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THE ROLE OF DOUBLE-LOOP LEARNING IN MANUFACTURING SUPPLY CHAINS. THE STUDY OF THE DISRUPTIONS DRIVEN BY COVID-19 IN POLAND

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Abstract. A global pandemic of coronavirus COVID-19 affects the manufacturing supply chains significantly. This study aims to identify and evaluate the reaction of manufacturing supply chains in using the concept of double-loop learning to mitigate the disruptions induced by COVID-19 at the early stage of pandemic. A two-stage research process has been developed that firstly involves determining the learning pattern of enterprises in industrial supply chains and identifying actions taken. Then, the relationship between taking actions in the field of double-loop learning in the manufacturing supply chains and expecting a change in their market situation, and having knowledge in the field of adaptation to changes caused by the COVID-19 pandemic was examined. The study shows that there is a high level of caution in taking proactive measures in supply chains and a lack of knowledge in the field of adapting industrial supply chains to sudden disruptions caused by the COVID-19 pandemic.

Keywords: manufacturing supply chain, organizational learning, double-loop learning, disruptions, COVID-19, taxonomic analysis.

JEL Classification: D22, D81, D83, D91.

Introduction

Under increasing uncertainty induced by unprecedented changes, the current supply chains are becoming increasingly complex and dynamic structures. A supply chain can be defined as a set of three or more companies directly linked in the upstream and downstream flows of products, information, and finances from a source to a customer (Mentzer et al., 2001). The structure of the supply chain, demonstrating its basic complexity, is formed by a focal company, its immediate supplier, and its immediate customer.

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Nowadays, supply chain managers are urgently forced to cope with these disruptions and look for new ways to survive and flourish in a completely unknown operating environment. One of the most effective tools in dealing with these negative consequences is inter-organizational learning (Ruhl, 2011; Adobor & McMullen, 2018). The concept of inter-organizational learning has gained increasing attention in recent years (Coghlan & Coughlan, 2015), as it concerns the process of learning that goes beyond the boundaries of individual organizations (Theodorakopoulos et al., 2005). Ramish and Aslam (2016) argue that the essence of inter-organizational learning is grounded on the model of double-loop learning. In line with the concept of double-loop learning, the organizational norms and assumptions typical for the current state are questioned to establish a new set of norms existing in the desired state (Argyris, 2003). It concentrates on detecting, revealing, and addressing the root causes of underperformance to form new ways of operating (Kululanga et al., 1999). Double-loop learning can be thus defined as the process that includes updating the actual goals and actions embedded in the standard operating procedures to cope with novel situations (Ogulin et al., 2020). As the concept of supply chain learning, based on the double-loop model, is rooted in inter-organizational learning (Bessant et al., 2003; Zhang & Lv, 2015), it should ideally involve the focal company (e.g. manufacturer), its suppliers, and customers (Golgeci & Arslan, 2014). In our study, we consider the manufacturing supply chains, which consist of suppliers, manufacturers, distributors, and customers, all linked together with a flow of products, information, and finances (Huang et al., 2002). In such a setting, manufacturers play an important role in the product transformation from raw material extraction through the end-use (Ben Yahia et al., 2017). Specifically, to enhance the product offerings, the manufacturers modify their supply chains to be more competitive towards the market rivals, responsive for the customers, and cost-effective in performing organizational activities (Kisperska-Moron & Swierczek, 2011). Consequently, the manufacturers are leaders that initiate and develop certain activities of double-loop learning to make their supply chains capable of adapting and responding to disruptions. Nevertheless, due to a high level of complexity and relational dynamics, the process of double-loop learning in supply chains is a difficult phenomenon to investigate (Flint et al., 2005; Yang et al., 2019). Accordingly, there is still a paucity of studies on supply chain learning, involving the double-loop model, which calls for further research efforts (Biotto et al., 2012).

Recently, the contemporary supply chains have been affected by the negative effects of coronavirus SARS-CoV-2, leading to the pandemic infection of the disease known as COVID-19 (Paul & Chowdhury, 2020). According to the World Health Organization (WHO), pneumonia of unknown cause detected in Wuhan, China, was first reported to the WHO Country Office in China on December 31, 2019. The outbreak was declared a Public Health Emergency of International Concern on January 30, 2020. On February 11, 2020, WHO announced a name for the new coronavirus disease: COVID-19. It was only February 26 when WHO had issued the COVID-19 guidance for businesses and employers, which outlined the basic ways to prevent the spread of the virus, things to consider when employees travel and how to get the business ready in case COVID-19 occurs. Finally, on March 11, WHO announced the pandemic of the new coronavirus, alarming the increasing toll of infection worldwide. More than 132,000 cases of COVID-19 have been reported to WHO from 123 countries and territories. 5,000 people have lost their lives.

Although Europe became the epicenter of the pandemic at that time, disruptions in supply chains were already global. This is because the global supply chain (GSC) extends beyond the geographic boundaries of a country, and suppliers are often located in different countries (Linton & Vakil, 2020). According to the surveys conducted in the early pandemic time, among the Fortune 1000 companies, 16%, and 94% had tier-1 and tier-2 suppliers, respectively, in Wuhan, China (Dun & Bradstreet, 2020). Other studies have shown that at least 5 million companies around the world had tier-2 suppliers located in the Wuhan region (Smith, 2020). Supply chains play a central role in economic growth and stability, therefore, the negative consequences of COVID-19 on the majority of global supply chains have disrupted the global economy, too (Majumdar et al., 2020). The impact of the COVID-19 coronavirus crisis on global trade and supply chains had become a major source of concern for the global economy with unknown implications for the future of manufacturing and sourcing.

