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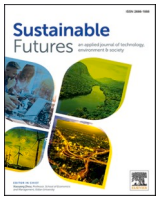

COVID-19 disruptions and Norwegian food and pharmaceutical supply chains: Insights into supply chain risk management, resilience, and reliability

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ABSTRACT

The purpose of this study is to investigate how the COVID-19 crisis affected delivery security and firms' preparedness and responses in Norway. Investigations focus on supply chains which were critical for maintaining the supply of essential goods when large parts of society closed down. This includes four firms belonging to food and pharmaceutical industries, representing different parts of the respective supply chains, and covering imports, exports, domestic distribution, and home-delivery services.

The originality of this article is that we employ theoretical models on supply chain risk management, resilience and reliability in conjunction, where these are usually used separately. Recognizing links, overlaps, and complementarity between the models, and using them step-by-step, we exploit synergies that enable more comprehensive assessments of strengths and weaknesses in firms' supply chains, covering gaps, prioritizing between improvement areas, and collecting input towards detailed, actionable risk mitigation actions. Investigations build on semi-structured interviews, systematically covering the formative elements for each of the models. Using the models in conjunction, we compare the firms and identify differences, similarities, strengths, and weaknesses in the consequences of pandemic-related disruptions and how firms approached the challenges.

The main challenges for the firms were sudden demand changes early in the pandemic. While the firms had minor differences, their pre-pandemic contingency plans were generally not actionable or detailed enough, nor prepared for the pandemic's longevity. Therefore, more detailed and long-term guidelines are desirable, noting the importance and interrelationships of elements of supply chain risk management, resilience, and reliability. A common feature for all firms, and crucial for handling disruptions, is the importance of good and long-term relationships with upstream and downstream supply chain partners and the need for improving contingency plans and future resilience.

1. Introduction

The COVID-19 pandemic is unprecedented in modern history and the disruptions it has induced have had profound impacts on global supply chains in both upstream and downstream operations [1]. Araz et al. [2] considered COVID-19 the most severe supply chain (SC) disruption the world has experienced in decades, and examples of unexpected challenges include demand and supply shocks related to hoarding, (foreign) labor shortages, and cross-border transportation restrictions [1,3,4]. When COVID-19 hit Europe, the business community was unprepared for its ramifications. Although firms usually have contingency plans, few foresaw the possibility of a pandemic or dealing with the types, combinations, and longevity of challenges the pandemic caused [4]. This necessitated more ad-hoc responses than might be desirable, often based on little information and preparation, and led to increased uncertainty.

The current article investigates how the COVID-19 crisis has affected the risk, resilience, and reliability of supply in food and pharmaceutical supply chains, industries that had to maintain the supply of essential goods when society otherwise closed with the first infection outbreak. We investigated four firms, all major players in their respective sectors in Norway. Our objective was to provide insights into successful and unsuccessful strategies for firms under pressure, the challenges that they faced, best practices, and recommendations for handling current and

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future situations. As such, this article contributes with lessons from the current crisis that may not only make supply chains more resilient and robust to future pandemics, but also to other economic shocks where similar patterns may occur, such as natural disasters.

In all, the article's overarching research questions can be summarized as follows:

- How did COVID-19 disruptions affect Norwegian food and pharmaceutical supply chains?
  - How did firms in these supply chains approach risk, resilience and reliability of supply?
  - How were delivery security and firms' responses affected by the crisis?
  - What lessons can be drawn from the pandemic to make supply chains and contingency plans more resilient and robust?

Our investigation is based on three theoretical models for supply chain analysis, which we utilize as tools for assessing and comparing how (1) risk, (2) resilience, and (3) reliability have affected supply chains for each of the four firms. These three models are often used separately (e.g. Fan and Stevenson [5] or El Baz and Ruel [6] for supply chain risk; Pourhejazy et al. [7], Ali and Golgeci [8] or Stone and Rahimifard [9] for supply chain resilience; Kano and Oh [10] for supply chain reliability). Recognizing several links, overlaps, and complementarity between the models, and using them step-by-step, this article exploits synergies that enable a comprehensive assessment of strengths and weaknesses, and suggests how the firms may become more prepared for future disruptions.

Learning from the current pandemic is important for several reasons, the most obvious of which is better future preparedness. While the last pandemic with comparable severity and scale to COVID-19 (the Spanish flu) occurred more than a century ago, epidemics with potential for long-term disruptions, high uncertainty, and unpredictable scaling have been more likely to occur since then as a result of increased globalization, population growth, and density increases [11,12]. At the same time, new challenges often go hand-in-hand with new opportunities, such as when disruptions lead to innovation or enable firms to gain competitive advantages and attract new customers during difficult times [12]. Lessons from such occurrences may also be valuable.

While the current article has a Norwegian perspective, reports throughout the pandemic suggest that SCs in many other developed countries face many of the same issues (at least partially). In this regard, particularly the investigation of major transport buyers, who are highly dependent on foreign sourcing and supply chains, can contribute to more generalizable and transferable results and lessons, such as those related to pharmaceutical and hospital supplies, as well as food distribution.

The present study demonstrates the synergy of using three theoretical models for SC analysis alongside, rather than separately, as is the standard in most literature. In doing so, this article helps improve future preparedness and contingency plans and provides improved insights into the interrelationships among risk management, resilience, and reliability. This can help firms establish broader, more comprehensive overviews of their strengths and weaknesses, cover gaps in contingency plans, prioritize between improvement areas, and formulate actionable risk mitigation actions.

2. Theoretical background

Supply chain disruption can be defined as "an indication of a firm's inability to match demand and supply", with widespread recognition existing of the negative impacts of disruptions on the economy ([13], p.35). Ellis et al. [[14], p.35] posited that SC disruptions are "unforeseen events that interfere with the normal flow of goods and/or materials within a supply chain", while Hendricks and Singhal [15] explained supply disruptions as glitches that can affect both the short- and long-term profitability of firms. For supply chains covering food and pharmaceutical products, supply chain disruptions can, in severe cases, directly affect food security (e.g. [16]), life, and health. The pandemic has induced a surge in policy attention for these topics, including in Norway (e.g. [17]).

In order to help firms become more prepared to handle uncertainty, and thereby become more robust, scientific literature has contributed with theoretical models on supply chain risk management, resilience and reliability, respectively. The current article employs these models to provide insights on firms' strengths and weaknesses, which can then be used to improve contingency plans, so that firms are more prepared if and when new disruptions materialize.

2.1. Risk management

Supply chain risk management (SCRM) is an important tool when experiencing disruption and can help reduce the likelihood and severity of potential risk scenarios occurring in SCs. Research shows that authors have diverse risk definitions for different parts of the SC [18]. Based on their review, Ho et al. [[18], p.5035] defined SC risk as "the likelihood and impact of unexpected macro- and/or micro-level events or conditions that adversely influence any part of a SC leading to operational, tactical, or strategic level failures or irregularities". Therefore, SCRM will have a broader scope than just a single firm and should account for how processes work between entities involved [19]. There must be an integrated process with risk management culture in focus and clear leadership by senior management [20].

Christopher and Peck [21] defined four types of risk within SCRM: supply risk, process risk, demand risk and control risk. During the COVID-19 pandemic, firms/establishments focused mostly on supply, demand, and control risk [22]. Supply risk refers to how dependent firms are on certain suppliers [23]. Demand risk during COVID-19 refers to spikes in demand and consequent bottlenecks. For example, sudden demand spikes led to SC bottlenecks, with several suppliers unable to deliver as expected. Bottlenecks were also a challenge related to supply risk as many plants closed down for short amounts of time, before opening up again and producing more than ever, without sufficient logistics capacity for delivering produced goods [22]. Finally, control risk is the ability to engage suppliers in the response to the pandemic (ibid).

SCRM plays an important role in enhancing SC resilience, and consists of a process with interconnected steps. A literature review [18] identified the following four steps as most common in SCRM approaches:

- Step 1, risk identification, is crucial to manage risk [18,24]. The aim is to identify all relevant risks and recognize future uncertainties, in order to successfully implement proper SCRM (Fan and Stevenson [5]. Risk awareness is key to being able to manage and understand how to mitigate risks [25].
- Step 2 entails risk assessment and placing risks in a prioritized order based on their likelihood and severity [6,26]. It generally builds on assessments using relevant data, expert opinions, or scenario thinking and also lays the basis for the two subsequent steps [5].
- Step 3, risk mitigation, focuses on reducing risks to acceptable levels by using different strategies [24,26].
- Step 4, riskcontrol, is important in order to monitor identified risks in case their status changes [5,6,24].

