Front. Eng. Manag. 2023, 10(1): 158–170
https://doi.org/10.1007/s42524-022-0238-9

RESEARCH ARTICLE

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Omnichannel retail operations with ship-to-store and ship-from-store options under supply disruption

Abstract Omnichannel retailing strategies are widely used in practice and have been extensively studied in recent years, but few studies have explored omnichannel retailing operations in response to supply disruption in the post-pandemic era. To fill this gap, this study explores whether the adoption of omnichannel fulfillment options (i.e., ship-from-store and ship-to-store options) can mitigate the risk of supply disruption in a supply chain where a retailer orders products from a reliable supplier and a risky supplier, respectively. Under the omnichannel retailing strategy, the retailer's order quantity from the risky supplier may increase or decrease while that from the reliable supplier may increase. Interestingly, it is possible to achieve a win–win–win outcome when the supply disruption risk is high and the market share of the channel offered by the risky supplier is low. Moreover, the entire supply chain benefits from the omnichannel retailing strategy even if it faces a high level of disruption risk.

Keywords supply chain disruption, omnichannel fulfillment option, ship-from-store, ship-to-store

1 Introduction

With economic globalization and environmental changes, the risk of supply chain disruption has exacerbated, becoming one of the most serious threats firms face (Saleheen and Habib, 2022). The specific factors of supply chain disruption may often be classified as human behaviors (e.g., industrial accidents, political events, and terrorist attacks) and natural disasters (e.g., earthquakes, hurricanes, volcanic eruptions, and public health safety events) (Liu et al., 2022). For example, the COVID-19 pandemic has severely affected global supply chains (Ivanov, 2020; El Baz and Ruel, 2021; Mahajan and Tomar, 2021; Moosavi et al., 2022). Based on experiments conducted from February 22 to March 5, 2020, the Institute for Supply Management of the United States revealed that nearly 75% of subject firms lost capacity owing to coronavirus-related shipping restrictions in the supply chain and that more than 80% believe that their organizations would experience some impact (Derry, 2020).

Scholars have studied ways to advance supply chain resilience, including safety inventory (Chen and Zheng, 1994; Darom et al., 2018), risk mitigation inventory and reserve capacity (DeCroix, 2013; Lücker et al., 2019), and dual/multiple sourcing (Tomlin, 2006; Ang et al., 2017; Li et al., 2022). Holding high inventory can certainly satisfy some demand in the event of a supply disruption, but firms would have to pay a high inventory cost for long-term supply disruption. Therefore, some firms try to solve supply disruptions by improving their channel operation strategies. For example, firms improve the management level of information systems, the real-time monitoring of inventory in various channels, and cross-warehouse distribution (Ishfaq and Raja, 2018).

After entering the omnichannel retailing era, firms can realize inventory sharing across channels, that is, fulfilling in-store orders by using online inventory and fulfilling online orders by using in-store inventory. These two fulfillment options, namely, ship-from-store (SFS) and ship-to-store (STS) options, have been widely used in retail operations. In an article in Practical Ecommerce, Roggio (2017) stated that implementing the SFS option may help mid-market multichannel retailers better serve customers and earn more profit. Walgreens, a pharmaceutical and food retailer in the United States, adopts the STS option to fulfill in-store orders. In the post-pandemic

Received June 30, 2022; accepted September 20, 2022

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This work was supported by the National Natural Science Foundation of China (Grant No. 71872075) and Hainan Provincial Natural Science Foundation of China (Grant No. 720RC568).

era, CR Vanguard, a large retail chain firm in China, procures products from one supplier and delivers them directly to distribution centers to meet online channel demand and quickly sources products from wholesale markets (another supplier) and ships them to stores to meet in-store channel demand. In case of a supply disruption involving suppliers, how do the SFS and STS options affect the decision making of supply chain members? The research on this issue is currently lacking. Therefore, we focus the current study on the following questions: (1) How do SFS and STS operations affect retailers' ordering decisions and suppliers' wholesale prices? (2) When a supply disruption occurs, can the SFS and STS options benefit each supply chain member or the entire supply chain? (3) How do consumers' channel preferences affect the profit of supply chain members?

To address these questions, we consider a supply chain where the retailer orders products from a reliable supplier and a risky supplier, respectively, under a random market demand while each supplier provides products for the retailer's online or offline channel separately. We develop a newsvendor model under two scenarios: A non-omnichannel retailing scenario and an omnichannel retailing scenario. In the non-omnichannel retailing scenario, the retailer cannot share inventory across channels. In the omnichannel retailing scenario, the retailer adopts SFS and STS options to fulfill orders. When the channel offered by the risky supplier is disrupted, the retailer can use the inventory from the reliable supplier to meet the demand of this channel. The optimal wholesale prices, ordering quantities, and profits under the two scenarios are obtained accordingly.

The main findings of this study are summarized as follows: First, the adoption of the omnichannel retailing strategy does not always allow the retailer to order fewer quantities from the risky supplier. Conversely, when the proportion of online channel consumers is not very large, the retailer increases the order quantity from the risky supplier. This is because the retailer can benefit from using the online channel inventory to replenish the in-store channel inventory. Second, given the effect of inventory sharing across channels, the two suppliers decrease the wholesale price to motivate the retailer to increase the ordering quantities. Third, when the risk of supply chain disruption is high and the proportion of corresponding channel consumers is relatively small, the adoption of the omnichannel retailing strategy can benefit the retailer and the two suppliers simultaneously, thereby leading to a win–win situation for all supply chain members.

The remainder of this paper is organized as follows. Section 2 summarizes the relevant studies. Section 3 presents the model settings and the derivation of optimal solutions under the two scenarios. Section 4 compares the supply chain members' profits and examines the value of SFS and STS options under supply disruption. Finally, Section 5 concludes the paper. The related proofs are presented in Appendix A.

2 Literature review

This study explores the role of omnichannel fulfillment options in advancing supply chain resilience. Therefore, there are two main streams of research related to our study: Omnichannel retailing and supply chain disruption.

A number of studies have explored the influences of different omnichannel fulfillment options on supply chain members' optimal ordering and pricing decisions. With the wide application of the buy online – pickup in store (BOPS) option in practice, scholars have paid more attention to issues related to this option, such as decisions on pricing (Gao and Su, 2017a; Kong et al., 2020), ordering (Xu et al., 2021), product quality (Lin et al., 2021), and sales effort levels (Yan et al., 2020). Some studies have further examined issues of store inventory management (Saha and Bhattacharya, 2021; Hu et al., 2022), design of service areas (Jin et al., 2018), and cooperative advertising strategies (Li et al., 2021) in combination with the BOPS option. The strategy of using a showroom, an effective fulfillment option to address the uncertainty of product value and availability faced by consumers, has been studied from the perspective of function, including reducing store inventory (Gao and Su, 2017b), amplifying demand and operational benefits (Bell et al., 2018), mitigating the disappointment caused by stockout (Du et al., 2019), and maximizing customer utility (Park et al., 2021). Other studies have also examined the store return option, in which retailers allow customers to return online orders at store locations (Mahar and Wright, 2017; Mandal et al., 2021). For the SFS and STS options, He et al. (2021) studied the effects of the SFS option on the pricing decisions of retailers and platforms and found that retailers can benefit from this option under certain conditions. Bayram and Cesaret (2021) studied the dynamic fulfillment decisions for online orders under the SFS option. They considered a retailer that operates online and in-store channels, each of which holds its own inventory. Serkan Akturk et al. (2018) explored the influence of the STS option on a retailer's operating performance and showed that store sales increase while online sales decrease. Yang and Zhang (2020) investigated the impact of the STS option on quick response strategies in the fast fashion industry.