The prior studies show how the negative consequences of coronavirus disrupted supply chains. For instance, one of the first survey focused on measuring COVID-19's impact on global supply chain was conducted by Institute of Supply Management between February 22 and March 5, 2020 (McCrea, 2020). It was found that nearly 75% of the companies were already reporting supply chain disruptions in some capacity due to coronavirus-related transportation restrictions. More than 80% believed their organizations will experience some impact because of COVID-19 disruptions. Reported problems concerned, among the others: longer lead times, lowering operating capacity and staff numbers, delays in receiving orders, moving or loading goods, as well as having difficulty getting supply chain information.

The impacts of the COVID-19 on supply chains gained attention not only from industry experts but also from the researchers. There was a common scientific effort to understand the nature of these unprecedented pandemic disruptions that are changing supply chains. References to these studies can be found in the works of the following authors: Magableh (2021), Cheema-Fox et al. (2020), Craighead et al. (2020), Hobbs (2020), Lin et al. (2020), Marusak et al. (2021) and, Chowdhury et al. (2021). Since the outbreak of the pandemic, scientists have been largely analysing the impact of COVID-19 on supply chain performance. This problem has been presented in the works of, inter alia, the following authors: Ivanov (2020), Meyer et al. (2021), Nordhagen et al. (2021) and, Do et al. (2021). Due to the critical shortage or disruption of supply chains some studies have also explored the solutions addressing those problems (Rowan & Laffey, 2020; Staal, 2020). They concerned, among the others, resources allocation and distribution using different approaches (Queiroz et al., 2020; Choi, 2020), streamlining the decision-making process and viability (Ivanov & Dolgui, 2020; Govindan et al., 2020), as well as studied supply chain sustainability (Fasan et al., 2021; Sarkis et al., 2020; Majumdar et al., 2020).

The COVID-19 outbreak has disrupted the supply chain with ripple effects. This challenge requires different strategies and actions, including robust supply chain resilience strategies which could play a dominant role in this pandemic period (Chen et al., 2019; Pournader et al., 2020; Paul et al., 2021). However, given such dramatic and extreme disruption, even the best combinations of traditional supply chain risk management strategies such as agility, flexibility, and surplus inventory have demonstrated to be insufficient to cope with this particular global pandemic (Fasan et al., 2021). This unanticipated COVID-19 crisis has a

far-reaching and significant impact on enterprises and their supply chains and, to reduce such impact requires not only effective organizational crisis management practice but also significant learning effort (Lagadec, 1997).

Despite the significance of coronavirus for the contemporary supply chains, there is still a dearth of research that depicts the role of inter-organizational learning, grounded upon the double-loop model in mitigating the disruptions driven by the coronavirus. Therefore, in the face of the negative effects of coronavirus, it is intriguing how the manufacturing companies that operate in the broader context of their supply chains cope with uncertainty induced by the COVID-19 pandemic. To address this gap, the goal of our study is to identify and evaluate the reaction of manufacturing supply chains using the concept of double-loop learning to mitigate the disruptions induced by COVID-19.

The research questions addressed in the paper are:

1. To what extent do the manufacturing supply chains use the double-loop learning activities under the epidemiological threats?
2. Is there a link between expecting market changes resulting from the COVID-19 pandemic and taking double-loop learning actions in the manufacturing supply chains?
3. Is there a relationship between the knowledge of adaptation to changes caused by the COVID-19 pandemic and applying double-loop learning actions in the manufacturing supply chains?

The paper offers several contributions. First, it is one of the very few studies that show how manufacturing companies in supply chains strive to deal with the unexpected disruptions induced by COVID-19 at the early stage of the pandemic. Secondly, the paper provides empirical evidence that the concept of double-loop learning can be instrumental when dealing with the negative consequences of COVID 19. The study also suggests that the proactive activities of double-loop learning performed by the investigated companies can be depicted as emergent in nature, which means they are not planned or designed in advance but are initiated spontaneously and impulsively.

The structure of the paper consists of several sections. Following the introduction, we proceed with the literature review and the methodology of the study. Then necessary methods to analyze empirical data and discuss research findings concerning the research hypotheses are developed. Finally, we conclude with a discussion of the findings, demonstrate the limitations of the study and indicate implications for future research.

1. Literature review

The analysis of the publications available in the Web of Science database shows that the issues related to the double learning loop are a relatively new research problem, not yet well recognized in the literature on the subject. A total of 333 publications referring to this term in the title, keywords, or abstract were identified in the Web of Science database. It is worth emphasizing that research in this field covers many different areas. Table 1 classifies research areas in which the concept of double-loop learning was analyzed. The most frequently cited papers in this field were taken into account.

Table 1. Areas of application of the concept of double-loop learning in the literature on the subject

Areas of applications	Number of publications	References
Management	53	Romme and van Witteloostuijn (1999), Mazutis and Slawinski (2008), Tosey et al. (2012)
Education & Educational Research	51	Scribner et al. (1999), Blaschke (2012), Carless (2019)
Business	38	Gottlieb and Sanzgiri (1996), Heracleous (1998), Chaston et al. (2001), Pittaway and Thorpe (2012)
Computer Science	33	McAvoy and Butler (2009), Hwang and Wang (2016)
Environmental aspects & Ecology	23	Fischer et al. (2009), Kreibich et al. (2011), Johannessen and Hahn (2013), Inman et al. (2018)
Engineering	23	Choularton (2001), Wong et al. (2009), Guo and Yiu (2016)
Health	14	Reason et al. (2001), Stavropoulou et al. (2015)
COVID-19	11	Ladi and Tsarouhas (2020), Jaaron et al. (2021)