El Baz and Ruel [6] showed that the four SCRM steps have a positive effect on SC resilience.

2.2. Resilience

Resilience is a confusing and contradictory concept that not even well-developed disciplines manage to define [27]. In SC terms, it can be summarized as a SC's ability to manage inevitable risk and still move

forward and return to a desired situation [21,28] or "the adaptive capability of the SC 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" ([27], p.131).

SC resilience is often discussed through certain formative elements. Jüttner and Maklan [29] explained four central elements: collaboration, visibility, flexibility, and velocity. In short, collaboration is the element influencing all other elements and ensures that elements are adopted by all parties in the SC [30]. Visibility focuses on the overview of the whole chain, how fast the SC detects signals, and the ability to share information [29]. Flexibility refers to the ability to adapt to both positive and negative impacts and the SC effectively absorbing these [27]. Velocity refers to how efficiently SCs react and recover from disruptions in SC processes [29].

Driven by significant breakthroughs in management thinking, the way that firms compete has evolved; from competition against firms, towards competition against SCs [31]. This development has increased the importance of collaboration across SC entities generally, but also the great essence of collaboration for SC resilience [19,21,32]. To build resilience, organizations in SCs need to collaborate and view the chain with a holistic approach [30]. Therefore, effective sharing of information and coordination have become important areas for risk handling, but require trust, collaboration, and commitment from involved parties [33,34]. Good coordination, collaboration, and communication and relationships with actors up- and downstream the SC will contribute to proactively enhance SC resilience – for example, by improving/steadying service levels and reducing misunderstandings – because all actors will better understand end customers' demands [4,34].

Also SC visibility is considered to be extremely important when facing disruptions. Visibility is the ability to share information across the SC, with timeliness and accuracy of this information being important (Barratt and Oke, 2017; [35,36]). Visibility can enable stronger relationships throughout the whole SC and contribute to better collaboration and higher levels of trust [35], although to improve operational efficiency, a prerequisite is that information is used well [36]. During the COVID-19 pandemic, visibility has been shown to be positively correlated with resilience [37].

With regard to flexibility, recent findings indicate that the firms that were the most resilient during the pandemic were the ones that were flexible [38]. The relationship with uncertainty can be pointed out because flexibility forms a direct response to changes in the existing situation [39].

Finally, velocity relates to the speed with which SCs are able to change, recover, and adapt to new desirable states [21,27,29,40]. Therefore, velocity a capability that is especially needed when encountering disruptions in a SC [40], and can, provided sufficient and correct information, reduce response and recovery times [30].

2.3. Reliability

For SC reliability, three distinct key elements are delivery reliability, customer relationship and supplier relationship. When choosing suppliers, reliability is a key factor [41]. Reliability can be defined as "the probability that all the required materials and products flowing through a supply network will arrive at their destination in a specified interval under stated conditions" ([42], p.264) and is key to ensuring both effectiveness and efficiency [43]. Research has argued that strong relationships with a few suppliers strengthen reliability more than weak relationships with several suppliers [44]. To enhance resilience, SC relationships must also be robust and reliable. Reliable relationships can be built through collaboration, which builds on trust and enables flexibility when unexpected market changes occur [4].

Although SC reliability is not a new area of research, interest in the subject has spiked recently, as the need for reliable deliveries of essential supplies became a focal theme globally [45]. During the pandemic, lead times for certain items became longer than expected [6] and in some areas, customer confidence in the ability of SCs to deliver has decreased [4]. Studying disruptions in relation to SC reliability, Chen et al. [46] found that for short-term disruptions, emergency procurement is a recommendable strategy, while for long-time disruptions, a combination of emergency procurement and a change of products is advised.

Reliability has a close connection with several elements of resilience. For example, long and trusting relationships with suppliers can contribute to good collaboration and flexibility, thereby enabling reliability. Reliability is also a two-way relationship between supplier and customer roles; being a reliable supplier is dependent on the reliability of one's own suppliers.

2.4. Contingency plans

To be better prepared for adverse events, many firms develop contingency plans that are meant to help them respond effectively to unfavorable or emergency situations that may or may not occur in the future [47]. Contingency plans mitigate impacts of unexpected incidents and outline strategies for ensuring business continuity (see e.g. [48]) and continuing daily business operations. These plans should be well-defined, with actionable points and clear instructions on how to prioritize [49].

Regarding emergency response preparation, SC literature refers to planning as an important strategic priority in crisis management, with the pandemic putting the need for holistic approaches to contingency planning high on the agenda [11,50,51,52]. SCs can mitigate risk and expedite disaster recovery by being proactive and investing in contingency plans, and can strengthen SC resilience by enabling the SC to turn around quickly and adapt pre-developed contingency plans to the current disruption [53]. However, creating the perfect contingency plan involves certain difficulties, since the world is constantly changing, and so are the potential risks. Other challenges are balancing the costs of preparing for all potential risks and the benefits of preparedness. According to Fernandes and Saldanha da Gama [53], while costs of planning for disruptions can be high, the consequences of not having a contingency plan can be disastrous.

While SC literature emphasizes the value of having a contingency plan, the reality is that far too many contingency plans are created and then sit dormant for extended periods of time, possibly becoming irrelevant when disruptions of low predictability and high severity arise [52]. A contributing factor is that responses to such disruptions are shaped by human's complex attitudes towards risk perception and management [54,55] and inter-human attitude variations [56]. Therefore, frequent updates of contingency plans, as well as employee involvement in the updates, are crucial to keep SCs prepared for disruptions. The COVID-19 pandemic has demonstrated both the lack of contingency planning and the limitations in contingency planning for extreme events (e.g. [48]). To better manage risk in the event of disruptions, factors such as labor shortages, inventory shortages, procurement, and logistical challenges in the SC should be evaluated in the contingency process and considered in the contingency plan. Post-pandemic, SCs should further review and iterate the contingency plan [4].

3. Materials and methods

3.1. Analytical framework

We employed the three theoretical models discussed above as tools of analysis for assessing and comparing how (1) risk, (2) resilience, and (3) reliability have affected supply chains for each of four firms, using input from semi-structured interviews (see the following sections). Fig. 1 provides a stylized illustration of the analytical framework of the current article. Hereby, we recognize that there are strong links between the models and that they are to some extent complementary, both in terms

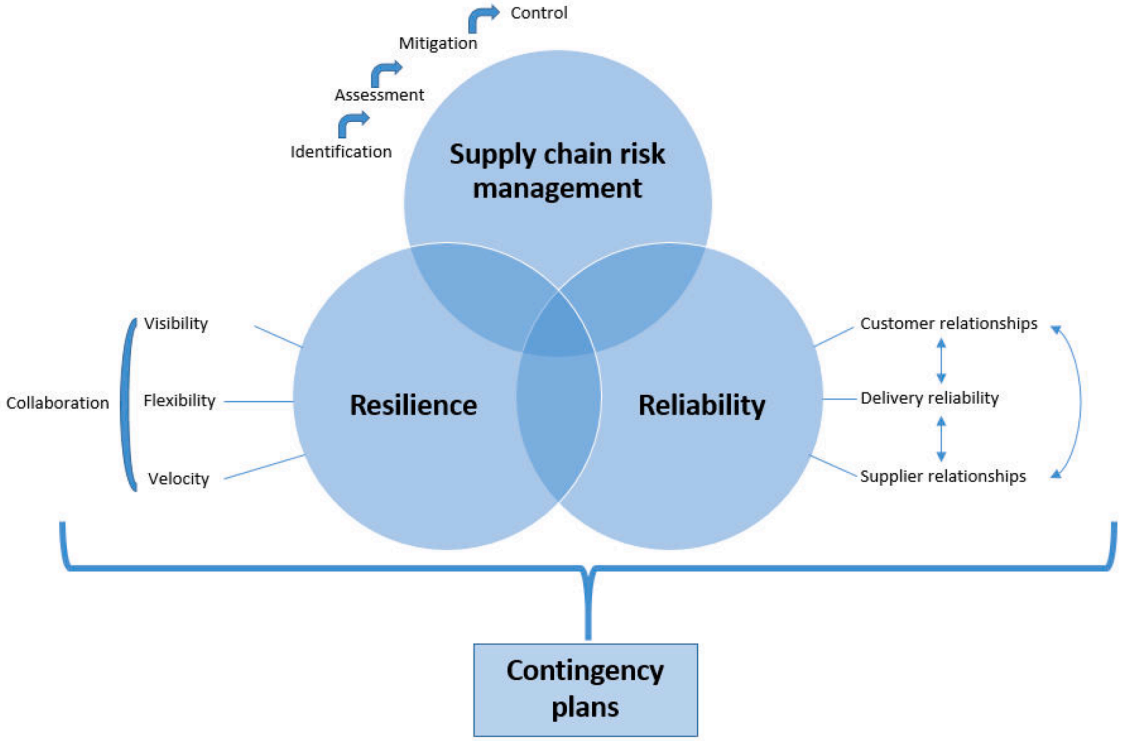

Fig. 1. The three theoretical models for supply chain analysis, the relationships between their steps and sub-elements, the complementarity and overlaps of the theoretical models, and their insights feeding into improved contingency plans.