Our study is also related to the literature on supply chain disruptions. An increasing number of studies have focused on the types of supply chain disruption, namely, production, demand, supply, process, control, and environmental risk (Qi et al., 2004; Wu et al., 2007; Ang et al., 2017; Li et al., 2017; 2020; Remko, 2020; Shekarian and

Mellat Parast, 2021; Liu et al., 2022). Resilient supply chains are an important tool for effectively coping with disruption risks (Gao et al., 2021). Some studies in this field have assessed the impact of practices that enhance supply chain resilience, such as demand management (Shao, 2012), inventory management (Parlar and Berkin, 1991; Chen et al., 2013; Lücker et al., 2021), and procurement strategies (Anupindi and Akella, 1993; Tomlin and Wang, 2005; Dada et al., 2007; Wang et al., 2010; Kumar et al., 2018; Yoon et al., 2020). Other studies have explored different measures to manage the risk of supply chain disruption. Gümüş et al. (2012) studied the role of supplier-initiated contracts (i.e., price and quantity guarantees) with consideration of supplier competition and information asymmetry. Qi and Lee (2015) examined the impact of expedited shipping under the optimal risk mitigation strategy. They demonstrated that expedited shipping is a good option when maintaining the flexible capacity of a reliable supplier is costly. Dong et al. (2018) provided insights into the interaction of three risk management measures, namely, inventory, preparedness, and insurance, in a two-stage supply chain. In particular, technology-aided tools have been implemented to improve supply chain resilience, and examples include artificial intelligence technology (Modgil et al., 2022), additive manufacturing technology (Naghshineh and Carvalho, 2022; Belhadi et al., 2022), and blockchain technology (Queiroz et al., 2019; van Hoek and Lacity, 2020).

Although some operating measures and technology-aided tools have been widely studied to manage supply chain disruption, no study has examined how the omnichannel retailing option mitigates the impact of supply chain disruption. Therefore, this study endeavors to fill this research gap. We highlight a few differences between our study and the abovementioned studies. (1) The first stream of literature primarily discusses the effects of different types of fulfillment options. However, it ignores the role of omnichannel retailing options under supply disruption. Therefore, this study explores the effects of two widely used omnichannel fulfillment options on retailers' responsiveness to supply chain uncertainties. (2) Unlike the second stream of literature, this study mainly focuses on supply risk and demand uncertainty in routine activities and examines the value of STS and SFS options in advancing supply chain resilience. We believe that these novel insights contribute to theoretical studies and also advance retail industry practices in the post-pandemic era.

3 Model setup

We consider a supply chain with two suppliers and a retailer. Each supplier provides products to the retailer's online or offline channel separately. We assume that supplier 1 satisfies the demand of the online channel and that supplier 2 serves the demand of the offline channel. These two suppliers may face the threat of supply disruption in the post-pandemic era. If supplier 1 is disrupted, then the retailer can only procure products from supplier 2 to meet the in-store demand. Therefore, online consumers are left unserved. Similarly, if supplier 2 is disrupted, then the retailer can only order products from supplier 1 to meet the online demand. Owing to a lack of supply, the in-store demand is unsatisfied.

To advance supply chain resilience, the retailer can implement the omnichannel retailing strategy and thereby achieve inventory sharing between the online and offline channels. The retailer can fulfill online orders using stock from a store (i.e., the SFS option). Moreover, the retailer can fulfill in-store orders by shipping products procured from supplier 1 to the local store (i.e., the STS option). In this study, we do not consider the condition in which online and offline channels are simultaneously disrupted. Thus, supplier 2 corresponds to a reliable supplier if supplier 1 is risky. In this context, the retailer can fulfill online orders by using the SFS option when a disruption occurs. Accordingly, if supplier 2 is risky, then supplier 1 is the reliable one. Under this condition, the retailer can fulfill in-store orders by using the STS option when supplier 2 is disrupted. Based on our comparison of these two contexts, we state that supply chains' situations are symmetric regardless of which supplier is disrupted. Therefore, we examine the situation in which supplier 1 is subject to disruption. We assume that the retailer can ascertain the amount of excess store inventory over the whole sell period. This is a reasonable assumption and we will explain the reasons. Before the start of the selling season, the retailer needs to determine the ordering quantity of two channels respectively. As the selling season approaches, more demand information is gathered. During the selling season, due to the rich first-hand data and the more skilled selling experience, the retailer can observe the accurate demand and timely check the store inventory (Yang et al., 2015; Zhang and Zhang, 2020). Thus, the retailer can tell consumers whether they can use the SFS option quickly. We also assume that when a supply chain disruption occurs at supplier 1, the retailer cannot source products from it and should thus not bear the cost of procurement.

The notations and specific descriptions in our model are summarized in Table 1.

In our models, the decision variables are the ordering quantities of the product from the two suppliers, Q_1 and Q_2; and the wholesale prices charged by the two suppliers, w_1 and w_2. Meanwhile, the other parameters are exogenous. We assume that the probability of disruption at supplier 1 is θ and that if disruption occurs, the supplier loses all capacity; then, the possibility of normal supply through the online channel is $(1-\theta)$. Market demand is

Table 1 Summary of notations

Notation	Description
θ	Probability of disruption at supplier 1
α	Proportion of market demand for online consumers
$1-\alpha$	Proportion of market demand for in-store consumers
p	The product retail price
w_1	Wholesale price to the retailer charged by supplier 1
w_2	Wholesale price to the retailer charged by supplier 2
x	Random variable denoting the probability of market demand
Q_1	Ordering quantity of the product from supplier 1
Q_2	Ordering quantity of the product from supplier 2

assumed to be x that obeys a probability density function $f(x)$ and a cumulative distribution function $F(x)$. In particular, we assume that random variable x follows a uniform distribution between 0 and 1. We also assume the proportion of market demand for online consumers to be α, where $\alpha \in [0, 1]$. Meanwhile, the proportion of market demand for in-store consumers corresponds to $(1-\alpha)$. This assumption has been widely used in previous studies (Dzyabura and Jagabathula, 2018; He et al., 2020; Xu et al., 2021). In line with the practices of most omnichannel firms, we assume that product price p is the same across channels (Jin et al., 2018; Nageswaran et al., 2020; Saha and Bhattacharya, 2021). We also normalize the unit inventory cost of the retailer and other fixed costs to zero. Although it is reasonable to assume that for each unit product that the retailer carries in its inventory, it incurs a holding cost, which is normalized to zero in our models. This assumption has also been used in previous studies (Cachon and Swinney, 2009; Li et al., 2014; Pang et al., 2021). Furthermore, we do not consider the fixed cost because it does not affect firms' regular operations as a sunk cost.

As the retailer may choose a non-omnichannel retailing strategy and an omnichannel retailing strategy, we study the supply chain members' optimal decisions in the following two scenarios. In particular, in the benchmark model, the retailer adopts a non-omnichannel strategy.

3.1 Benchmark

In this scenario, if supplier 1 is disrupted, then the retailer can only order products from supplier 2 to satisfy the in-store demand; otherwise, the retailer can purchase products from suppliers 1 and 2. Therefore, the retailer's expected profit is

$$\pi_r = \underbrace{p(1-\theta)E(\alpha x \wedge Q_1)}_{(1)} - \underbrace{(1-\theta)w_1 Q_1}_{(2)} + \underbrace{pE((1-\alpha)x \wedge Q_2)}_{(3)} - \underbrace{w_2 Q_2}_{(4)}. \tag{1}$$

In Eq. (1), the retailer's expected revenues from online and in-store consumers are shown in terms (1) and (3), respectively; terms (2) and (4) show the procurement costs of the products ordered from suppliers 1 and 2, respectively. Note that the number of customers purchasing online is $(1-\theta)E(\alpha x \wedge Q_1)$ and that the number of customers purchasing in-store is $E((1-\alpha)x \wedge Q_2)$.