Nowadays, the primary source of concern for manufacturing supply chains is the negative impact of COVID-19 coronavirus (e.g. Ladi & Tsarouhas, 2020; Jaaron et al., 2021). Both the spread of coronavirus and the reactions of individual companies and supply chains to disruptions were diverse. Nonetheless, the coronavirus and its negative consequences have recently become the major external environmental factor that has affected the companies and their supply chains. The supply chains are challenged to look for new ways of operating, including inter-organizational learning, to deal with those disruptions. In general, when reviewing existing literature, Yang et al. (2019) identify three major research strands on supply chain learning. First, a large body of literature combines supply chain learning with other constructs to explore their relationships (e.g. supply chain learning and innovation). Second, prior studies also examine the process of supply chain learning through qualitative research, involving a case study method, and building a conceptual framework. Third, previous research also pays attention to the application of supply chain learning in specific contexts, involving third-party logistics and vendor-managed inventory. Following Zhang and Lv (2015), supply chain learning can be defined as the process of acquiring knowledge, perfecting behavior, and optimizing the organizational system to maintain the supply chain's capability of sustainable survival, and development in dynamically changing environments. The other interpretation was delivered by Silvestre (2015) who argues that supply chain learning involves the development and use of new knowledge that has the potential to affect the supply chain competitive advantage.

Organizational researchers have long argued that inter-organizational learning plays a pivotal role in response and adaptation to dynamic changes in an environment (Fontaine et al., 2012; Fulmer & Keys, 2004). Argyris and Schön (1978) define two major learning modes: single- and double-loop learning. The first one works well in a stable and predictable environment, and thus involves standard operating procedures (rules) to conduct and monitor activities, while the latter one includes updating the actual goals and actions to deal

with novel situations (Ogulin et al., 2020). As highlighted by Hayes and Allinson (1998), the major difference between single and double-loop learning can be grasped by the shorthand of "doing things better" versus "doing things differently". In other words, while single-loop learning is rather focused on making adjustments in actions and strategies, double-loop learning concentrates on re-thinking the underlying goals and policy (Dunlop, 2010). Figure 1 illustrates the model of single and double-loop learning.

As depicted in Figure 1, single-loop learning is embedded within double-loop learning, and, in consequence, double-loop learning extends single-loop learning by the ability to generate new organizational practices and processes (Thomas et al., 2017). Generally speaking, double-loop learning occurs when the existing norms and assumptions are questioned to maintain a new set of norms (Argyris & Schön, 1978; Argyris, 1990; Barlow & Jashapara, 1998). Double-loop learning thus requires asking questions about the reasons and motives that stand behind the organizational policy (Fontaine et al., 2012). It tends to publicly understand and discuss the shared mental model of the group (Senge, 1990). The concept of double-loop learning can be traced back to the multifaceted deep-rooted causes (Kululanga et al., 1999). Through developing double-loop learning, the supply chain partners can learn from each other and enhance their processes (Ogulin et al., 2020). Double-loop learning is perceived to be an essential tool for transformational change (Fontaine et al., 2012; Argyris, 2004). In other words, when facing disruptions, double-loop learning makes the supply chains to be capable of transitioning from one state of equilibrium to another state of equilibrium.

The manufacturing companies as leaders in their supply chains, ought to practically employ double-loop learning to face the disruptions driven by COVID-19, and to initiate the necessary processes to follow a new state of equilibrium. In other words, double-loop learning requires the manufacturers to be creative, seek new knowledge, question the existing status quo, and be holistic when making future-based decisions concerning supply chains (Thomson et al., 2014). In the case of double-loop learning, the goals and policy are critically examined to determine whether the routine is sustainable and resilient to the expected changes over a particular period. Prior studies provide a broad spectrum of activities typical for double-loop learning. They can be conventionally split into reactive and proactive activities (Swierczek, 2018). Regarding the nature of the response, the reactive activities usually involve building redundancies which take the form of excess inventory and surplus capacity to reduce the severity of the event (Chopra & Sodhi, 2004; Kwak et al., 2018; Sheffi & Rice, 2005; Thun et al., 2011), while the proactive activities depend on using fixed assets into new facilities, supplier contracts, or risk monitoring systems (Elluru et al., 2019; Knemeyer et al.,

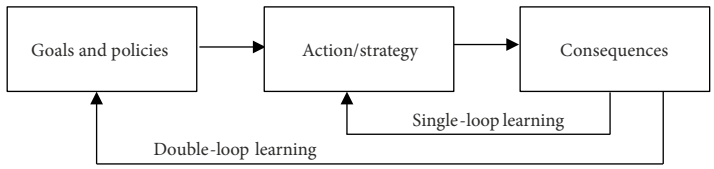

Figure 1. The concept of single and double-loop learning (Adapted from Dunlop (2010))

2009). Nonetheless, the need for double-loop learning mainly stems from the fact that traditional organizations and their inflexible management systems are not sufficient to face the current dynamic environment, as they lack the capabilities needed to grasp unpredictable opportunities (Soltani et al., 2011). In the light of those above, we propose the following hypothesis:

H1: There is a relationship between double-loop learning and the expected change of the market position of manufacturing supply chains exposed to the disruptions driven by COVID-19.

It is worth mentioning that not only does double-loop learning involve the simple correction of activities, as illustrated by single-loop learning, but most of all, it engages a more profound modification of the existing mental model. The perception of environmental uncertainty has a strong influence on the market behavior of enterprises. Responding to uncertainty as a psychological state begins with the individual cognitive needs of managers (Frankowska, 2018). The mental models used by the managers of supply chains are lenses through which they perceive the world they operate in. However, the managers do not operate in isolation. On the contrary, they interact in teams, sharing their mental models (Stacey, 1993). Although the managers are under intense pressure to accept group thinking unconsciously, the dynamic environmental conditions require questioning the implicit shared models (Stacey, 1996).