of overlaps (depicted in the figure) and in terms of possible synergies when employing the models in conjunction. Elements on the outside of the circles represent the formative elements of the three models and illustrate the relationships and linkages between these elements for each of the models individually. For SCRM, these are the four different consecutive steps. For resilience, these are visibility, flexibility and velocity, with collaboration influencing all other elements and ensuring that elements are adopted by all SC partners [30]. For reliability, the elements 'customer relationships', 'delivery reliability', and 'supplier relationships' are all interrelated.

Considering the models together, there are strong linkages and interactions between formative elements of resilience and reliability, and these, in turn, build naturally on the steps of the SCRM and its four discussed risk types (supply, process, demand and control risk). In conjunction, the models can provide comprehensive insights on strengths and weaknesses for the firms and interrelationships between these. Such insights can then be used as inputs for improving contingency plans and firms' future preparedness by covering gaps in current plans, and by allowing comprehensive prioritization of improvement areas and formulation of actionable points. Running through the models in conjunction, and step-by-step, helps to ensure that contingency plans can become both more comprehensive and detailed, can increase awareness, and reduces the risk of inadvertently leaving out important elements by effectively providing a 'checklist'. By systematically addressing all of the three model's steps and sub-components for each of the investigated firms, they can further be compared with each other, and differences and similarities can be identified in terms of how they were affected by pandemic-related disruptions and their approaches to these challenges.

3.2. Firm description and background

When the first wave of infections hit Norway, the country's government decided to shut down large parts of society, including shops, cafes, restaurants, and cultural life. Exemptions were made for grocery stores and pharmacies, which were deemed essential to keep society going, as was the safeguarding of necessary hospital deliveries. In analyzing the vulnerability of SCs in relation to the pandemic, the research project underlying the current article focused on covering SCs for essential goods (food and pharmaceuticals) and SCs from the supply side (production and import) to exports and domestic distribution, as well as last-mile and home deliveries, and thereby to obtain a 360-degree perspective. The current article is based on investigations of the four suppliers participating in the research project. Of these, three are actors in (fresh) food supply chains (FSCs) as producer and exporter, importer and distributor, and distributor for home deliveries, respectively. The fourth firm is an actor in a pharmaceutical supply chain (PSC) that imports pharmaceutical products and distributes them to pharmacies, hospitals and municipalities (nursing and retirement homes) throughout Norway. Table 1 provides a summary of the characteristics of each firm, which are referred to hereafter as (1) fish farming firm, (2) food distributor, (3) home-delivery firm and (4) pharmaceutical firm. While the analysis has a Norwegian context, the firms investigated have dominant market positions and operate in an international market. This makes their SCs extra vulnerable, but also adds an international perspective to the analyses. It can be noted that turnover per employee increases from left to right in the table, illustrating each firms' placement within SCs and the high unit values of pharmaceutical products.

Generally, FSCs have increasingly become more complex and diverse due to globalization, enabling people all over the world to eat food that is grown (and produced) in other climates than their own. Today, a (simplified) FSC essentially consists of five entities: producer, processor, distributor, retailer, and consumer. For FSCs, important aspects are how globalization has affected food security, safety, and integrity [57]. The main difference between normal SCs and FSCs is the continuous change in the quality of products in all joints between producer and consumer [58,59]. Furthermore, the availability of temperature-regulated transportation and shipping options throughout SCs is often an important factor [60]. FSCs can face challenges in every part of the SC, and this complexity can make FSCs vulnerable in times of crisis. Therefore, these

Table 1
Overview of each investigated firm's broad characteristics.

	Fish farming firm	*Food distributor*	*Home-delivery firm*	*Pharmaceutical firm*
Type of organization	Global group	National group	National group	Global group
Trading product	Farmed fish	Perishable goods	Groceries	Medicines and pharmaceutical goods
Role in value chain	Producer	Distributor	Last-mile	Distributor
Main market upstream	Domestic	Abroad	Domestic	Abroad
Main market downstream	Abroad	Domestic	Domestic	Domestic
Turnover per employee, 2020, million NOK (rounded) *	3.3	6.7	8.3	45.0
Number of employees	>5,000	<5,000	<500	<500
Establishment	1992	1914	2013	1995

* Average exchange rates for 2020 (2021): 1 EUR ≈ 10,72 (10,16) NOK; 1 USD ≈ 9,95 (10,17) NOK.

SCs require agility in order to meet customers' demand in normal times, and resilience in the face of disruptions [61].

A PSC is "a special SC in which medications are produced, transported and consumed" (Xie and Breen, 2012, p.41). While there are many variations of the structural PSC, this study will use the simplified SC demonstrated for FSCs, as it creates a common understanding when later comparing the four firms. PSCs are global, complex, and strictly regulated. Pharmaceutical products also need temperate-regulated transport, and often have short shelf lives.

The COVID-19 pandemic affected every part of the FSC and PSC. Overseas markets and sourcing locations have been challenging to reach due to collapses in passenger flights and price rate increases for freight flights and international container shipping, while also closed borders have affected transportation times. Domestically and internationally, FSCs have experienced demand shocks from grocery stores, alongside steep demand reductions in, for example, the HORECA sector (hotel, restaurant and café) or food services market (e.g. [3,4]). PSCs experienced challenges long before the pandemic outburst (for example, drug shortages and delivery problems throughout the globe) and vulnerabilities became more apparent in the midst of it, with hoarding and general demand increases putting extra strain on already fragile PSCs. While shortages of supply in some SCs have caused no trouble other than extra waiting time, shortages in PSCs can put health and human lives at risk.

3.3. Data collection

Data collection was based on semi-structured interviews with key logistics staff at all four firms. Each firm was interviewed at least twice (around New Year 2020/2021 and in spring/early summer 2021) to capture both early experiences and new(er) challenges and developments. Interviews followed a general interview guide, which was adjusted to fit each firm's SC role. All interviews were structured in the same way and addressed the same topics, revolving around the formative elements of the three theoretical models for SC analysis summarized in Fig. 1. Questions were open-ended and differentiated by category to identify (1) how prepared the firms were for a state of emergency such as the pandemic (what was set out in their contingency plans?); (2) to identify the main SC risk factors and approaches to risk assessment, mitigation and control; (3) How reliable their security of supply was; and (4) how resilient the firms were in periods with outbreaks and/or market shortages. Examples of interview topics include the existence of any contingency plans and details on their scope, infection control measures, any staffing challenges or solutions, market and demand dynamics, changes in demand for and organization of transport, changes in transport and logistics costs, different themes regarding any operational changes/adaptations, use of foreign workers, challenges and solutions related to border crossings, implications for the firms' economic situation and investments, implementation of new solutions, and whether the pandemic changed the firms' approach to robustness in the longer term. In addition, specific pandemic-related cases occurring at some firms were discussed, and all firms were given an opportunity to bring up additional topics they considered relevant.

All interviews were transcribed and sent to the interviewees for fact-checking, correction of any misunderstandings, and approval. Interview feedback was then categorized based on the formative elements of the three analytical models. By approaching analyses in this way, we sought to satisfy objectivity, auditability, validity, and application criteria for qualitative data analysis [62].

Based on the above, Fig. 2 provides a comprehensive overview of the current study's methodology and analytical steps.