The expected profits for suppliers 1 and 2 are respectively shown as

$$\pi_{s1} = (1-\theta)w_1 Q_1, \tag{2}$$

$$\pi_{s2} = w_2 Q_2. \tag{3}$$

Let Q_1^*, Q_2^*, w_1^*, w_2^* be the optimal solutions that maximize Eqs. (1)–(3). We can then easily obtain the retailer's expected profit π_r^*, supplier 1's profit π_{s1}^*, and supplier 2's profit π_{s2}^*, with superscript "*" denoting the optimal outcome. The results are presented in Table 2.

Table 2 Optimal solutions and expected profits under different strategies

Non-omnichannel retailing strategy	Omnichannel retailing strategy	
	Case 1	Case 2
$Q_1^* = \frac{\alpha}{2}$	$Q_1^{u*} = \frac{1}{\theta+3}$	$Q_1^{e*} = \frac{\alpha}{2}$
$Q_2^* = \frac{1-\alpha}{2}$	$Q_2^{u*} = \frac{2}{\theta+3}$	$Q_2^{e*} = \frac{1-\alpha}{2(1-\theta\alpha)}$
$w_1^* = \frac{p}{2}$	$w_1^{u*} = \frac{\theta p}{\theta+3}$	$w_1^{e*} = \frac{p}{2}$
$w_2^* = \frac{p}{2}$	$w_2^{u*} = \frac{2\theta p}{\theta+3}$	$w_2^{e*} = \frac{p}{2}$
$\pi_r^* = \frac{p(1-\alpha\theta)}{8}$	$\pi_r^{u*} = \frac{(9-5\theta)p}{2(\theta+3)^2}$	$\pi_r^{e*} = \frac{\left(1-\alpha\theta-(1-\theta)\theta\alpha^2\right)p}{8(1-\alpha\theta)}$
$\pi_{s1}^* = \frac{(1-\theta)\alpha p}{4}$	$\pi_{s1}^{u*} = \frac{\theta(1-\theta)p}{(\theta+3)^2}$	$\pi_{s1}^{e*} = \frac{(1-\theta)\alpha p}{4}$
$\pi_{s2}^* = \frac{(1-\alpha)p}{4}$	$\pi_{s2}^{u*} = \frac{4\theta p}{(\theta+3)^2}$	$\pi_{s2}^{e*} = \frac{(1-\alpha)p}{4(1-\theta\alpha)}$

3.2 Omnichannel retail operations with SFS and STS options

In this scenario, the retailer adopts omnichannel retailing strategies, SFS and STS options, to share inventory between online and in-store channels. When supplier 1 is disrupted, the retailer can use the SFS option to fulfill online orders by utilizing the store inventory when there is excess inventory. However, only when supplier 1 is running normally can the retailer apply the STS option to replenish the store inventory by using the online inventory. Thus, we formulate the retailer's expected profit function as follows

$$\begin{aligned}\pi_r = {} & p(1-\theta)E(\alpha x \wedge Q_1) - (1-\theta)w_1 Q_1 \\ & + pE((1-\alpha)x \wedge Q_2) - w_2 Q_2 \\ & + \underbrace{p\theta E(\alpha x \wedge (Q_2-(1-\alpha)x)^+)}_{(1)} \\ & + \underbrace{p(1-\theta)E((\alpha x - Q_1)^+ \wedge (Q_2-(1-\alpha)x)^+)}_{(2)} \\ & + \underbrace{p(1-\theta)E((Q_1-\alpha x)^+ \wedge ((1-\alpha)x - Q_2)^+)}_{(3)} . \end{aligned} \tag{4}$$

Comparing the retailer's expected profits in the two scenarios, one can notice that the terms (1), (2), and (3) in Eq. (4) represent the extra profit from adopting the omnichannel retailing strategy. Here, the additional expected profit of the SFS option under the conditions of supplier 1 disruption and normal operation are shown in terms (1) and (2), respectively; term (3) shows the extra benefit of the STS option when supplier 1 operates normally.

Additionally, the expected profits for suppliers 1 and 2 are similar to those in Eqs. (2) and (3) and can be respectively defined in this scenario as

$$\pi_{s1} = (1-\theta)w_1 Q_1, \tag{5}$$

$$\pi_{s2} = w_2 Q_2. \tag{6}$$

As mentioned earlier, the difference between the retailer's product order quantity and consumer demand affects the actual sales of the two channels. For simplicity, we characterize this effect in terms of service levels $Q_1/\alpha x$ and $Q_2/(1-\alpha)x$ for the two channels, respectively. Based on the relationship of the service level between online and offline channels, we discuss two cases.

Case 1: The service levels of two channels are unequal.

In this case, when supplier 1 is operating normally, the online channel's service level $Q_1/\alpha x$ is unequal to the in-store channel's service level $Q_2/(1-\alpha)x$. If $Q_1/\alpha x > Q_2/(1-\alpha)x$, that is, $Q_1/\alpha > Q_2/(1-\alpha)$, then the service level of the online channel is higher than that of the in-store channel, meaning that the STS option is working. If $Q_1/\alpha x < Q_2/(1-\alpha)x$, that is, $Q_1/\alpha < Q_2/(1-\alpha)$, then the service level of the online channel is lower than that of the in-store channel, meaning that the SFS option is functioning.

Let Q_1^{u*}, Q_2^{u*}, w_1^{u*}, w_2^{u*} be the optimal solutions that maximize Eqs. (4)–(6). Then, we can easily obtain the expected retailer's profit π_r^{u*}, supplier 1's profit π_{s1}^{u*}, and supplier 2's profit π_{s2}^{u*}, with superscript "u" denoting the optimal outcomes in case 1. The results are presented in Table 2.

Case 2: The service levels of two channels are equal.

In this case, the two channels' service levels $Q_1/\alpha x$ and $Q_2/(1-\alpha)x$ are equal, that is, $Q_1/\alpha = Q_2/(1-\alpha)$. Thus, when supplier 1 operates normally, the SFS and STS options do not function. Note, the expression in Eq. (4) is expressed in the following form

$$\begin{aligned}\pi_r = {} & p(1-\theta)E(\alpha x \wedge Q_1) - (1-\theta)w_1 Q_1 \\ & + pE((1-\alpha)x \wedge Q_2) - w_2 Q_2 \\ & + p\theta E(\alpha x \wedge (Q_2-(1-\alpha)x)^+). \end{aligned} \tag{7}$$

Let Q_1^{e*}, Q_2^{e*}, w_1^{e*}, w_2^{e*} be the optimal solutions that maximize Eqs. (5)–(7). Then, we can easily obtain the retailer's expected profit π_r^{e*}, supplier 1's profit π_{s1}^{e*}, and supplier 2's profit π_{s2}^{e*}, with superscript "e" denoting the optimal outcomes in case 2. The results are presented in Table 2.

Proposition 1. The optimal solutions and expected profits under the non-omnichannel and omnichannel retailing strategies are presented in Table 2.

4 Analysis

In this section, we first analyze the optimal ordering decisions and wholesale pricing decisions and then evaluate the expected profits under different scenarios and cases.

4.1 Ordering decision of the retailer

In Section 4.1, we examine the retailer's optimal ordering decisions. Proposition 2 shows the relationships between the optimal ordering quantities of the retailer from supplier 1 and those from supplier 2 when omnichannel and non-omnichannel retailing strategies are adopted, respectively.

Proposition 2. The relationship between the retailer's optimal ordering quantities from the two suppliers is as follows:

(a) In the scenario of non-omnichannel retailing, if $0 < \alpha \leqslant 1/2$, $Q_1^* \leqslant Q_2^*$; otherwise, $Q_1^* > Q_2^*$;

(b) In the scenario of omnichannel retailing, we have $Q_1^{u*} < Q_2^{u*}$ in case 1. In case 2, when $0 < \alpha \leqslant (1-\sqrt{1-\theta})/\theta$, $Q_1^{e*} \leqslant Q_2^{e*}$, and when $(1-\sqrt{1-\theta})/\theta < \alpha < 1$, $Q_1^{e*} > Q_2^{e*}$.