To sum up, double-loop learning works well when the organization is permeated with new values due to questioning the existing mental model under the pressure of unprecedented and uncertain disruptions (Bagodi & Mahanty, 2013). This makes managers face new challenges, as they should rather contest the implicit group models to respond better to the ongoing disruptions driven by COVID-19 and continuously apply new ways of solving the managerial problems and indicate future development directions. As highlighted by Beckett and Murray (2000), double-loop learning requires more creativity and adaptation of managers as they seek to tap the implicit knowledge of individuals. Double-loop learning is thus a deeper change than single-loop learning because it transforms the underlying system that produces the current organizational behavior (Hovlid et al., 2012). In other words, double-loop learning occurs when individuals question the existing status quo to allow changes in the current values of the organizational theory in use (Argyris & Schön, 1996). The manufacturing supply chains learn when discoveries, evaluations, and insights by individuals are successfully embedded in the organization's mental models or cognitive systems and memories (Simon, 1991). Following Kim (1993), we believe that double-loop learning emerges when individual models of managers become incorporated into the manufacturing supply chain through shared mental models, affecting organizational action. However, managers are usually focused on past solutions, as these are entrenched in their mental models and thus pay little attention to find new, revolutionary solutions (Beckett & Murray, 2000). These mental models define underlying beliefs, values, and habits through which managers interpret the world. When applying double-loop learning, managers need to challenge the existing mental model – adapt it or discard it (Henderson, 1997). In the light of those mentioned above, we postulate the following hypothesis:

H2: There is a relationship between double-loop learning and the expertise of managers in how the manufacturing supply chains should operate to adapt to the new environmental conditions caused by COVID-19.

2. Research methodology

2.1. Research framework

The practical emanation of double-loop learning within the supply chain is the concept of risk management, which promotes sustainability and greater resilience against uncertain disruptions (such as those induced by COVID-19) (McCann et al., 2014). In other words, double-loop learning requires supply chain risk management to be creative, seek new knowledge, question the existing status quo, and be holistic when making future-based decisions (Thomson et al., 2014). In the case of double-loop learning, the current supply chain risk management goals are critically examined to determine whether the routine is sustainable and resilient to the expected changes over a particular period. Consequently, it prompts questions whether the increased probability of losses justifies certain risk management decisions, which usually entail the growth of costs (Intergovernmental Panel on Climate Change [IPCC], 2012). Prior studies provide a broad spectrum of activities typical for supply chain risk management as a component of double-loop learning. A list of actions planned or taken by manufacturers using double-loop learning has been developed to determine the scope of adaptation of industrial supply chains endangered by the COVID-19 pandemic. A set of 6 different types of activities were identified in total based on the literature review and assigned to particular groups (Table 2).

Although in the literature on double-loop learning, mainly reactive and proactive activities are distinguished, this study additionally distinguishes the *so-called* basic actions (O1) that arise from the exceptional situation related to the COVID-19 pandemic. The second group (O2) includes the reactive actions that are assumed to be undertaken as soon as possible by most manufacturing companies operating on the market under the epidemiological threat with the main goal of duplicating resources and maintaining redundancy. They particularly cover: company expenses limitation, use of surplus resources, creating inventory, and delaying purchases what is presented in the studies of the following authors: Rice and Caniato (2003); Sheffi (2001); Soler and Bassetto (2008); Goldsby and Garcia-Dastugue (2003); van Hoek (2001); Yang et al. (2004). The third group includes activities defined as proactive, whose main goal is to ensure the flexibility of manufacturing supply chains in relationships among companies (O3a) and within the company (O3b).

The flexibility in relationships among companies was studied by) Norrman and Jansson (2004); Craighead et al. (2007); Knemeyer et al. (2009); Skipper and Hanna (2009) and, Swierczek (2018). The indicated authors have (stressed) highlighted the following activities: introducing online activities, renegotiation of contracts with banks, renegotiation of contracts and agreements with co-operators (suppliers/ customers), modification of the supplier base, searching for new clients/orders, modification in logistics and transport services for contractors.

Table 2. Structure of the activities of double-loop learning assessed in the study, undertaken in manufacturing supply chains under epidemiological threat

The area of activities undertaken or planned to be undertaken by the companies participating in the study		Actions	O4 All Activities
O1 Basic activities		x_{11} – ensuring work safety for employees on the company's premises (disinfection, etc.); x_{12} – ensuring the security of contacts in the company for contractors (e.g., suppliers);	$x_{11} - x_{34b}$
O2 Reactive actions: "resources duplication and redundancy"		x_{21} – company expenses limitation; x_{22} – use of surplus resources; x_{23} – create an inventory; x_{24} – delaying purchases;	
O3 Proactive activities: "ensuring flexibility in the functioning of supply chains"	in relationships in the supply chain	x_{31a} – introducing on-line activities (for customers / suppliers); x_{32a} – renegotiation of contracts with banks; x_{33a} – renegotiation of contracts and agreements with co-operators (suppliers/customers); x_{34a} – modification of the supplier base; x_{35a} – searching for new clients/orders; x_{36a} – modification in logistics and transport services for contractors;	
	in the internal functioning of the company	x_{31b} – home-office work entry; x_{32b} – company restructuring (layoffs); x_{33b} – reorganization of production processes; x_{34b} – modification of the company's offer (product, service).	