4. Results

The current section presents findings from interviews for each of the four firms. Hereby, we follow the three key analytical models for supply chain risk management, resilience and reliability, and their multiple elements and steps. The main findings regarding each of the models are summarized in Tables 2, 3 and 4, each of which is followed by more in-depth findings descriptions.

4.1. Risk management

4.1.1. Identification

While all four firms have an identification phase in their risk management approaches, this phase was most extensive for the pharmaceutical firm and the food distributor. The pharmaceutical firm employs a process for continuous risk identification and focuses on identifying risks at an early stage, while the food distributor started an extensive risk identification process in January 2020, before the pandemic hit Norway. The home-delivery firm, in turn, identified capacity risks (staff, transport, etc.) pre-pandemic, but had less focus on or only later identified other risks (such as supply base risk). The fish farming firm identified and to a large degree focused on a specific set of risks (such as price and biological risks) with less thorough identification of other risk types, especially operational and market risks. Because risk identification is a prerequisite for assessing, preparing for, mitigating, and controlling risk, starting early or continuous risk monitoring (such as done by the food distributor and fish farming firm) can be beneficial – although overdoing this can also be costly. The home-delivery and the fish farming firm could have benefited from broader or earlier identification of other risks than the ones focused upon, such as by improving preparedness or having "bought more time" than when risks are first identified when they are about to materialize.

4.1.2. Risk assessment

Risk assessment is also incorporated to some extent in all the four firms' approaches to risk management. Risk assessment seems to be a more continuous process at the pharmaceutical firm and the food distributor, where risks were ranked and then (re)prioritized, while the fish farming firm's assessment phase seems somewhat less continuous and, to some extent, reactive, with risks identified upon materialization. The home-delivery firm assessed risks quickly once identified, but with initial focus on capacity, several other risks were first identified and assessed after the pandemic hit. Feedback further revealed that three of the firms considered that their approach to risk assessment benefited from previous experiences with disruptions and previously established

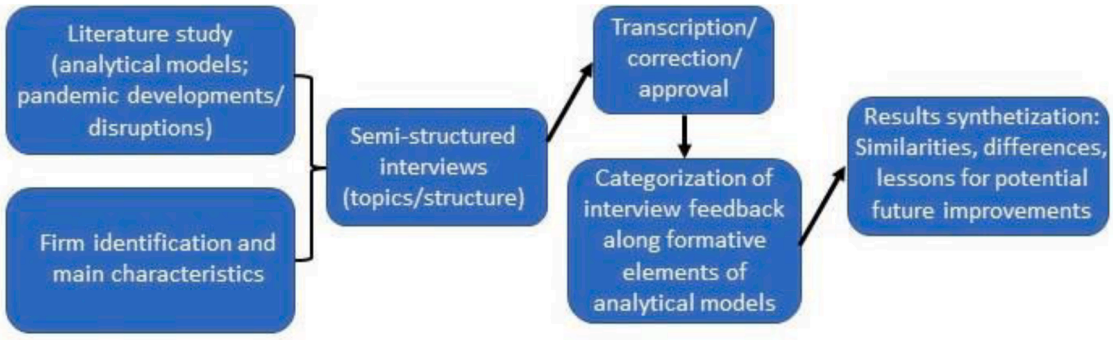

Fig. 2. Overview of methodology and analysis steps.

Table 2
Main findings on the four steps in the supply chain risk management process.

	Fish farming firm	Food distributor	Home-delivery firm	Pharmaceutical firm
Identification	Overarching capacity evaluation pre-pandemic. Identification of supply base risk after pandemic reached Norway	Investigation of how the pandemic would affect the firm started in January 2020, including risk evaluation of (how) whether the virus could spread through food	Establishment of crisis management team after pandemic outbreak	Continuous monitoring of risks already in place pre-pandemic
Assessment	Ability to rapidly assess risks, but dependent on proper identification. Less formal implementation of risk identification and assessment in routines	Assessment and ranking of all identified risks. Some risks discarded/ downgraded, others (e.g., supply risk) highly prioritized	Contingency plans for different risk scenarios	Frequent assessment of identified risks and prioritization thereafter
Mitigation	Some lack of established plans/mitigation for risks inherent in the firm's SC and capacity limitations. Some extent of (rapid) ad-hoc mitigation	Plans for most identified risks, e.g. food security and supply base. Sketch of what to do in case of main terminal closure (not necessarily detailed plans with actionable options)	Contingency plan covering several risk scenarios	Strategies for different risk scenarios
Control	(Continuous) monitoring of staffing capacity risk. Challenges during first days of each new infection wave. Improved control during later waves vs. first wave	Monitoring of different risks throughout the pandemic. Continuous tweaking to keep routines and procedures up-to-date	Close monitoring of the situation. Prepared for different alternatives, if needed	(Continuous) monitoring of identified risks. Special focus on trends relevant also pre-pandemic

Table 3
Main findings on the four elements of supply chain resilience.

	Fish farming firm	Food distributor	Home-delivery firm	Pharmaceutical firm
Collaboration	Well-established network in export markets. Assistance from customers in relocating fish products from HORECA to retail market	Assistance in transferring excess products from HORECA to retail market. Assistance from a foreign factory and local producers during outbreak at one own factory	Collaboration with suppliers, but the firm experienced being downgraded/ not prioritized during periods with shortages of goods due its relative size vs. other actors	Assistance from international parent company
Visibility	Control over entire value chain and locations worldwide. Improved visibility considered important; plans for improvement using more/ better IT	Good flow of information to/from both suppliers and customers. Some desire for more forecasts for planning ahead	Good information flow with customers. Uncertainty about deliveries from some suppliers. Generally good visibility in internal systems	Updates on demand increases and bottlenecks throughout pandemic
Flexibility	Adjustment of volumes of fish going into production (e.g., slow down production). Further flexibility through use of smokehouses	Several suppliers for most products. Tackled large shift in demand. Flexibility in some new routines (terminal, delivery timeframes)	Rapid capacity increases, changed delivery time slots and some delivery procedures, expanded delivery areas	Medicine procurement from open market possible, if needed (often expensive). Flexibility through procedures for prioritizing critical vs. non-critical goods
Velocity	Rapid adaption to new situation by delaying production speed. Turnover challenges due to fall in important HORECA market	Fast action in moving excess goods from HORECA to retail, despite this necessitating extra processing steps. Rapid solutions after a factory closure	Fast capacity increases both during 1st and 2nd infection waves. Capacity challenges still occurred, but less so during 2nd and later waves	Fast adjustment to new situation, reaching satisfactory levels

risk scenarios. It was further noted that, in retrospect, it would have been wise to put more resources into assessing certain risks (such as a potential shutdown of the food distributor's main terminal), but also that a balance must be struck between costs and benefits of extensive identification and assessment processes.

4.1.3. Risk mitigation

Although not all firms had mitigation strategies for direct pandemic risks, they did all have, to some extent, strategies for other risk scenarios that were relevant considering pandemic disruptions (such as transportation issues or temporary closure of facilities). The food distributor and pharmaceutical firm had mitigation plans for different risk scenarios; for example, concrete options in case of capacity problems, alternative suppliers, and food security. However, mitigation alternatives in case the food distributors' main terminal should be closed would likely have been suboptimal and presented challenges, while mitigation responses to initial medicine hoarding were largely successful (only short periods with lower service levels), but still suboptimal from a

business perspective, as servicing peaks is expensive.

The home-delivery firm faced capacity issues immediately after the first Norwegian lockdown in March 2020 due to the sharp growth in demand for home deliveries. While responses were rapid and mitigation plans were in place for hiring staff through employment agencies, some practical issues occurred (such as lower staff availability than expected) and mitigation was initially insufficient to keep up with extreme demand increases. As part of one ad-hoc mitigation measure, the firm rapidly (within a few days) introduced a standardized box with products considered most essential/demanded. It was possible to process this box at a separate location and in an efficient way, thereby lifting some capacity pressure. Further, the firm did not foresee that some product supplies would not be delivered and that suppliers would not prioritize them during a crisis, and did not have mitigation measures prepared. On the other hand, the firm reports that it was able to improve mitigation plans throughout the pandemic, which enabled it to handle later waves of infections better.

The fish farming firm was able to act quickly, utilizing flexibility of delaying production by postponing the gutting of fish or sending fish to smokehouses for preservation. This provided flexibility in case of sudden demand drops for fresh fish or transportation challenges. However, challenges related to reduced belly-capacity for air freight due to loss of passenger flights on some overseas routes with too-small volumes for dedicated cargo flights, followed by sharp increases in transportation prices, were not mitigated as efficiently as hoped.