Proposition 2(a) intuitively shows that under the non-omnichannel retailing scenario, as two channels are not allowed to share inventory, the retailer orders more for the channel with greater demand. Proposition 2(b) shows, when the service levels of the two channels are unequal (i.e., case 1), the retailer always orders more products from supplier 2 than from supplier 1. This can be explained by the fact that supplier 1 may suffer from a disruption threat, whereas supplier 2 is reliable. Therefore, the retailer is prone to procuring more products from supplier 2 to counter the risk of insufficient product supply. This also indicates that the retailer's optimal ordering decision is independent of the proportion of market demand in case 1.

Proposition 2(b) also indicates that when the retailer provides the same level of service in both channels (i.e., case 2), the retailer orders more from supplier 1 if the proportion of online demand is greater than the threshold (i.e., $\bar{\alpha}_1 = (1-\sqrt{1-\theta})/\theta$); otherwise, the retailer orders more from supplier 2. Furthermore, the threshold $\bar{\alpha}_1$ is greater than $1/2$. This implies that in practice, the higher market share of the channel does not necessarily translate to more products offered by the retailer. Given the online channel's market demand $\alpha \in (1/2, \bar{\alpha}_1)$, the optimal order quantity of the retailer from supplier 2 is higher than that from supplier 1 under the omnichannel retailing scenario. In case 2, the inventories of the two channels cannot be replenished when supplier 1 operates normally while the store inventory can replenish the online inventory only if supplier 1 is interrupted. Given the risk of disruption at supplier 1, the retailer has the opportunity to generate additional revenue by leveraging the store inventory to replenish the online inventory. Thus, on a certain scale, the opportunity drives the retailer to hold more store inventory against the risk of supply disruption.

Proposition 3 presents the results of the comparison of the retailer's optimal ordering decisions between the benchmark and omnichannel retailing.

Proposition 3. The comparison results for the retailer's optimal ordering decisions between different strategies and cases have the following properties:

(a) When $Q_1/\alpha \neq Q_2/(1-\alpha)$, if $0 < \alpha \leqslant 2/(\theta+3)$, $Q_1^{u*} \geqslant Q_1^*$; and if $2/(\theta+3) < \alpha < 1$, $Q_1^{u*} < Q_1^*$. When $Q_1/\alpha = Q_2/(1-\alpha)$, $Q_1^{e*} = Q_1^*$;

(b) $Q_2^{u*} > Q_2^*$, $Q_2^{e*} > Q_2^*$.

Proposition 3(a) shows that if the demand of online consumers is not relatively large and is below a particular threshold (i.e., $\bar{\alpha}_2 = 2/(\theta+3)$), the retailer increases the ordering quantity from supplier 1 under the omnichannel retailing scenario relative to that under non-omnichannel retailing, and vice versa. However, this is counterintuitive. A possible reason is that in the case where the service levels of the two channels are different, the retailer needs to balance the power of inventory mismatch (i.e., overage and underage) costs against the additional benefits. There may be high holding costs for the retailer when the risk of supplier 1's disruption is low; otherwise, there may be high out-of-stock costs. Moreover, the retailer can gain extra revenue by utilizing the SFS and STS options to replenish each channel's stock. We observe that the extra benefits dominate the holding and out-of-stock costs when online consumers' demand is not relatively large. After adopting the omnichannel retailing strategy, the retailer is willing to order more from supplier 1. By contrast, when the market share of online consumers is high, holding or out-of-stock costs dominate the extra benefits. Thus, the retailer decides to reduce the optimal order quantity from supplier 1 to reduce costs.

Proposition 3(a) also shows that when the two channels satisfy the market with equal service levels, the optimal order quantity of the retailer from supplier 1 is unchanged regardless of whether the retailer adopts the omnichannel retailing strategy. This is reasonable as supplier 1 cannot replenish the store inventory; that is, the STS option is malfunctioning.

Proposition 3(b) implies that after using the omnichannel retailing strategy, the retailer prefers to order more quantities from supplier 2. The main reason for this is that the SFS option allows the sharing of stock and cross-channel supply whenever supplier 1 is disrupted or operates normally. Thus, the retailer has an incentive to procure more quantities from supplier 2 to earn extra profit by servicing the online channel.

4.2 Wholesale pricing decision of the two suppliers

In Section 4.2, we examine the wholesale pricing decisions of the two suppliers under different strategies; these decisions are characterized in the following proposition.

Proposition 4. The optimal wholesale pricing decisions of suppliers 1 and 2 in different situations have the following relationships: $w_1^* = w_2^*$, $w_1^{u*} < w_2^{u*}$, and $w_1^{e*} = w_2^{e*}$.

Proposition 4 indicates the two suppliers set identical optimal wholesale prices (i.e., $p/2$) to maximize their respective profits when the retailer adopts the non-omnichannel retailing strategy. However, when the two channels have unequal service levels (i.e., case 1), the adoption of the omnichannel retailing strategy induces supplier 1 to charge a lower wholesale price than supplier 2. As supplier 1 faces a disruption risk, the retailer tends to procure fewer products from supplier 1 to reduce procurement costs. This means that supplier 1 is less competitive than supplier 2. Thus, supplier 1 charges a low wholesale price to motivate the retailer to purchase more products from it. When the two channels have equal service levels (i.e., case 2), similar to the non-omnichannel retailing scenario, the optimal wholesale prices charged by the two suppliers are identical. In this case, the omnichannel retailing strategy is less effective because the STS option is not working while the SFS option functions only if supplier 1 is disrupted; thus, the two suppliers have no incentive to change their decisions regarding optimal wholesale prices under the omnichannel retailing strategy relative to that under the non-omnichannel retailing strategy.

Next, we demonstrate the relationship of the optimal wholesale prices of suppliers 1 and 2 in the benchmark and omnichannel retailing cases.

Proposition 5. The relationship of the optimal wholesale prices of the two suppliers between different situations is as follows:

(a) When $Q_1/\alpha \neq Q_2/(1-\alpha)$, $w_1^{u*} < w_1^*$, $w_2^{u*} < w_2^*$;

(b) When $Q_1/\alpha = Q_2/(1-\alpha)$, $w_1^{e*} = w_1^*$, $w_2^{e*} = w_2^*$.

Proposition 5(a) shows that when the two suppliers have different service levels, the optimal wholesale prices under omnichannel retailing are lower than those under non-omnichannel retailing. Given the effect of inventory sharing across channels, the suppliers have an incentive to decrease the wholesale prices to motivate the retailer to increase its ordering quantity.

Interestingly, in Proposition 5(b), the retailer's decisions regarding the wholesale price under the non-omnichannel and omnichannel retailing strategies are the same if the retailer sets identical service levels in the two channels (i.e., case 2). In case 2, because supplier 1 does not need to replenish the store inventory, it cannot earn additional revenue. In this situation, reducing the wholesale price undoubtedly damages the supplier's profit; therefore, it is reluctant to lower the wholesale price. However, if a disruption occurs at supplier 1, supplier 2 can replenish the online inventory to ensure that more online consumers can be serviced. In this situation, the retailer can only purchase products from supplier 2, thus allowing supplier 2 to maintain the optimal wholesale price and maximize its profits.

4.3 Profits of each channel member

In Section 4.3, we first compare the expected profits of suppliers 1 and 2 and then summarize the influence of the omnichannel retailing strategy on the profits of supply chain players.

