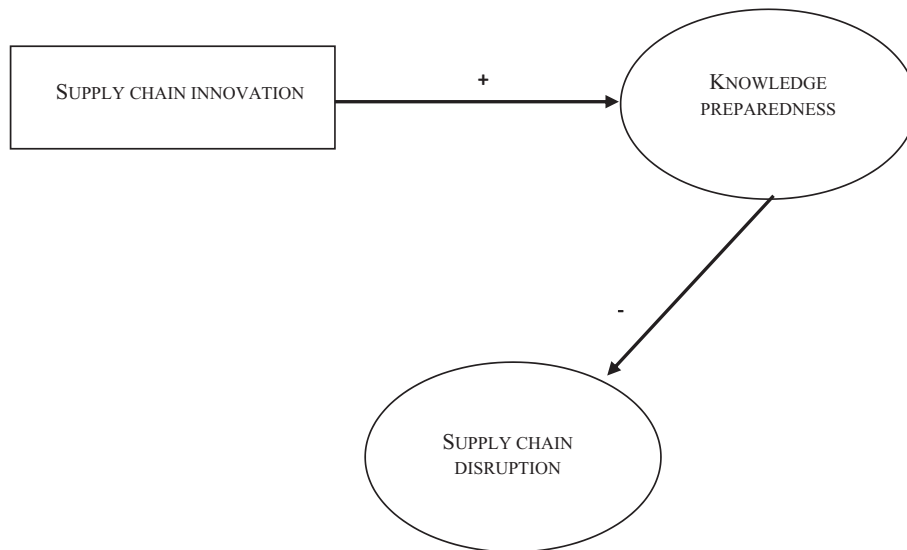
Appendix A. Appendices

Fig. 1. Research model.

Table 1
Supply chain resilience definitions.

Authors	Definition
Rice and Caniato (2003, p. 25)	Resilience is widely used to characterize an organization's ability to react to an unexpected disruption, such as one caused by a terrorist attack or a natural disaster, and restore normal operations
Christopher and Peck (2004, p. 2)	The ability of a system to return to its original state or move to a new, more desirable state after being disturbed
Sheffi and Rice (2005, p. 41)	The ability to bounce back from a disruption
Datta et al. (2007, p. 189)	Supply chain resilience is defined as not only the ability to maintain control over performance variability in the face of disturbance but also a property of being adaptive and capable of sustained response to sudden and significant shifts in the environment in the form of uncertain demands.
Ponomarov and Holcomb (2009, p. 131)	The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function
Kim et al. (2015, p. 287)	Resilience is the capability of a[n] SCN to avoid disruptions or quickly recover from failures.
Pettit et al. (2010, p. 1)	The capacity for an enterprise to survive, adapt and grow in the face of turbulent change
Jüttner and Maklan (2011, p. 247)	Supply chain resilience addresses the supply chain's ability to cope with the consequences of unavoidable risk events in order to return to its original operations or move to a new, more desirable state after being disturbed.
Blackhurst et al. (2011, p. 374)	We specifically define supply chain resilience as a firm's ability to recover from disruptive events.
Ponis and Koronis (2012, pp. 925–926)	The ability to proactively plan and design the Supply Chain network for anticipating unexpected disruptive (negative) events, respond adaptively to disruptions whilst maintaining control over structure and function and transcending to a post-event robust state of operations, if possible, more favourable than the one prior to the event, thus gaining competitive advantage
Wieland and Wallenburg (2013, p. 301)	In this research, resilience is understood as the ability of a supply chain to cope with change.
Melnyk et al. (2014, p. 36)	The ability of a supply chain to both resist disruptions and recover operational capability after disruptions occur
Day (2014, p. 3)	

Table 1 (*continued*)

Authors	Definition
	The capability to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change
Hohenstein et al. (2015, p. 108)	Supply chain's ability to be prepared for unexpected risk events, responding and recovering quickly to potential disruptions to return to its original situation or grow by moving to a new, more desirable state in order to increase customer service, market share and financial performance
Ambulkar et al. (2015, p. 112)	Firm's resilience to supply chain disruptions is defined as the capability of the firm to be alert to, adapt to and quickly respond to changes brought by a supply chain disruption.