4.1.4. Risk control

All four firms have been monitoring risks throughout the pandemic to be prepared for risks changing fast or suddenly becoming severe. For example, the food distributor continuously tweaked and strengthened routines and procedures and ensured these remained up-to-date. The pharmaceutical firm continuously monitored identified risks, including transport, by such means as considering capacity and by tracking of transport routes. Due to the critical nature of the firms' activities and trends of global medicine shortages already pre-pandemic, this risk received focus. Around the time of the first Norwegian lockdown, some sold-out situations materialized after extensive medicine hoarding by consumers. This was not the case in later waves, both due to better preparedness, consumers realizing that supply would be sufficient, and people not suddenly becoming ill more often. The home-delivery firm closely monitored capacity risks and, as a result, improved its mitigation strategies. While new waves still yielded short-term capacity challenges, these were considerably less substantial than they were around the time of the first Norwegian lockdown.

4.2. Resilience

4.2.1. Collaboration

For the food distributor, good collaboration contributed to resilience in several ways. The firm has strong, long-term, and collaborative relationships with key suppliers and was prioritized during difficult times, while examples were given that this was less the case for actors with supplier-buyer relationships focused mainly on pricing. Similarly, good relations with its own customers allowed agility when the need arose to rapidly shift large quantities of products from HORECA to retail. During an infection outbreak that necessitated a short closure of an own factory, local suppliers and a foreign factory quickly stepped in. The home-delivery firm, in turn, struggled to match supply and skyrocketing demand. The firm was not prioritized by its main supplier, and also some other suppliers provided low service levels. Initiating closer collaboration with several of the latter suppliers, the firm managed to increase service levels from as low as 70 percent up to 99 percent. For the pharmaceutical firm, strong supplier relationships globally were critical during the pandemic, as the pandemic impacted the production, supply, and distribution of pharmaceuticals and caused bottlenecks in global supply chains. A complicating factor is that frameworks set by Norwegian authorities effectively determine which manufacturers are relevant to consider. Therefore, manufacturers that are "not on the list", even with good long-term relationships with the pharmaceutical firm are, in practice, not chosen. This framework makes it harder to build collaborative relationships based on mutual trust and shared interests.

While the above three firms have large buyer roles, the fish farming firm, covering the entire value chain from feed to finished product, is primarily a global supplier. In this role, strong relationships with customers helped transfer a lot of products to other markets. Further, the Asian HORECA market did not shut down the same way as in Europe, and in part due to close collaboration, many products could still be delivered. Experience from previous air freight disruptions and collaboration with customers also gave some knowledge edge on maintaining good collaboration during crises.

4.2.2. Visibility

The food distributor focused on consistent, timely, accurate, and open communication with both suppliers and customers. While deliberately choosing not to share too much information, information sharing has increased compared to pre-pandemic. Throughout, it has become clearer which information must be shared, such as for planning and monitoring. The home-delivery firm has a dedicated department for collecting and analyzing important data. This department is central in terms of enhancing visibility internally and for external partners, and data collection and analyses have increased to yield more insights. Good information flows with customers also improve delivery efficiency. However, a lack of correct visibility or receiving incorrect information from suppliers led to stock-outs of products already ordered by customers. Further, supplier information often only arrived for the first time when it was asked for. The food distributor also experienced not receiving enough useful information or receiving unnecessary information. Overall, the firm started sharing more information themselves than it had previously and reported that this had positively benefited it and its surroundings.

The fish farming firm started implementing systems to enhance visibility, especially in real-time. Examples include tracking of temperature and visibility (traceability) of orders for customers. The pharmaceutical firm's systems are partly synchronized with its parent company's and automated procurement enables the optimization of entire supply chains and full control over fill rates and stock quality. Information sent to customers is said to be good, but information from suppliers is not always accurate or complete.

4.2.3. Flexibility

The food distributor and fish farming firm experienced lower demand when the pandemic hit, while the home-delivery and pharmaceutical firms experienced demand increases. The food distributor managed good volume control and was able to redirect most excess products to the retail market when HORECA/business markets plunged, although some food had to be given away or discarded. Further, the firm was able to rapidly respond to shifts in types of products demanded by consumers, meaning procurement of different kinds of products from suppliers at short notice. The firm also managed to deal with longer lead times from Southern Europe and with necessary changes to procedures at both its own and the suppliers' terminals.

While the home-delivery firm was somewhat overwhelmed by massive demand increases immediately after the first Norwegian societal restrictions, it did manage to increase capacity substantially in the course of few weeks in terms of staff, vehicles, and longer delivery windows. During later demand peaks, the firm was able to scale up relatively well and was prepared for new demand increases that it expected in relation to government press conferences on restrictions.

For the fish farming firm, flexibility was relatively good through help of customers worldwide in redirecting high-quality seafood to retail and by changing production speed (such as feeding rates, postponing slaughter, etc.). The availability of alternative facilities along the

Table 4
Main findings on the three elements of supply chain reliability.

	Fish farming firm	Food distributor	Home-delivery firm	Pharmaceutical firm
Delivery reliability	As supplier: delivery was reliable, managed, i.a. through changing production speed. Delivery to customers in some countries was negatively affected due to transport challenges	Had to allow slightly longer delivery times from Southern Europe. Accommodation of demand shifts through delivery of alternative products. Hoarding and temporary factory closing caused some empty shelves in stores	Sold out-situations for some products. Back-orders many days ahead due to capacity constraints	Sold-out situations due to medicine hoarding around first lockdown, followed by demand fall; challenges for both the firm and transport providers, but managed relatively rapidly. Reduced domestic air capacity tackled by more slack in transport schedules
Customer relationship	Good and well-established relationships with customers: customer retention and customer help in transferring products from HORECA to retail markets	Assistance from retail market customers in transferring much of excess HORECA products to retail	Customer loss in HORECA and business market. Improved solutions for private consumers; e.g., implementation of contactless deliveries/solutions for people in quarantine/isolation	No problems with loss of customers or bad relationships. Medicine shortages could affect customer relationship negatively
Supplier relationship	Firm with largely a supplier role. Much use of air freight and international road freight. Long-term contracts with carriers, but price increases, particularly for air freight, mostly set by market	Several alternative suppliers for most products, often long, collaborative relationships (a few product groups with just one supplier). No 'COVID-19-compensation' of suppliers, despite some suppliers' demand	Mostly local/ Norwegian suppliers. In-house carriers, complemented with some external delivery hire-ins. Considered a relatively small actor by suppliers	Relatively few problems with procurement. Good cooperation with international parent firm. No payment of higher rates, despite demands from carriers supplying transport service, arguing pandemic-related cost increases

Norwegian coast also offers flexibility if a specific facility would suddenly have to close. For air freight abroad, freight capacity to countries with large demand volumes mostly remained sufficient (but at high prices), but for lower-demand countries (reliant on passenger flight belly-capacity), deliveries in earlier phases of the pandemic had to be cancelled.

The pharmaceutical firm had procedures to quickly implement prioritization of critical goods capacity at the expense of non-critical goods, and for getting in temporary staff in case supply and delivery of critical goods was at risk. Normally, automatic procurement systems ensure flexibility and preparedness by matching customer demand and volumes procured. However, extreme medicine hoarding around the first Norwegian lockdown led to systems interpreting this peak demand as a 'new normal', requiring manual corrections. The firm further responded to reduced domestic flight capacity by rescheduling their air freight transportation and adding more 'slack' in time schedules.

For all firms, infection outbreaks at important terminals could have caused substantial problems, despite available (suboptimal) fallback alternatives. Feedback also indicates that strong, long-term relationships with suppliers and customers positively impacted flexibility and resilience, while short or weaker relationships at times have created challenges.

4.2.4. Velocity

The food distributor and fish farming firm were able to quickly redirect products from markets in decline to retail, and in part to switch between product types. The firms' flexibility and quick responses likely shortened their recovery times or reduced negative impacts of pandemic disruptions, and had the firms adapt to new environments and demand. Still, demand dynamics had an impact on turnover, because the reduced markets normally buy finer and more expensive products, while increasing (retail) markets are more quantity-driven. This applied especially to the fish farming firm.