Proposition 6. The relationship between the expected profits of the two suppliers under different scenarios is as follows:

(a) Under the non-omnichannel retailing scenario, if $0 < \alpha \leqslant 1/(2-\theta)$, $\pi^*_{s1} \leqslant \pi^*_{s2}$; and if $1/(2-\theta) < \alpha < 1$, $\pi^*_{s1} > \pi^*_{s2}$;

(b) Under the omnichannel retailing scenario, when $Q_1/\alpha \neq Q_2/(1-\alpha)$, $\pi^{u*}_{s1} < \pi^{u*}_{s2}$. When $Q_1/\alpha = Q_2/(1-\alpha)$, if $0 < \alpha \leqslant \bar{\alpha}_3$, $\pi^{e*}_{s1} \leqslant \pi^{e*}_{s2}$, where $\bar{\alpha}_3 = (2-\theta-\sqrt{5\theta^2-8\theta+4})/2\theta(1-\theta)$; and if $\bar{\alpha}_3 < \alpha < 1$, $\pi^{e*}_{s1} > \pi^{e*}_{s2}$.

Proposition 6(a) states that in the non-omnichannel retailing scenario, when the proportion of the market demand from online consumers is larger than a particular threshold, that is, $1/(2-\theta)$, the expected profit of supplier 1 is greater than that of supplier 2; otherwise, the expected profit of supplier 2 is relatively large. Note that the suppliers' profits depend on their wholesale prices and the retailer's ordering quantity. When the non-omnichannel retailing strategy is adopted, the two suppliers set the same optimal wholesale price, resulting in the suppliers' profit being dominated by the retailer's ordering decision. In addition, the retailer is prone to order a more optimal order quantity from supplier 1 when the demand stems mainly from online consumers. Similarly, when the market share of the in-store channel is large, the retailer is willing to procure more from supplier 2. This explains why the profit relationship between the two suppliers is influenced by market share.

Proposition 6(b) implies that if the service levels of the two channels are different, supplier 2 always obtains a larger profit than supplier 1 in the omnichannel retailing scenario. As indicated in the analysis in Propositions 2(b) and 4, the omnichannel retailing strategy enables supplier 2 to maintain a great competitive advantage in setting wholesale prices and selling products relative to supplier 1; thus, supplier 2 is better off.

Proposition 6(b) also reveals that in an omnichannel retailing scenario, if the service levels of the two channels are equal, the expected profit of the supplier depends on the size of the supplied channel consumers. In this case, the functions of sharing inventory in the two channels are partially working. When the market demand of the online channel is sufficiently low, that is, less than a specific threshold, supplier 2 earns more profit than supplier 1; otherwise, supplier 1 is better off than supplier 2. The reasons for this are similar to those given in Proposition 6(a).

Proposition 7. The effects of the omnichannel retailing strategy on the profits of supply chain players are characterized as follows:

(a) $\pi^{u*}_r > \pi^*_r$, $\pi^{e*}_r > \pi^*_r$;

(b) When $Q_1/\alpha \neq Q_2/(1-\alpha)$, if $0 < \alpha \leqslant \bar{\alpha}_4$, $\pi^{u*}_{s1} \geqslant \pi^*_{s1}$, where $\bar{\alpha}_4 = 4\theta/(\theta+3)^2$; otherwise, $\pi^{u*}_{s1} < \pi^*_{s1}$. Moreover, if $0 < \alpha \leqslant \bar{\alpha}_5$, $\pi^{u*}_{s2} \leqslant \pi^*_{s2}$, where $\bar{\alpha}_5 = (\theta^2-10\theta+9)/(\theta+3)^2$; otherwise, $\pi^{u*}_{s2} > \pi^*_{s2}$;

(c) When $Q_1/\alpha = Q_2/(1-\alpha)$, $\pi^{e*}_{s1} = \pi^*_{s1}$, $\pi^{e*}_{s2} > \pi^*_{s2}$.

Proposition 7(a) shows that the retailer gains more profit when implementing the omnichannel retailing strategy. This is because the omnichannel retailing strategy significantly increases the total optimal quantity ordering from both suppliers, thereby exerting a positive effect on the retailer's profit. Meanwhile, procurement costs are reduced because inventory sharing across channels leads to aggressive competition between the two suppliers. These two positive effects enable the retailer to earn more profit after adopting the omnichannel retailing strategy.

Proposition 7(b) shows that if the service levels of the two channels are different, whether the supplier benefits from implementing omnichannel retailing depends on the market share of the channel it serves. The adoption of the omnichannel retailing strategy is beneficial to supplier 1 only when the proportion of online consumers is sufficiently small; this notion is contrary to our perception. There is a positive effect (inventory sharing across channels to increase sales) and a negative wholesale price effect on supplier 1's profitability. When the demand of the online channel is low, the positive effect can offset the negative effect and make supplier 1 better off. However, as the online channel's demand increases, the scale of the loss of profits from decreasing wholesale prices gradually increases. Consequently, the adoption of the omnichannel retailing strategy is worse for supplier 1. Similarly, when the proportion of in-store consumers is small, the adoption of the omnichannel retailing strategy favors supplier 2. The reason for this is the same as that for supplier 1. Although supplier 2 can also replenish online inventory to gain profit, the cost of decreasing the wholesale price dominates when the proportion of in-store consumers is small.

Proposition 7(c) shows that if the service levels of the two channels are equal (i.e., case 2), the implementation of the omnichannel retailing strategy has no effect on supplier 1's expected profit, whereas it is always beneficial for supplier 2. This can be explained as follows. On the one hand, according to the analysis in Proposition 3(a), the retailer's decision on the optimal ordering quantity from supplier 1 in case 2 is consistent with that in the non-omnichannel retailing scenario. This result implies that supplier 1's sales are not affected by the omnichannel retailing strategy. On the other hand, according to the discussion in Proposition 5(b), supplier 1 sets an identical optimal wholesale price under different strategies. Thus, supplier 1 earns equal expected profit in case 2 as in the non-omnichannel scenario. Similar to the previous analysis, supplier 2's optimal wholesale price decisions under different strategies are equal while product sales under the omnichannel retailing strategy are larger than those under the non-omnichannel retailing strategy. Combining these two factors, the expected profit of supplier 2 under the omnichannel retailing strategy is greater than that under the non-omnichannel retailing strategy.

Next, we use numerical analysis to explore the effects of α on supply chain members' profits in different situations. We define the value of the x-axis α, and change it from 0 to 1. First, we set $\theta = 0.2$, $p = 0.35$. The expected profits of the retailer and the two suppliers with respect to α are given in Fig. 1. Second, we set $\theta = 0.5$, $p = 0.35$. The expected profits of the retailer and two suppliers with respect to α are given in Fig. 2. Third, we set $\theta = 0.8$, $p = 0.35$. The expected profits of the retailer and the two suppliers with respect to α are given in Fig. 3.

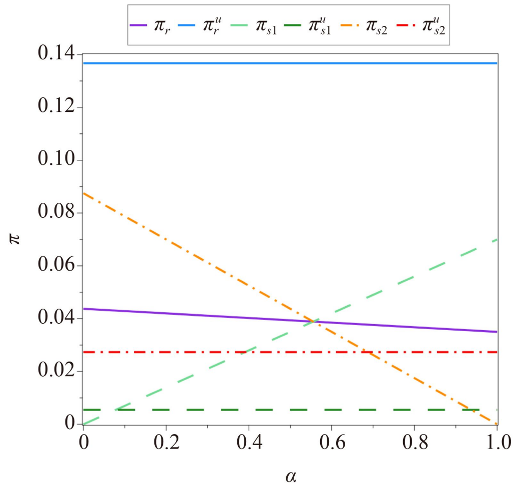

Fig. 1 Effects of α on supply chain members' profit ($\theta = 0.2$, $p = 0.35$).

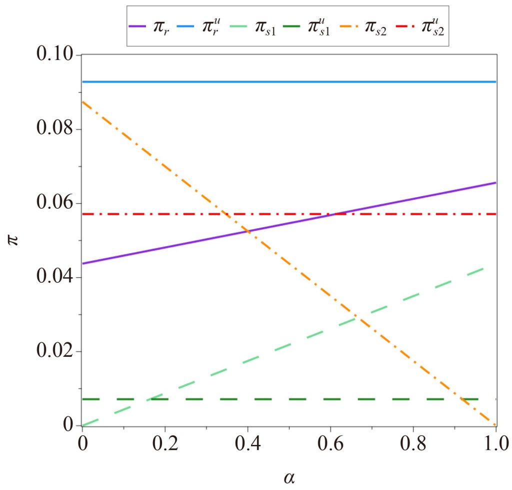

Fig. 2 Effects of α on supply chain members' profit ($\theta = 0.5$, $p = 0.35$).