Source: Ali et al. (2017, p. 22).

Table 2
List of variables and abbreviations.

Name	Abbreviation	Type of variable
International trade in goods of COVID-19 medical supplies	ITmed	Dependent
International trade in goods	ITG	Dependent
Balance of payments by country	BPC	Control
Sentiment indicator	SI	Control
Enterprises that either introduced innovation in logistics or not by type of innovation	LogINN	Independent
Enterprises with expenditures for innovation in logistics	LogExp	Independent

Table 3
Descriptive statics.

Variable	Mean	Standard error	Standard deviation	Variance
SI	−11,247581699346407	3,450518912638896	14,226853940001565	202,403
New delivery models, including the use of alternatively fuelled vehicles or multi-modal logistics	839,71	319,808	1318,604	1738716,471
Reverse logistics	1184,12	473,660	1952,952	3814022,485
Redesign of shipment (packaging, weight and density)	1312,00	469,335	1935,116	3744673,875
Unique and automatic identification of products within the whole supply chain	1402,71	550,732	2270,726	5156194,721
BPC	1517,473529411764500	1195,773565983894300	4930,300716873086000	24307865,159
Digital supply chain management	1778,12	685,121	2824,825	7979638,485
E-procurement	2287,06	839,873	3462,883	11991561,559
Inventory management systems	2698,88	1083,281	4466,480	19949447,110
ITG	4277,916176470589000	3705,949048814810000	9223,372036854777000	233478991,991
ITmed	68758862,419607850000000	37293385,054110970000000	153764565,714930500000000	23643541669501184,000

Table 4
Between subjects effects with alfa = 0,05, a. R-squared = 0,706 (Adjusted R-squared = 0,664), b. R-squared = 0,909 (Adjusted R-squared = 0,896).

Origin	Dependent variable	F	Sign.	Partial eta-squared
Correct model	ITG	16,837	0,000	0,706
	ITmed	70,192	0,000	0,909
Intercept	ITG	1,016	0,331	0,068
	ITmed	1,058	0,321	0,070
LogExp	ITG	0,161	0,695	0,011
	ITmed	0,110	0,745	0,008
LogINN	ITG	32,911	0,000	0,702
	ITmed	138,688	0,000	0,908

Table 5
Between subjects effects by type of innovation with alfa = 0,05, a. R-squared = 0,973 (Adjusted R-squared = 0,993), b. R-squared = 0,993 (Adjusted R-squared = 0,986).

Origin	Dependent variable	F	Sign.	Partial eta-squared
Correct model	ITG	36,351	,000	,973
	ITmed	145,667	,000	,993
Intercept	ITG	,113	,746	,014
	ITmed	,014	,908	,002
Other innovations in logistics	ITG	18,941	,002	,703
	ITmed	3,175	,113	,284
Redesign of shipment packaging weight and density	ITG	,287	,607	,035
	ITmed	17,396	,003	,685
Inventory management systems	ITG	3,962	,082	,331
	ITmed	,000	,987	,000
Digital supply chain management	ITG	,319	,588	,038
	ITmed	,003	,956	,000
E-procurement	ITG	,153	,706	,019
	ITmed	2,052	,190	,204
Unique and automatic identification of products within the whole supply chain	ITG	,124	,733	,015
	ITmed	,583	,467	,068
Reverse logistics	ITG	3,279	,108	,291
	ITmed	,783	,402	,089
New delivery models including the use of alternatively fuelled vehicles or multi-modal logistics	ITG	,158	,702	,019
	ITmed	,360	,565	,043

Shaded data are highly significant.

Table 6

Between subjects effects with sentiment indicator as independent variable with alfa = 0,05, a. R-squared = 0,126 (Adjusted R-squared = 0,067), b. R-squared = 0,164 (Adjusted R-squared = 109).

Origin	Dependent variable	F	Sign.	Partial eta-squared
Correct model	ITG	2,157	0,163	0,126
	ITmed	2,949	0,107	0,164
Intercept	ITG	3,439	0,083	0,187
	ITmed	6,752	0,020	0,310
SI	ITG	2,157	0,163	0,126
	ITmed	2,949	0,107	0,164

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