For the home-delivery firm, rapid responses and capacity increases enabled conversion of a large part of the huge demand increases into sales. Fast decision-making on increasing capacity also helped in terms of catching up on delays relatively fast. Velocity in information flows helped reduce the firm's recovery time. Although the firm expressed that, in hindsight, it would have made some hasty decisions differently, these examples illustrate the firm's ability to quickly implement solutions and adapt operations.

The pharmaceutical firm largely handled the pandemic well, despite raw material shortages for pharmaceutical supplies that existed already pre-pandemic. Velocity was a theme with regard to suddenly procuring personal protective equipment (such as face masks) in large quantities at a time of extreme global demand. Further, the firm was able to quickly respond to medicine hoarding and consequent demand falls with regard to changing their use of distribution transport suppliers.

4.3. Reliability

4.3.1. Delivery reliability

Both the food distributor and pharmaceutical firm managed to adjust well to changes in demand volumes and type of demand, with both having established long-term relationships with current key suppliers. While there were some sold-out situations, mostly related to higher-than-normal demand, these were managed relatively quickly. The food distributor had alternative suppliers for most products and incorporated slightly longer delivery times for produce from Southern Europe (cf. also e.g. [3]), without significant deterioration in delivery reliability. During the closure of one factory, delivery reliability was reduced for some products, but to a substantial extent managed through alternatives. The pharmaceutical firm proactively added time slack on domestic air freight deliveries, thereby ensuring reliable and in-time deliveries.

The home-delivery firm, which relied heavily on just-in-time deliveries from suppliers, experienced reduced delivery reliability on products from some suppliers. This affected orders made by the firm's own customers. However, the firm offers similar products from different brands, and could often offer customers a relevant alternative product, rather than nothing. The firm's challenges are thought to be correlated with weaker or less-committal supplier relationships than for the other investigated firms.

Both the food distributor and home-delivery firm experienced local outbreaks at facilities. The former managed to use alternatives, but the latter, while not closing down fully, did not have proper backup solutions. To ensure delivery reliability, the home-delivery firm tightened infection control measures and worked on hiring more people to take care of other parts of operations and who could be transferred in case of operational disturbances.

The fish farming firm, as a supplier, managed reliable delivery of products throughout the pandemic by making production adjustments while minimizing waste and costs. Delivery reliability to consumers in certain lower-demand Asian countries was affected, but for countries with larger demand volumes (serviced using dedicated freight flights), this was not a significant problem.

4.3.2. Customer relationship

Both the food distributor and fish farming firm expressed that they have well-established relationships with their customers and that customers helped them move products between markets. This willingness to help can be a sign of the desire to continue long relationships and also reduce uncertainty from suppliers [63]. While the home-delivery firm also lost much of its HORECA/business market, the private end-consumer market increased considerably. Unlike the markets for the food distributor and fish farming firm, these markets buy through the same platform, which meant that fewer changes were necessary. Solutions for order visibility and communication between carrier and customer about issues such as quarantines and delivery have contributed to reducing uncertainty and dependency related to grocery shopping in physical stores. The pharmaceutical firm reported very few challenges when it comes to its customers. There are well-established plans for what to do if some things cannot be procured, and which customers have seemingly agreed upon. This agreement makes orders predictable, with the firm being perceived as reliable. However, had substantial medicine shortages occurred and pharmacies, hospitals and end-consumers not received important medicines for critical time periods, this could have affected consumer relationships negatively.

4.3.3. Supplier relationship

The food distributor has alternative suppliers to choose from for most products, with often long and well-established relationships, but for a few product groups only has one supplier. This resulted in challenges upon the abovementioned facility closure, but could also lead to challenges for other products. The pharmaceutical firm had few supplier problems and was helped and partly coordinated by its international parent organization.

Both the food distributor and pharmaceutical firm were asked by carriers to increase transport payments, but neither were willing to agree to such requests. If transport suppliers should be paid too little, there is a potential risk in losing them if suppliers believe they can earn more elsewhere. However, the firms reported that not giving in to the carriers' demands has not caused problems throughout the pandemic. It is unclear whether carriers might have attempted to exploit an extraordinary situation to extract higher margins, or whether alleged pandemic-related cost increases were indeed substantial enough to demand higher payments.

The fish farming firm is highly dependent both on air freight for overseas deliveries (mainly to Asia and to some degree also North-America), but also on road transportation to the European continent. Despite often having long-term contracts, the firm faced high freight rates, especially for air transport, but also that it became challenging to cover the transport needs by truck. In all, the firms' dependency necessitated the accepting of transport at much higher costs than pre-pandemic.

The home-delivery firm had some trouble with suppliers during the pandemic. As a relatively small player in grocery retail, the firm is dependent on suppliers, but large Norwegian suppliers do not necessarily need the home-delivery firm to survive. Therefore, codependency is minimal, which could explain why the firm's increased demand was not prioritized by several suppliers. Creating a more codependent relationship might help improve this. A positive factor is that nearly all suppliers are Norwegian, which yields fewer challenges in the firm's own supply chain.

5. Discussion

This article has assessed how pandemic-induced disruptions affected four firms in Norwegian food and pharmaceutical supply chains, how they approached supply chain risk management prior to and during the pandemic, and strengths and weaknesses of their SC's resilience and reliability. The objective of our investigations was to provide insights into challenges and opportunities during the current pandemic, and lessons for improving preparedness, resilience, and robustness towards future pandemics and shocks yielding similar disruptions and dynamics. Through several rounds of semi-structured interviews with each of the firms, we systematically addressed the main elements of three theoretical models for SC analysis. Using the models in conjunction, and given overlaps and complementarity between them, allowed us to provide comprehensive assessments of strengths and weaknesses of the individual firms, as well as common experiences, and to make suggestions for improving future preparedness.

The four firms investigated faced different challenges, with the main ones materializing during the pandemic's earlier stages and particularly related to sudden demand changes. The food distributor, home-delivery firm, and pharmaceutical firm all experienced immediate and sharp demand increases due to panic responses in society and hoarding by consumers, although the former two firms also experienced (smaller) decreases from their business/HORECA segments. The fish farming firm, primarily directed at the global HORECA market, experienced immediate drops in demand from European and world markets. This necessitated an adjustment in production volumes and redirection of deliveries to the retail market and fish processing industry (at lower prices), resulting in temporary cash flow reductions. As has also been observed elsewhere (cf. [12]), these dynamics forced the firms to adapt both their SCs and product ranges (for example, smaller packages) from HORECA and to the retail markets.

Regarding risk management, we found differences in the four firms' scope, completeness, continuity, and timeliness of risk identification and assessment phases, with the pharmaceutical firm and food distributor identifying risks pre-pandemic or continuously, compared to some important risks for the home-delivery and fish farming firm first being recognized after the pandemic hit. While follow-ups in these cases were fast, they were also more reactive than desired and based on less rigorous analysis than usual underlying decisions (in line with observations by [22]). Furthermore, we found differences regarding how risk mitigation and control were approached, depending on how the previous SCRM steps were managed. Generally, however, all firms had mitigation strategies for some risks, albeit not directly for pandemic-specific risks. Many mitigation measures were relatively ad-hoc in early stages and then improved throughout the pandemic. A common factor here was the lack of actionable and sufficiently detailed points in the firms' strategies and (contingency) plans. Interview feedback generally points to the importance of both sufficient and timely monitoring of potential risks, with risk assessment and control being up-to-date so that firms are more prepared for future disruptions (flexibility) and can act quickly when these disruptions materialize (velocity). Feedback suggests that, in retrospect, the firms would have put more resources into assessing certain risks. These findings are in line with El Baz and Ruel [6], who concluded that firms' priority should be to develop efficient and updated risk identification measures, as these affect the other SCRM stages, and that firms need to develop interconnected SCRM practices to improve their robustness and resilience.

Regarding supply chain resilience, we found differing extents of collaboration between firms and upstream and downstream parts of SCs. In particular, the fish farming and pharmaceutical firm and the food distributor highlighted good collaboration as an important factor for their resilience, while less established collaborative ties for the home-delivery firm were reported as a challenge. While the visibility of important information varied between firms, good visibility was reported to have helped resilience and decreased response time. Common tendencies across the investigated firms are an increased valuation of the importance of high-quality information, movements towards increasing information collection and analysis, and learning to focus and better distinguish between important and superfluous information. Confronted by disruptions, all four firms benefited from flexibility and responsiveness (velocity) in important parts of their activities and supply chains, either dampening potential negative effects (pharmaceutical and fish farming firm, food distributor), or successfully converting opportunities

into value (home-delivery firm and personal protective equipment for the pharmaceutical firm). Researchers such as Hobbs [4] also highlighted such drivers in concluding that SC responsiveness is key for resilience. Simultaneously, underlying drivers (changes in demand levels and between demand segments) were largely beyond the firms' control. All firms further worked to enhance digital communication skills, either before or during the pandemic. This allowed relatively smooth transitions to administrative employees working from home (flexibility), but also collaboration and visibility through more regular communication with external suppliers than pre-pandemic.