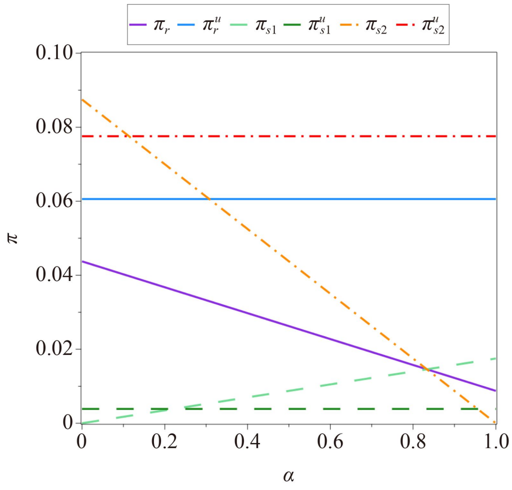

Fig. 3 Effects of α on supply chain members' profit ($\theta = 0.8$, $p = 0.35$).

Figure 1 shows that when the retailer adopts the omnichannel retailing strategy, the profits of the retailer and two suppliers are constant, meaning that profits are independent of the channel market share. We also find that if $0 < \alpha \leqslant 0.078$, the expected profit of supplier 1 under omnichannel retailing is greater than that under traditional retailing; otherwise, the expected profit of supplier 1 under traditional retailing is large. Moreover, if $0 < \alpha \leqslant 0.688$, the expected profit of supplier 2 under traditional retailing is greater than that under omnichannel retailing; otherwise, the expected profit of supplier 2 under omnichannel retailing is large. Thus, when the risk of supplier 1 disruption is low, there is always a win–lose situation for the two suppliers.

Similar to that shown in Fig. 1, the profits of the retailer and the two suppliers are constant under the omnichannel retailing scenario in Fig. 2. We find that if $0 < \alpha \leqslant 0.163$, the expected profit of supplier 1 under omnichannel retailing is greater than that under traditional retailing; otherwise, the expected profit of supplier 1 under traditional retailing is large. Moreover, if $0 < \alpha \leqslant 0.347$, the expected profit of supplier 2 under traditional retailing is greater than that under omnichannel retailing; otherwise, the expected profit of supplier 2 under omnichannel retailing is large. Thus, when the risk of supplier 1 disruption is moderate, there is still a win–lose situation for the two suppliers.

In Fig. 3, under the omnichannel retailing scenario, the supplier's profit still remains independent of α. We find that under the omnichannel retailing strategy, unless α is too small, supplier 2 is always better off. In contrast to the two figures above, when $0.114 < \alpha < 0.222$, there is a win–win situation for the two suppliers. In sum, owing to the risk of supplier 1 disruption, the adoption of the omnichannel retailing strategy does not improve supplier 1's situation to some extent. Conversely, the greater the risk of supplier 1 disruption is, the more beneficial it is for supplier 2 to adopt omnichannel retailing. Specifically, as θ increases, the out-of-stock risk in the online channel increases, thereby prompting the retailer to procure more products from supplier 2. Thus, supplier 2 is better off.

4.4 Effect on the whole supply chain

In the benchmark setting, we express the supply chain's expected profit as $\pi_{sc} = \pi_r + \pi_{s1} + \pi_{s2}$. Similarly, under the omnichannel retailing scenario, the supply chain's expected profits in cases 1 and 2 are presented as π_{sc}^u and π_{sc}^e, respectively. We use Proposition 8 to present the effects of the omnichannel retailing strategy on the profit of the whole supply chain.

Proposition 8. The relationship between the expected profits of the supply chain under different scenarios and cases is $\pi_{sc}^u > \pi_{sc}, \pi_{sc}^e > \pi_{sc}$.

Proposition 8 implies that the adoption of omnichannel retailing strategy always makes the supply chain better off. A key driver of this outcome is that adopting the omnichannel retailing strategy encourages the retailer to order more quantities to serve consumers.

5 Conclusions

In the past two years, dual-channel retailers have utilized the omnichannel retailing strategy (i.e., SFS and STS options) to mitigate the negative effects of the COVID-19 pandemic on the retail industry. This study develops a newsvendor model to explore the role of SFS and STS fulfillment options in cases of supply chain disruptions under the omnichannel context. We use numerical analysis to examine how the key factors of consumer preference and risk levels affect supply chain members' profits.

The main findings are summarized as follows: First, we find that when adopting the omnichannel retailing strategy, the retailer's order quantity from the risky supplier may increase or decrease, whereas the order quantity from the normal supplier certainly increases. Second, the suppliers decrease or maintain the wholesale price, and the risky supplier charges a lower wholesale price than the normal supplier. Third, when supply disruption risk is high and the market share of the channel offered by the risky supplier is low, it is possible to achieve a win–win–win outcome for all three parties by adopting the omnichannel retailing strategy. Moreover, the entire supply chain benefits from the omnichannel retailing strategy even if the supply chain faces a high level of disruption risk.

The management insights derived from the above analysis are as follows: First, retailers should adopt the omnichannel retailing strategy to share inventory between online and in-store channels. Under the scenario where the online channel faces the threat of disruption, online consumers can be satisfied by using in-store inventory. Similarly, online inventory can be used to meet the requirements of in-store consumers when the in-store channel faces supply disruption risks. Furthermore, cross-channel fulfillment works when the two suppliers operate normally and the service levels of the two channels are different. Second, our study provides recommendations for managers, including determining the optimal wholesale price and deciding the ordering quantity. For suppliers, different procurement decisions should be made for disparate service levels. It is wise for suppliers to charge a lower wholesale price to encourage retailers to order more quantities unless the two channels have an identical service level. In addition, when the proportion of consumers in online channels is small, suppliers serving online channels can reserve more orders to compensate for the inventory of offline channels.

Future research could extend toward the following directions: First, we consider that price and other market parameters are exogenous. One can consider that prices are endogenous. Second, we explore retailer sourcing from two suppliers, each of which is responsible for supplying the products in one channel. Future research could assume that one of the suppliers provides products for both the retailer's online and offline channels.

Appendix A

Proof of Proposition 1

In the non-omnichannel retailing scenario, the retailer's expected profit is as follows

$$\begin{aligned}\pi_r &= p(1-\theta)E(\alpha x \wedge Q_1) - (1-\theta)w_1 Q_1 \\ &\quad + pE((1-\alpha)x \wedge Q_2) - w_2 Q_2 \\ &= p(1-\theta)\left(\frac{Q_1^2}{2\alpha} + Q_1\left(1-\frac{Q_1}{\alpha}\right)\right) - (1-\theta)w_1 Q_1 \\ &\quad + p\left(\frac{Q_2^2}{2(1-\alpha)} + Q_2\left(1-\frac{Q_2}{1-\alpha}\right)\right) - w_2 Q_2 \end{aligned} \quad . \quad \text{(A1)}$$

The first derivatives of π_r with respect to Q_1 and Q_2 are $\partial\pi_r/\partial Q_1 = p(1-\theta)(1-Q_1/\alpha)-(1-\theta)w_1$ and $\partial\pi_r/\partial Q_2 = p(1-Q_2/(1-\alpha))-w_2$, respectively. The second derivatives of π_r with respect to Q_1 and Q_2 are $\partial^2\pi_r/\partial Q_1^2 = -p(1-\theta)/\alpha$ and $\partial^2\pi_r/\partial Q_2^2 = -p/(1-\alpha)$, respectively.