The flexibility in relationships among companies covers the following activities: introducing online activities, renegotiation of contracts with banks, renegotiation of contracts and agreements with co-operators (suppliers/customers), modification of the supplier base, searching for new clients/orders, modification in logistics and transport services for contractors (Knemeyer et al., 2009; Skipper & Hanna, 2009; Swierczek, 2018; Craighead et al., 2007; Norrman & Jansson, 2004). The flexibility within the company covers home-office work entry, company restructuring, reorganization of production processes, modification of the company's offer (Mellat-Parast & Digman, 2008; Huang & Chu, 2010). On the other hand, all identified activities undertaken by enterprises were defined as the fourth area (O4). The creation of an area covering all activities will make it possible to check which sub-areas were most decisive for the final result of the surveyed enterprises. In line with the adopted assumptions, enterprises and supply chains that best adapt to the new operating conditions caused by the COVID-19 pandemic will use a wide range of double-loop learning activities. Therefore, it can be assumed that the model will be an enterprise operating in a manufacturing supply chain that applies all the proposed activities, allowing for a better adaptation to the changed market functioning conditions. Therefore, one of the research goals will be to build a model describing the behavior of enterprises in the manufacturing supply chain under changed conditions of epidemiological threat and indicate the areas where the distance to the established pattern is the smallest and the largest. A two-stage research process was

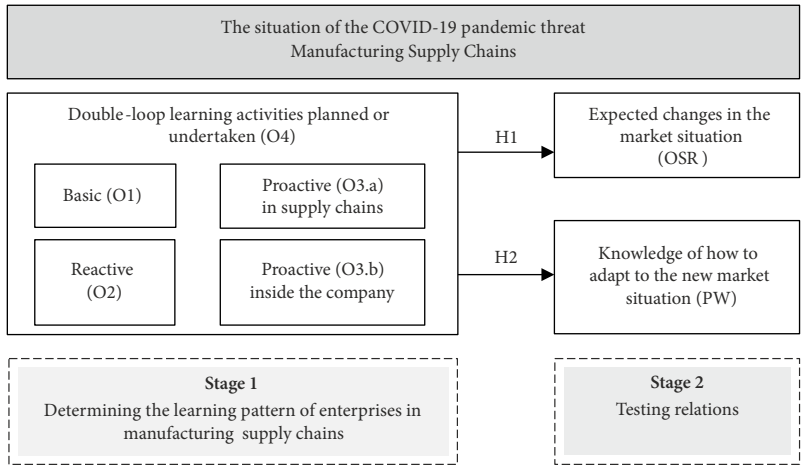

Figure 2. Research concept

developed, bearing in mind the purpose of the work and the need to answer the formulated research questions. It first involves determining the learning pattern of enterprises in manufacturing supply chains and assessing the application of double-loop learning activities. Then, an examination of the relationships determined by the research hypotheses will be carried out. The research concept is presented in Figure 2.

2.2. Research material

The information basis for the analyzes presented in the paper was the data collected during in-depth interviews (IDI) based on a prepared semi-structured research questionnaire. The survey was carried out on March 19–23, 2020. The interviews were conducted with senior management representatives (interviews lasted 45–60 minutes). The selection of enterprises for the study was deliberate – 30 respondents representing enterprises belonging to the so-called metal and machine industry sector in Poland. The operation of the surveyed companies on the market was significantly diversified and ranged from 3 to even 75 years. A detailed description of the sample contains Table 3.

The dataset that underwent further analysis included 16 different actions that could be taken presented in Table 2. All respondents' responses were measured on a 5-point Likert scale, with 5 being a strongly affirmative answer and 1 being a negative answer. In stage 2, the declarations of the research participants, following the adopted assumptions, were also compared with the respondents' answers regarding:

- assessing the possibility of changes in the market situation and the functioning of industrial supply chains in the situation of the COVID-19 pandemic (OSR, where 1 – means that, according to the respondents, changes in the market situation and the functioning of manufacturing supply chains will not occur, and 5 – the opposite);
- having knowledge of how manufacturing supply chains should function to adapt to the new conditions related to the COVID-19 threat (PW, where 1 – means a definite lack of knowledge in this area, and 5 – the opposite).

Table 3. Main characteristics of the sample

Characteristics of the sample	Origin of capital (dominant capital):	
	Polish capital (N = 21)	Foreign capital (N = 10)
1. Enterprise size:		
a) small enterprise	8	1
b) medium	13	6
c) large	–	2
2. The average length of operation on the market		
a) 5 year and less	1	1
b) 6–15	8	7
c) over 15 year	12	1

2.3. Research methods

Following the adopted research concept, a two-stage research procedure was used in the paper. The first stage aimed to define the learning pattern of enterprises in manufacturing supply chains. Therefore, it was necessary to build a model describing the behavior of enterprises operating in manufacturing supply chain in the changed conditions of epidemiological threat and to indicate the areas where the distance to the established pattern is the smallest and the largest. Hence, taxonomic measures of development were determined for each area analyzed in the study.

First, the development pattern method proposed by Hellwig (1968) was used. Its effect are the rankings of enterprises built separately for each analyzed area (O1–O3) and all areas jointly (O4). The detailed course of the research procedure using the development pattern method includes several steps.

In the first one, the values of diagnostic features for individual objects (enterprises) are subjected to normalization. Since the assessed features are mainly qualitative, the zero unitarisation method proposed by Kukuła (2000) was used to normalize the features. The standardizing formula in this method is carried out according to the following formula:

$$z_{ij} = \frac{x_{ij} - \min\limits_{i} x_{ij}}{\max\limits_{i} x_{ij} - \min\limits_{i} x_{ij}}, \text{ when } x_j \text{ is a stimulant;} \tag{1}$$

$$z_{ij} = \frac{\max\limits_{i} x_{ij} - x_{ij}}{\max\limits_{i} x_{ij} - \min\limits_{i} x_{ij}}, \text{ when } x_j \text{ is a destimulant.} \tag{2}$$

In the next step, the so-called development pattern P_0 is established with coordinates (z_{01} , z_{02} , ..., z_{0m}), if the feature being examined is a stimulant: $z_{0j} = \max\limits_{i} z_{ij}$, and if it is a destimulant: $z_{j} = \min\limits_{i} z_{ij}$ and Euclidean distance (D_{i0}) of the examined objects (enterprises) from a given pattern, based on the formula:

$$D_{i0} = \sqrt{\sum_{j=1}^{m} \left(z_{ij} - z_{0j} \right)^2}, \quad i = 1, \ldots, n. \tag{3}$$