Considering SC reliability, delivery reliability has been essential during the pandemic, with all firms experiencing increased lead times for certain items and customer confidence in the ability of SCs to deliver in some areas being decreased (in line with, e.g., Hobbs [4] and El Baz and Ruel [6]). While service levels towards customers were reduced to some extent and during some shorter periods for all investigated firms, reliable deliveries were largely maintained throughout the crisis. The same goes for transport (cf. also e.g. [3]), although this often required adjustment (such as new solutions when belly capacity onboard passenger flights suddenly disappeared for the fish farming firm). Regarding customer and supplier relationships, our investigations suggest a connection between long-term and trusting relationships and information sharing. The home-delivery firm experienced that its size and lack of long-term relationships and co-dependency meant that they were not always prioritized by suppliers, while the other firms gave examples of good long-term relationships with customers and suppliers having been success factors, both in transferring products between markets and in relation to local outbreaks at own facilities. In line with suggestions by Hobbs [4], long and trusting relationships have proven to contribute to good collaboration and flexibility, thereby enabling reliability.

6. Conclusion

Overall, while the four investigated firms had contingency plans prior to the pandemic, these generally both had gaps and lacked the actionable points and level of detail reported to be desirable in retrospect (in line with broader industry observations by [22]). At the same time, detailed strategies were highlighted as important for being able to adapt quickly.

6.1. Implications

Insights from this article can contribute to improving future preparedness and contingency plans in several ways by utilizing the three SC models in conjunction, and may have practical, research, and operational implications. Finding suggest that ongoing societal trends of facility centralization may add an element of vulnerability for firms, while spreading important functions over multiple locations can ensure more operational flexibility. The pharmaceutical firm, for example, accelerated the establishment of a planned emergency warehouse, where it originally operated from one large warehouse where infection outbreaks in the worst case could endanger distribution of critical products. Both the food distributor and home delivery firm demonstrated some flexibility in moving production to other facilities, but could have been affected more severely if outbreaks had occurred at more critical sites than was the case.

6.2. Theoretical and practical contributions

From a research perspective, our study demonstrates the synergy of using three theoretical models for SC analysis alongside, rather than separately. This approach also made it possible to more comprehensively compare firms with each other and to extract insights on more general tendencies and lessons with relevance also for other firms. By systematically running through each of the models, interrelationships among elements of risk management, resilience, and reliability become more visible, increasing awareness and providing firms a 'checklist' that forces them to consider and incorporate specific dimensions. This enables firms to establish a broader and more comprehensive picture of their strengths and weaknesses, cover gaps, prioritize between improvement areas, and collect input towards formulating detailed, actionable points.

6.3. Limitations

A limitation of investigations based on semi-structured interviews is that some bias may occur. For example, firms may want to hold back on discussing certain aspects of the challenges and weaknesses they faced, but also on particularly successful coping strategies. Similarly, while findings build on educated observations and experiences reported by knowledgeable staff, findings would be strengthened if concrete supporting data had been available. Another limitation of our study is that the investigated firms coped relatively well with challenges caused by the pandemic, where larger volatility might have been expected. It is not unlikely that investigations of firms that either really suffered from the pandemic or ceased new opportunities, could have provided particularly valuable lessons. Analyses in this article are further based on firm experiences in the first year of the pandemic. Our overarching research project on the pandemic's consequences has since continued. Early observations suggest that many of the crisis' stronger effects took more time to materialize. Examples include supply chain challenges due to shortages of raw materials, intermediate goods, and shipping containers, manifold increases in shipment rates, delays and unpredictable lead times, and increasing driver shortages, both in individual countries (such as the UK and the USA), but also in Europe as a whole. The current pandemic stands out both in terms of its longevity compared to many other crises and the continued intensity of challenges and disruptions throughout.

6.4. Further research

Further research could benefit from focusing on challenges and improvements from more medium-to-long term effects and changes, and changes that might become structural, rather than temporary. Examples may include temporary lay-offs becoming permanent or tendencies that are reported of foreign workers having become less interested in working in Norway because of long-term border-crossing challenges, and now filling vacancies in countries closer to home. Also the recent war in Ukraine is observed to cause major new challenges and to reinforce supply chain challenges that started with the pandemic.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

References

[1] K. Nikolopoulos, S. Punia, A. Schäfers, C Tsinopoulos, C. Vasilakis, Forecasting and planning during a pandemic: COVID-19 growth rates, supply chain disruptions, and governmental decisions, European Journal of Operational Research 290 (1) (2021) 99–115.
[2] O.M. Araz, T.M. Choi, D.L. Olson, F.S. Salman, Data Analytics for Operational Risk Management, Decision Sciences 51 (6) (2020) 1316–1319.
[3] B. Coluccia, G.P. Agnusdei, P.P. Miglietta, F. De Leo, Effects of COVID-19 on the Italian agri-food supply and value chains, Food Control 123 (2021), 107839.
[4] J.E. Hobbs, Food supply chains during the COVID-19 pandemic, Canadian Journal of Agricultural Economics 68 (2) (2020) 171–176.