As the second derivatives of π_r with respect to Q_1 and Q_2 are both negative, the retailer's profit function is concave in Q_1 and Q_2. Thus, by solving the first-order conditions $\partial\pi_r/\partial Q_1 = 0$ and $\partial\pi_r/\partial Q_2 = 0$, we have

$$Q_1 = \frac{\alpha(p-w_1)}{p},\ Q_2 = \frac{(1-\alpha)(p-w_2)}{p}. \tag{A2}$$

The profit functions of the two suppliers are

$$\pi_{s1} = (1-\theta)w_1Q_1,\ \pi_{s2} = w_2Q_2. \tag{A3}$$

By substituting Eq. (A2) into Eq. (A3), we obtain the first and second derivatives with respect to w_1 and w_2, respectively. Thus, by solving the first-order conditions $\partial\pi_{s1}/\partial w_1 = 0$ and $\partial\pi_{s2}/\partial w_2 = 0$, we obtain $w_1^* = w_2^* = p/2$.

By substituting w_1^* and w_2^* into the functions in Eq. (A2), we obtain the optimal ordering quantity for the two suppliers (Q_1^* and Q_2^*). Next, by substituting w_1^*, w_2^*, Q_1^*, and Q_2^* into the profit functions in Eqs. (A1) and (A3), we can derive the expected optimal profits π_r^*, π_{s1}^*, and π_{s2}^*.

In the omnichannel retailing scenario, the retailer's expected profit is as Eq. (4).

In the case of $Q_1/\alpha \neq Q_2/(1-\alpha)$, the retailer's expected profit is simplified as

$$\begin{aligned}\pi_r^u = {} & \frac{p}{2}((\theta-1)Q_1^2 - Q_2(Q_2-2)) \\ & - p(1-\theta)Q_1(Q_2-1) - (1-\theta)w_1Q_1 - w_2Q_2.\end{aligned} \tag{A4}$$

In the case of $Q_1/\alpha = Q_2/(1-\alpha)$, the retailer's expected profit is shown as

$$\begin{aligned}\pi_r^e = {} & p(1-\theta)\left(\frac{Q_1^2}{2\alpha} + Q_1\left(1-\frac{Q_1}{\alpha}\right)\right) - (1-\theta)w_1Q_1 \\ & + p\left(\frac{Q_2^2}{2(1-\alpha)} + Q_2\left(1-\frac{Q_2}{1-\alpha}\right)\right) - w_2Q_2 \\ & - \theta p\left(\frac{1-\alpha}{2}\left(\frac{Q_2^2}{(1-\alpha)^2} - Q_2^2\right) - Q_2\left(\frac{Q_2}{1-\alpha} - Q_2\right) - \frac{\alpha Q_2^2}{2}\right).\end{aligned} \tag{A5}$$

The profit functions of the suppliers in different scenarios are identical. Similar to that in the non-omnichannel retailing scenario, we can derive the optimal wholesale prices (w_1^{u*}, w_2^{u*}, w_1^{e*}, w_2^{e*}) and optimal order quantities (Q_1^{u*}, Q_2^{u*}, Q_1^{e*}, Q_2^{e*}). Subsequently, by substituting these into the profit functions in Eqs. (A3)–(A5), we can obtain the expected optimal profits of the retailer (π_r^{u*}, π_r^{e*}) and the suppliers (π_{s1}^{u*}, π_{s2}^{u*}, π_{s1}^{e*}, π_{s2}^{e*}).

Proof of Proposition 2

Proof of Proposition 2(a). Based on the optimal solutions under the non-omnichannel retailing strategy in Table 2, we set $Q_1^* - Q_2^* = 0$ to derive $\alpha = 1/2$. We find that when $0 < \alpha \leqslant 1/2$, $Q_1^* \leqslant Q_2^*$; otherwise, $Q_1^* > Q_2^*$.

Proof of Proposition 2(b). It is obvious that $Q_1^{u*} < Q_2^{u*}$. To identify the relationship between Q_1^{e*} and Q_2^{e*}, we set $\Delta_1 = Q_1^{e*} - Q_2^{e*}$. The first and second derivatives of Δ_1 with respect to α are $\frac{\partial\Delta_1}{\partial\alpha} = 1 - \frac{2(\alpha^2\theta - 2\alpha + 1)\theta}{4(1-\alpha\theta)^2}$ and $\frac{\partial^2\Delta_1}{\partial\alpha^2} = \frac{\theta(1-\theta)}{(1-\alpha\theta)^3}$, respectively. As the second derivative of Δ_1 with respect to α is positive, the difference between Q_1^{e*} and Q_2^{e*} is convex in α. To solve $\Delta_1 = 0$, we can derive $\alpha = (1-\sqrt{1-\theta})/\theta$, $\alpha = (1+\sqrt{1-\theta})/\theta$ (rejected). It is easy to see that if $0 < \alpha \leqslant (1-\sqrt{1-\theta})/\theta$, $Q_1^{e*} \leqslant Q_2^{e*}$; otherwise, $Q_1^{e*} > Q_2^{e*}$.

Proof of Proposition 3

Proof of Proposition 3(a). Similar to the proof of Proposition 2(a), we set $Q_1^{u*} - Q_1^* = 0$ to derive $\alpha = 2/(\theta+3)$. When $0 < \alpha \leqslant 2/(\theta+3)$, $Q_1^{u*} \geqslant Q_1^*$; otherwise, $Q_1^{u*} < Q_1^*$. Moreover, it is clear that $Q_1^{e*} = Q_1^*$.

Proof of Proposition 3(b). To compare the optimal ordering quantities from supplier 2 under two cases (i.e., $Q_1/\alpha \neq Q_2/(1-\alpha)$ and $Q_1/\alpha = Q_2/(1-\alpha)$), we obtain $Q_2^{u*} > Q_2^*$ and $Q_2^{e*} > Q_2^*$ when $0 < \alpha < 1$.

Proof of Proposition 4

By comparing the optimal wholesale prices of suppliers under the omnichannel retailing and non-omnichannel retailing strategies, we can easily judge that $w_1^* = w_2^*$, $w_1^{u*} < w_2^{u*}$, and $w_1^{e*} = w_2^{e*}$.

Proof of Proposition 5

We have $w_1^{u*} - w_1^* = -\frac{p(1-\theta)(3-\theta)}{2(\theta+3)} < 0$, $w_2^{u*} - w_2^* = -\frac{3p(1-\theta)}{2(\theta+3)} < 0$. It can be observed that $w_1^{u*} < w_1^*$, $w_2^{u*} < w_2^*$. Moreover, it is clear that $w_1^{e*} = w_1^*$, $w_2^{e*} = w_2^*$.

Proof of Proposition 6

Proof of Proposition 6(a). Based on the optimal profits of the two suppliers under the non-omnichannel retailing strategy in Table 2, we set $\Delta_2 = \pi_{s1}^* - \pi_{s2}^* = 0$ to derive $\alpha = 1/(2-\theta)$. The first derivative of Δ_2 with respect to α is $\partial\Delta_2/\partial\alpha = p(2-\theta)/4 > 0$, that is, the difference between the two suppliers increases with α. When $0 < \alpha \leqslant 1/(2-\theta)$, we have $\Delta_2 \leqslant 0$; otherwise, $\Delta_2 > 0$. Thus, Proposition 6(a) is proven.

Proof of Proposition 6(b). By comparing the optimal profits of the two suppliers under omnichannel retailing in case 1, we have $\pi_{s1}^{u*} - \pi_{s2}^{u*} = -\theta p/(\theta+3) < 0$. Therefore, we have $\pi_{s1}^{u*} < \pi_{s2}^{u*}$.