Then based on the distance series received: D_{10}, D_{20}, ..., D_{n0}, the following is determined:

$$\overline{D_0} = n^{-1}\sum_{i=1}^{n} D_{i0}; \tag{4}$$

$$S_0 = \sqrt{n^{-1}\sum_{i=1}^{n}(D_{i0} - \overline{D}_0)^2}; \tag{5}$$

$$D_0 = \overline{D}_0 + 2S_0, \tag{6}$$

where: $\overline{D_0}$ – the arithmetic average of the distance series: D_{10}, D_{20}, ..., D_{n0}, S_0 – its standard deviation. The value of the development measure is determined based on the formula:

$$d_i = 1 - \frac{D_{i0}}{D_0},\ i = 1,\ldots,n, \tag{7}$$

receiving the string: d_1, d_2, ..., d_n. The values of this measure, corresponding to individual objects (in this case, enterprises), are ordered from the highest to the lowest value. The higher the d_i measures are adopted by the object, the more similar it is to the pattern model object.

The values of the taxonomic measure of development (d_i), corresponding to individual objects (in this case, surveyed firms), are ordered from the highest to the lowest value. Based on the results of this measure, the typological groups containing companies characterized by a similar level of development can be distinguished. For this purpose, the following procedure can be applied:

- group 1: $d_i \geq \overline{d_i} + S_{d_i}$ – a high level of development in considered areas,
- group 2: $\overline{d_i} + S_{d_i} > d_i \geq \overline{d_i}$ – an average level of development,
- group 3: $\overline{d_i} > d_i \geq \overline{d_i} - S_{d_i}$ – a low level of development,
- group 4: $d_i < \overline{d_i} - S_{d_i}$ – a very low level of development.

Then, the second stage of the research was started. The aim of which was to test the formulated research hypotheses indicating the relationship between the behaviors of the surveyed companies and their opinions regarding the assessment of the possibility of changes in the market situation of manufacturing supply chains in connection with the disruptions of the COVID-19 (H1) pandemic and their self-assessment of knowledge how manufacturing supply chains should function to adapt to the new conditions of the COVID-19 (H2) pandemic. Pearson's correlation coefficient was used to evaluate the relationships occurring in the studied areas.

A detailed description of the methods applied in the study can be also found in the following papers: Cheba (2019), Zioło et al. (2019), Cheba et al. (2020).

3. Results and analysis

The analysis results in stage 1 resulting from the applied calculation procedure are presented in Tables 3–4. Table 3 contains the results of the division of the surveyed enterprises into typological groups in each of the analyzed areas (O1–O3) and additionally taking into account all possible actions analyzed in the study (O4).

Table 4. Division of surveyed enterprises into typological groups

Actions taken or planned to be undertaken by participating companies		Group	The boundaries of the interval	Number of companies
O1 Basic activities		I II III IV	> 0.9999 (max. 1.0000) (0.9999; 0.6835> (0.6835; 0.0.3418> <0.3418 (min. 0.0980	16 – 7 7
O2 Reactive actions: "duplication and redundancy of resources"		I II III IV	> 0.6357 (max. 0.8746) (0.6357; 0.4640> (0.4640; 0.2924> <0.2924 (min 0.1776)	3 10 11 6
O3 Proactive activities: "ensuring flexibility in the functioning of supply chains"	in relationships in the supply-chain	I II III IV	> 0.6726 (max. 0.7750) (0.6726; 0.5096> (0.5096; 0.3465> <0.3465 (min 0.1952)	6 9 9 6
	in the internal functioning of the company	I II III IV	> 0.6409 (max. 0.8268) (0.6409; 0.4489> (0.4489; 0.2570> <0.2570 (min 0.0202)	3 13 9 5
O4 All Activities		I II III IV	> 0.5726 (max. 0.7686) (0.5726; 0.4287> (0.4287; 0.2848> <0.2848 (min 0.0742)	5 9 14 2

As can be seen from the information presented in Table 4, the smallest range (R – the difference between the maximum and minimum value) was typical for the division of the surveyed enterprises into typological groups obtained as the result of enterprises' declarations concerning undertaking basic activities (O1, $R = 0.9020$) and the activities of the so-called proactive actions aimed at ensuring the flexibility of the internal functioning of the company (O3b, $R = 0.8066$).

The situation is different concerning the subsequently received divisions. The respondents' responses being the basis for dividing the surveyed enterprises into groups are much more varied in their case. The result is the classification of companies into all distinguished typological groups. It is worth noting that the respondents were the least interested in the so-called reactive activities consisting of duplication and redundancy of resources. A similar situation was noted in the third analyzed area – proactive activities: ensuring flexibility in the supply chain. This applies, for example, to activities aimed at modifying the supplier base – 16 respondents declared no interest in such activities or the renegotiation of contracts and agreements with co-operators – 11 representatives of enterprises declared no interest in such activities.

Table 5 presents, as an example, the detailed results obtained during the research for the four enterprises with the highest and the lowest values of the synthetic measure. They were calculated, considering all possible measures to adapt the industrial supply chains under investigation to the new market situation caused by the epidemiological threat. On the other hand, Figure 3 shows the evolution of the responses of enterprises occupying the first and last place in the rankings, respectively.