[5] Y. Fan, M. Stevenson, A review of supply chain risk management: definition, theory, and research agenda, International Journal of Physical Distribution & Logistics Management 48 (3) (2018) 205–230.
[6] J. El Baz, S. Ruel, Can supply chain risk management practices mitigate the disruption impacts on supply chains' resilience and robustness? Evidence from an empirical survey in a COVID-19 outbreak era', International Journal of Production Economics 233 (2021), 107972.
[7] P. Pourhejazy, O.K. Kwon, Y-T. Chang, H. Park, Evaluating Resiliency of Supply Chain Network: A Data Envelopment Analysis Approach, Sustainability 9 (2) (2017) 255.
[8] I. Ali, I. Gölgeci, Where is supply chain resilience research heading? A systematic and co-occurrence analysis, International Journal of Physical Distribution & Logistics Management 49 (8) (2019) 793–815.
[9] J. Stone, S. Rahimifard, Resilience in agri-food supply chains: a critical analysis of the literature and synthesis of a novel framework, Supply Chain Management 23 (3) (2018) 207–238.
[10] L. Kano, C.H. Oh, Global Value Chains in the Post-COVID World: Governance for Reliability, Journal of Management Studies 57 (8) (2020) 1773–1777.
[11] D. Ivanov, Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case, Transportation Research Part E: Logistics and Transportation Review 136 (2020), 101922.
[12] L. Veselovská, Supply chain disruptions in the context of early stages of the global COVID-19 outbreak, Problems and Perspectives in Management 18 (2) (2020) 490–500.
[13] K.B. Hendricks, V.R. Singhal, An Empirical Analysis of the Effect of Supply Chain Disruptions on Long-Run Stock Price Performance and Equity Risk of the Firm, Production and Operations Management 14 (1) (2005) 35–52.
[14] S.C. Ellis, R.M. Henry, J. Shockley, Buyer perceptions of supply disruption risk: A behavioral view and empirical assessment, Journal of Operations Management 28 (1) (2010) 34–46.
[15] K.B. Hendricks, V.R. Singhal, The effect of supply chain glitches on shareholder wealth, Journal of Operations Management 21 (5) (2003) 501–522.
[16] C. Béné, Resilience of local food systems and links to food security – A review of some important concepts in the context of COVID-19 and other shocks, Food Security 12 (2020) 805–822.
[17] S.V. Dombu, A. Bardalen, E. Strand, B. Henriksen, L. Lamprinakis, Norsk matsikkerhet og forsyningsrisiko - Rapport fra arbeidsgruppe i NIBIO, NIBIO research report 7 (145) (2021).
[18] W. Ho, T. Zheng, H. Yildiz, S. Talluri, Supply chain risk management: A literature review, International Journal of Production Research 53 (16) (2015) 5031–5069.
[19] U. Jüttner, Supply chain risk management: Understanding the business requirements from a practitioner perspective, International Journal of Logistics Management 16 (1) (2005) 120–141.
[20] O. Khan, B. Burnes, Risk and supply chain management: Creating a research agenda, International Journal of Logistics Management 18 (2) (2007) 197–216.
[21] M. Christopher, H. Peck, Building the Resilient Supply Chain, International Journal of Logistics Management 15 (2) (2004) 1–14.
[22] R. van Hoek, Research opportunities for a more resilient post-COVID-19 supply chain – closing the gap between research findings and industry practice, International Journal of Operations & Production Management 40 (4) (2020) 341–355.
[23] G.A. Zsidisin, L.M. Ellram, J.R. Carter, J.L. Cavinato, An analysis of supply risk assessment techniques, International Journal of Physical Distribution & Logistics Management 34 (5) (2004) 397–413.
[24] D. Neiger, K. Rotaru, L. Churilov, Supply chain risk identification with value-focused process engineering, Journal of Operations Management 27 (2) (2009) 154–168.
[25] I. Heckmann, T. Comes, S. Nickel, A critical review on supply chain risk – Definition, measure and modeling, Omega (Oxford) 52 (2015) 119–132.
[26] I. Manuj, J.T. Mentzer, Global supply chain risk management, Journal of Business Logistics 29 (1) (2008) 133–155.
[27] S.Y. Ponomarov, M.C. Holcomb, Understanding the concept of supply chain resilience, International Journal of Logistics Management 20 (1) (2009) 124–143.
[28] H. Peck, Drivers of supply chain vulnerability: an integrated framework, International Journal of Physical Distribution & Logistics Management 35 (4) (2005) 210–232.
[29] U. Jüttner, S. Maklan, Supply chain resilience in the global financial crisis: an empirical study, Supply Chain Management 16 (4) (2011) 246–259.
[30] K. Scholten, S. Schilder, The role of collaboration in supply chain resilience, Supply Chain Management 20 (4) (2015) 471–484.
[31] M. Christopher, The Agile Supply Chain: Competing in Volatile Markets, Industrial Marketing Management 29 (1) (2000) 37–44.
[32] T.J. Pettit, K.L. Croxton, J. Fiksel, Ensuring Supply Chain Resilience: Development and Implementation of an Assessment Tool, Journal of Business Logistics 34 (1) (2013) 46–76.
[33] V. Jain, S. Kumar, U. Soni, C. Chandra, Supply chain resilience: model development and empirical analysis, International Journal of Production Research 55 (22) (2017) 6779–6800.
[34] C.-L. Liu, M.-Y. Lee, Integration, supply chain resilience, and service performance in third-party logistics providers, International Journal of Logistics Management 29 (1) (2018) 5–21.
[35] M. Caridi, A. Moretto, A. Perego, A. Tumino, The benefits of supply chain visibility: A value assessment model, Intl. Journal of Production Economics 151 (2014) 1–19.
[36] S. Somapa, M. Cools, W. Dullaert, Characterizing supply chain visibility – a literature review, International Journal of Logistics Management 29 (1) (2018) 308–339.
[37] G. Zhu, M.C. Chou, C.W. Tsai, Lessons Learned from the COVID-19 Pandemic Exposing the Shortcomings of Current Supply Chain Operations: A Long-Term Prescriptive Offering, Sustainability 12 (14) (2020) 5858.
[38] S. Gunessee, N. Subramanian, Ambiguity and its coping mechanisms in supply chains lessons from the Covid-19 pandemic and natural disasters, International Journal of Operations & Production Management 40 (7–8) (2020) 1201–1223.
[39] S. Vickery, R. Calantone, C. Dröge, Supply Chain Flexibility: An Empirical Study, Journal of Supply Chain Management 35 (2) (1999) 16–24.
[40] S. Mandal, R. Sarathy, V.R. Korasiga, S. Bhattacharya, S.G. Dastidar, Achieving supply chain resilience, International Journal of Disaster Resilience in the Built Environment 7 (5) (2016) 544–562.
[41] M. Kamalahmadi, M. Mellat-Parast, Developing a resilient supply chain through supplier flexibility and reliability assessment, International Journal of Production Research 54 (1) (2016) 302–321.
[42] B. Adenso-Diaz, C. Mena, S. García-Carbajal, M. Liechty, The impact of supply network characteristics on reliability, Supply Chain Management 17 (3) (2012) 263–276.
[43] C. Wu, D. Barnes, Design of agile supply chains including the trade-off between number of partners and reliability, International Journal of Advanced Manufacturing Technology 97 (9) (2018) 3683–3700.
[44] N. Toshihiro, B. Alexandre, The Toyota Group and the Aisin Fire, MIT Sloan Management Review 40 (1) (1998) 49.
[45] R.K. Goel, J.W. Saunoris, S.S. Goel, Supply chain performance and economic growth: The impact of COVID-19 disruptions, Journal of Policy Modeling 43 (2) (2021) 298–316.
[46] J. Chen, H. Wang, R.Y. Zhong, A supply chain disruption recovery strategy considering product change under COVID-19, Journal of Manufacturing Systems 60 (2021) 920–927.
[47] S.K. Sharma, A. Bhat, Risk Mitigation in Automotive Supply Chain: An Empirical Exploration of Enablers to Implement Supply Chain Risk Management, Global Business Review 17 (4) (2016) 790–805.
[48] A.E. Dohmen, J.R.W. Merrick, L.W. Saunders, T.P. Stank, T.J. Goldsby, When preemptive risk mitigation is insufficient: The effectiveness of continuity and resilience techniques during COVID-19, Production and operations management (2022). Special Issue January 2022.
[49] J.B. Skipper, J.B. Hanna, Minimizing supply chain disruption risk through enhanced flexibility, International Journal of Physical Distribution & Logistics Management 39 (5) (2009) 404–427.
[50] T. Hale, C.R. Moberg, Improving supply chain disaster preparedness: A decision process for secure site location, International Journal of Physical Distribution & Logistics Management 35 (3) (2005) 195–207.
[51] A.B. Lopes de Sousa Jabbour, C.J. Chiappetta Jabbour, M. Hingley, E.L. Vilalta-Perdomo, G. Ramsden, D. Twigg, Sustainability of supply chains in the wake of the coronavirus (COVID-19/SARS-CoV-2) pandemic: Lessons and trends, Modern Supply Chain Research and Applications 2 (3) (2020) 117–122.
[52] C.F. Payne, Contingency plan exercises, Disaster Prevention and Management 8 (2) (1999) 111–117.
[53] L.J. Fernandes, F. Saldanha da Gama, Contingency planning – a literature review, Supply Chain Management and Competitiveness (2008) 457–467.
[54] K. Rimiene, D. Bernatonyte, Supply chain management trends in the context of change, Economics & Management 18 (3) (2013) 596.
[55] A. Skalli, Risk attitudes and human mobility during the COVID-19 pandemic, Nature Scientific Reports 10 (1) (2020) 19931.
[56] J.W. Pratt, Risk Aversion in the Small and in the Large, Econometrica 32 (1/2) (1964) 122.
[57] A. Kamilaris, A. Fonts, F.X. Prenafeta-Boldú, The rise of blockchain technology in agriculture and food supply chains, Trends in Food Science & Technology 91 (2019) 640–652.
[58] F. Dabbene, P. Gay, N. Sacco, Optimisation of fresh-food supply chains in uncertain environments, Part I: Background and methodology, Biosystems Engineering 99 (3) (2008) 348–359.
[59] M. Yu, A. Nagurney, Competitive food supply chain networks with application to fresh produce, European Journal of Operational Research 224 (2) (2013) 273–282.
[60] M.M. Aung, Y.S. Chang, Temperature management for the quality assurance of a perishable food supply chain, Food Control 40 (2014) 198–207.
[61] G. Dellino, T. Laudadio, R. Mari, N. Mastronardi, C. Meloni, A reliable decision support system for fresh food supply chain management, International Journal of Production Research 56 (4) (2018) 1458–1485.
[62] M.B. Miles, A.M. Huberman, J. Saldaña, Qualitative Data Analaysis: A Methods Sourcebook, Sage, London, 2014.
[63] E. Ambrose, D. Marshall, D. Lynch, Buyer supplier perspectives on supply chain relationships, International Journal of Operations & Production Management 30 (12) (2010) 1269–1290.