Table 5. Detailed results of selected enterprises

Area		Performance assessed	Company No.			
			1	2	29	30
O1 Basic activities		x_{11} – ensuring work safety for employees on the company's premises (disinfection, etc.);	5	5	5	2
		x_{12} – ensuring the security of contacts in the company for contractors (e.g., suppliers);	5	5	4	4
O2 Reactive actions: "duplication and redundancy of resources"		x_{21} – company expenses limitation;	5	5	2	1
		x_{22} – use of surplus resources;	3	5	2	1
		x_{23} – create inventory (e.g. components);	5	5	2	5
		x_{24} – delaying purchases (e.g. components);	4	5	2	5
O3 Proactive activities: "ensuring flexibility in the functioning of supply chains"	in relationships in the supply chain	x_{31a} – introducing on-line activities (for customers / suppliers);	3	4	1	1
		x_{32a} – renegotiation of contracts with banks;	5	3	2	1
		x_{33a} – renegotiation of contracts and agreements with co-operators (suppliers / customers);	4	4	2	1
		x_{34a} – modification of the supplier base;	5	5	3	1
		x_{35a} – searching for new clients / orders;	5	2	3	1
		x_{36a} – modification in logistics and transport services for contractors;	5	4	2	1
	in the internal functioning of the company	x_{31b} – introduction of home-office mode;	4	4	2	1
		x_{32b} – company restructuring (layoffs);	5	5	4	5
		x_{33b} – reorganization of production processes;	4	5	2	1
		x_{34b} – modification of the company's offer (product, service).	4	5	2	5

Note: 5 means a definite interest in undertaking activities of this type, and 1 – a definite lack of such interest.

In the case of the former, only two solutions: x_{22} – using the surplus resources and x_{31} – introducing online activities (for customers/suppliers) were not assessed as applicable. The situation is entirely different in the case of the enterprise classified at the last place in the ranking, which declared an evident lack of interest in the majority of possible actions allowing for its better adaptation to the changing conditions of the functioning of industrial supply chains.

In turn, in stage 2, following the described research procedure, an analysis was made of the relationships between the respondents' responses concerning the actions taken (O1, O2, O3a, O3b, O4) with the assessment of the possibility of changes in the market situation of industrial supply chains (OSR) related to the COVID-19 (H1) pandemic and their self-assessment of knowing how industrial supply chains should function (PW), to adapt to the new conditions caused by the COVID-19 (H2) threat. The results of the analysis are presented in Table 6.

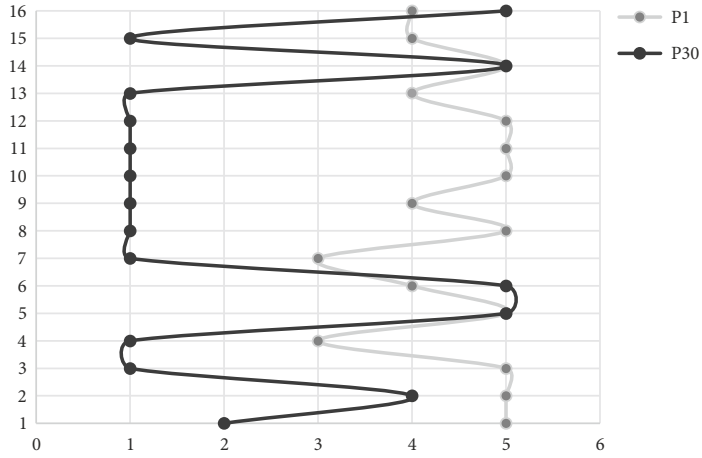

Figure 3. Extreme results of selected enterprises

Table 6. Correlation coefficients of *r*-Pearson between the analysed areas

Area	O1	O2	O3a	O3b	O4	OSR	PW
O1	1.0000	0.0265	–0.0125	0.5007	0.4802	–0.1528	–0.0028
O2	0.0265	1.0000	0.3948	0.2878	0.6476	–0.0729	–0.2473
O3a	–0.0125	0.3948	1.0000	0.4609	0.7398	0.3842	–0.2208
O3b	0.5007	0.2878	0.4609	1.0000	0.8060	0.3853	–0.1549
O4	0.4802	0.6476	0.7398	0.8060	1.0000	–0.3185	–0.2954
OSR	–0.1528	–0.0729	0.3842	0.3853	–0.3185	1.0000	–0.2344
PW	–0.0028	–0.2473	–0.2208	–0.1549	–0.2954	–0.2344	1.0000

The information presented in this Table shows that the highest scores of correlation coefficients were obtained for the following areas:

- Area of basic activities: O1 and O3b (r = 0.5007) and O1 and O4 (r = 0.4802),
- Area of reactive actions: O2 and O3a (r = 0.3948) and O2 and O4 (r = 0.6476),
- Area of proactive activities in relationships in the supply chain: O3a and O3b (r = 0.4609), O3a and O4 (r = 0.7398) as well as O3a and RIA (r = 0.3842),
- Area of proactive activities in the internal functioning of the company: O3b and O4 (r = 0.8060) as well as O3b and OSR (r = 0.3853).

All the indicated coefficients are positive, which means that improvement in one area also causes improvement in the other.

4. Discussion

The obtained results show there is a diversity of double-loop learning activities represented by the surveyed companies, which illustrates a wide spectrum of behavior in the manufacturing supply chains (Table 4, Figure 2). Nonetheless, when interpreting the obtained results,

one should consider the time of conducting the research, which was carried out immediately after the lockdown in Poland and the EU. Sudden disruptions in the manufacturing supply chains were not expected. Accordingly, what is presented in Table 6, is not surprising to observe relatively high values of correlation coefficients for the first area (O1 – basic actions) and the third area (O3 – proactive actions, focused internally in the company). The findings suggest that these activities were usually carried out simultaneously (or their simultaneous implementation was planned). On the other hand, the values of correlation between O2 (reactive actions) and O3b (proactive actions aimed at the company's internal functioning) are slightly lower, which suggests a moderate relationship.

Furthermore, a moderate correlation can be observed between the OSR area (the possibility of a change in the market situation of manufacturing supply chains as a result of the COVID-19 pandemic) with the third area (O3a and O3b). This means that the inevitable changes in the market situation due to the current coronavirus pandemic are linked to proactive actions. On the other hand, there is no correlation between reactive actions and the market situation. Consequently, H1 is partially supported. The results also suggest that is no relationship between double-loop learning and the expertise of managers in how the manufacturing supply chains should operate to adapt to the new environmental conditions caused by COVID-19, giving no support to H2.

In line with the prior studies, the concept of double-loop learning may be one of the most effective tools in dealing with disruptions (Ruhl, 2011; Adobor & McMullen, 2018). It enables establishing a new set of norms embedded in the desired state through questioning the norms and assumptions typical for the current state (Argyris, 2003). As a result, when the disruptions occur, the supply chain can transit from one state of equilibrium to another state of equilibrium, regarded as the desired state of invulnerability and resistance. Our research results show that managers are not aware of the need to change and question the existing mental model, nonetheless, they perform some portion of double-loop learning actions. More specifically, managers do not have the necessary expertise to lead the companies during crisis, however, they still perform some actions typical for double-loop learning. This might be due to the first shock and small amount of time for managers to change their mindset and work out new solutions. The obtained research results thus provide evidence that the managers in the surveyed companies were startled and unprepared to respond to the sudden and unpredictable disruptions driven by COVID-19. Therefore, as evidenced in our study, the requirement of questioning the existing mental model in the face of unprecedented and uncertain disruptions (Bagodi & Mahanty, 2013) has not been met, before the double-loop learning activities are performed. This may be due to the critical moment of the study, which was conducted right after the pandemic erupted. While an early stage of the appearance of disruptions is not a positive symptom indicating caution in making decisions, it is surely connected to the lack of necessary expertise and managerial experience on how to deal with the possible scenarios of actions. Likewise, as there was no time to change the existing mental model, only a proactive portion of double-loop learning activities was carried out. It may thus suggest that full adoption of double-loop learning requires the mental model to be changed. This is corroborated by Senge (1990) who argues that the ultimate goal of double-loop learning is to understand and discuss the shared mental model of the group.

Moreover, the whole process should start with managers who are engaged in double-loop learning (Fulmer & Keys, 2004). The shared mental model is affected by the beliefs of individuals and at the same time, individuals are socialized into the beliefs represented by the shared mental model. Nevertheless, March (1991) suggests that there is a potential threat for the organization when individual organizational members thoughtlessly adjust to the shared mental model before this model can learn from them. This threat might be even magnified when individuals represent a strong and credulous ideological commitment to the shared model ignoring or pretending to ignore the possible appearance of deviant collective thinking (Hayes & Allinson, 1998).

On the other hand, the results may suggest that the strength of disruptions induced by the coronavirus made the managers react more definitely and extensively to deal with unexpected uncertainty. In other words, building excessive resources, as recommended by the reactive approach, to mitigate the negative effects of the coronavirus may appear to be insufficient regarding the impact of disruptions. This might be due to the fact that the disruptions driven by the coronavirus are so severe for the manufacturing supply chains that a reactive portion of double-loop learning activities is not enough. Therefore, as evidenced in our study, the managers in the investigated companies reach for more advanced solutions, including the proactive approach to flexibly and quickly respond to the negative effects of the coronavirus.

Consequently, we believe that the proactive actions performed by the investigated companies can be depicted as emergent in nature, which means they are not planned or designed in advance but are initiated spontaneously and impulsively. In other words, the double-loop learning actions are organized voluntarily and thus can yield a new pattern of behavior without any blueprint. More notably, these patterns cannot be predicted or reduced to the individual actions that produce them (Stacey, 1996).

Conclusions and limitations of the study

The goal of our study was to identify and evaluate the reaction of manufacturing supply chains in using the concept of double-loop learning to mitigate the disruptions induced by COVID-19. Specifically, the results show that there is a relationship between a proactive portion of double-loop learning activities and the expected change of the market position of manufacturing supply chains exposed to the disruptions driven by COVID-19. Likewise, as evidenced in our research, there is no relationship between double-loop learning and the expertise of managers in how the manufacturing supply chains should operate to adapt to the new environmental conditions caused by COVID-19. Our study shows that a proactive portion of double-loop learning activities can be used to mitigate the disruptions driven by COVID-19, however, to partially perform the double-loop learning activities, the existing mental model does not necessarily need to be changed.

The COVID-19 pandemic has changed market conditions rapidly, which forced the need to update the actual governing norms and values embedded in the standard operating procedures to cope with novel situations. The difficulty in formulating clear conclusions results from the limitations in the implementation of the research. A relatively small research sample is the most important one. However, it should be taken into account that it was a challenging

moment in the functioning of enterprises and obtaining research material at the time of the COVID-19 pandemic was extremely difficult. It is also worth noting that the research was sector-specific (metal and machine industry) and geographically limited (Polish market), although the selection of respondents took into account the international scope of the supply chain. In addition, the research is static. It is a picture of the current situation, i.e., at the beginning of the widely announced COVID-19 pandemic. Therefore, it would be interesting to repeat the research to verify respondents' attitudes regarding the application of double-loop learning in the manufacturing supply chains. The study brings a significant application value for the managers of industrial supply chains, indicating the need to apply to more activities related to risk management. In in-depth interviews conducted at that time, all respondents were convinced that the situation would return to normal within one year. However, the reality is different. The economy functions in what is known as the new normality, where pandemic restrictions still apply. Therefore, the organizational learning ability of enterprises operating in industrial supply chains in conditions of uncertainty and constant disruptions is even more important than before.

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Author contributions

Conceptualization: M.F., A.S; methodology: M.F., A.S., K.Ch; software: M.F., K.Ch.; validation: M.F., K.Ch.; formal analysis: M.F., A.S., K.Ch; investigation: M.F., A.S., K.Ch.; resources: M.F., A.S., K.Ch; data curation: M.F., K.Ch.; writing original draft preparation: M.F., A.S., K.Ch; writing review and editing: M.F., A.S., K.Ch; visualization: M.F., K.Ch; supervision: M.F., A.S., K.Ch.; project administration: M.F., A.S., K.Ch.

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