We then compare the relationship between π_{s1}^{e*} and π_{s2}^{e*}. By setting $\Delta_3 = \pi_{s1}^{e*} - \pi_{s2}^{e*}$, we find that the first derivative of Δ_3 with respect to α is positive. To solve the function in which $\Delta_3 = 0$, we have $\alpha = \frac{2-\theta-\sqrt{5\theta^2-8\theta+4}}{2\theta(1-\theta)}$,

$\alpha = \dfrac{2-\theta+\sqrt{5\theta^2-8\theta+4}}{2\theta(1-\theta)}$ (rejected). Therefore, if $0 < \alpha \leqslant \dfrac{2-\theta-\sqrt{5\theta^2-8\theta+4}}{2\theta(1-\theta)}$, $\pi_{s1}^{e*} \leqslant \pi_{s2}^{e*}$; and if $\dfrac{2-\theta-\sqrt{5\theta^2-8\theta+4}}{2\theta(1-\theta)} < \alpha < 1$, $\pi_{s1}^{e*} > \pi_{s2}^{e*}$.

Proof of Proposition 7

Proof of Proposition 7(a). To compare the relationship between π_r^{u*} and π_r^*, we set $\Delta_4 = \pi_r^{u*} - \pi_r^*$. When $0 < \alpha < 1$, the first derivative of Δ_4 with respect to α is positive. Then, we set $\Delta_4 = 0$ to derive $\alpha = -\dfrac{(1-\theta)(\theta+27)}{\theta(\theta+3)^2} < 0$ (rejected). Thus, if $0 < \alpha < 1$, $\Delta_4 > 0$, that is, $\pi_r^{u*} > \pi_r^*$. In addition, we have $\pi_r^{e*} - \pi_r^* = \dfrac{p(1-\alpha)\alpha\theta}{8(1-\alpha\theta)} > 0$. Thus, it is clear that $\pi_r^{e*} > \pi_r^*$.

Proof of Proposition 7(b). To compare the relationship between π_{s1}^{u*} and π_{s1}^*, we set $\Delta_5 = \pi_{s1}^{u*} - \pi_{s1}^*$. The first derivative of Δ_5 with respect to α is $\partial\Delta_5/\partial\alpha = -(1-\theta)p/4 < 0$. Then, we let $\Delta_5 = 0$ to derive $\alpha = 4\theta/(\theta+3)^2$. Thus, if $0 < \alpha \leqslant 4\theta/(\theta+3)^2$, $\pi_{s1}^{u*} \geqslant \pi_{s1}^*$; otherwise, $\pi_{s1}^{u*} < \pi_{s1}^*$.

Similarly, we set $\Delta_6 = \pi_{s2}^{u*} - \pi_{s2}^*$. The first derivative of Δ_6 with respect to α is $\partial\Delta_6/\partial\alpha = p/4 > 0$. We solve the function $\Delta_6 = 0$ to deduce $\alpha = (\theta^2-10\theta+9)/(\theta+3)^2$. Hence, if $0 < \alpha \leqslant (\theta^2-10\theta+9)/(\theta+3)^2$, $\pi_{s2}^{u*} \leqslant \pi_{s2}^*$; otherwise, $\pi_{s2}^{u*} > \pi_{s2}^*$.

Proof of Proposition 7(c). By comparing the optimal profit of supplier 1 under different scenarios in Table 2, we find that $\pi_{s1}^{e*} = \pi_{s1}^*$. By comparing the optimal profit of supplier 2 under different scenarios in Table 2, we obtain $\pi_{s2}^{e*} - \pi_{s2}^* = \dfrac{p(1-\alpha)\alpha\theta}{4(1-\alpha\theta)} > 0$. Thus, $\pi_{s2}^{e*} > \pi_{s2}^*$.

Proof of Proposition 8

Based on the optimal profits of the retailer and the suppliers under different scenarios in Table 2, we find the profit of the entire supply chain as $\pi_{sc}^* = \pi_r^* + \pi_{s1}^* + \pi_{s2}^* = 3p(1-\alpha\theta)/8$, $\pi_{sc}^{u*} = \pi_r^{u*} + \pi_{s1}^{u*} + \pi_{s2}^{u*} = \dfrac{p(9-2\theta^2+5\theta)}{2(\theta+3)^2}$, $\pi_{sc}^{e*} = \pi_r^{e*} + \pi_{s1}^{e*} + \pi_{s2}^{e*} = \dfrac{3p(1-\theta(1-\theta)\alpha^2-\theta\alpha)}{8(1-\alpha\theta)}$. Through calculation, we find that $\pi_{sc}^{u*} - \pi_{sc}^* > 0$, $\pi_{sc}^{e*} - \pi_{sc}^* > 0$. Thus, Proposition 8 is proven.

References

Ang E, Iancu D A, Swinney R (2017). Disruption risk and optimal sourcing in multitier supply networks. Management Science, 63(8): 2397–2419

Anupindi R, Akella R (1993). Diversification under supply uncertainty. Management Science, 39(8): 944–963

Bayram A, Cesaret B (2021). Order fulfillment policies for ship-from-store implementation in omni-channel retailing. European Journal of Operational Research, 294(3): 987–1002

Belhadi A, Kamble S S, Venkatesh M, Chiappetta Jabbour C J, Benkhati I (2022). Building supply chain resilience and efficiency through additive manufacturing: An ambidextrous perspective on the dynamic capability view. International Journal of Production Economics, 249: 108516

Bell D R, Gallino S, Moreno A (2018). Offline showrooms in omnichannel retail: Demand and operational benefits. Management Science, 64(4): 1629–1651

Cachon G P, Swinney R (2009). Purchasing, pricing, and quick response in the presence of strategic consumers. Management Science, 55(3): 497–511

Chen F, Zheng Y S (1994). Lower bounds for multi-echelon stochastic inventory systems. Management Science, 40(11): 1426–1443

Chen J, Sohal A S, Prajogo D I (2013). Supply chain operational risk mitigation: A collaborative approach. International Journal of Production Research, 51(7): 2186–2199

Dada M, Petruzzi N C, Schwarz L B (2007). A newsvendor's procurement problem when suppliers are unreliable. Manufacturing & Service Operations Management, 9(1): 9–32

Darom N A, Hishamuddin H, Ramli R, Mat Nopiah Z (2018). An inventory model of supply chain disruption recovery with safety stock and carbon emission consideration. Journal of Cleaner Production, 197: 1011–1021

DeCroix G A (2013). Inventory management for an assembly system subject to supply disruptions. Management Science, 59(9): 2079–2092

Derry T (2020). 75% of companies report supply chain disruption. Online Report

Dong L, Tang S Y, Tomlin B (2018). Production chain disruptions: Inventory, preparedness, and insurance. Production and Operations Management, 27(7): 1251–1270

Du S, Wang L, Hu L (2019). Omnichannel management with consumer disappointment aversion. International Journal of Production Economics, 215: 84–101

Dzyabura D, Jagabathula S (2018). Offline assortment optimization in the presence of an online channel. Management Science, 64(6): 2767–2786

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

Gao F, Su X (2017a). Omnichannel retail operations with buy-online-and-pick-up-in-store. Management Science, 63(8): 2478–2492

Gao F, Su X (2017b). Online and offline information for omnichannel retailing. Manufacturing & Service Operations Management, 19(1): 84–98

Gao Y, Feng Z, Zhang S (2021). Managing supply chain resilience in the era of VUCA. Frontiers of Engineering Management, 8(3): 465–470

Gümüş M, Ray S, Gurnani H (2012). Supply-side story: Risks, guarantees, competition, and information asymmetry. Management Science, 58(9): 1694–1714

He Y, Xu Q, Shao Z (2021). "Ship-from-Store" strategy in platform retailing. Transportation Research Part E: Logistics and Transportation Review, 145: 102153

He Y, Xu Q, Wu P (2020). Omnichannel retail operations with refurbished consumer returns. International Journal of Production Research, 58(1): 271–290

Hu M, Xu X, Xue W, Yang Y (2022). Demand pooling in omnichannel operations. Management Science, 68(2): 883–894

Ishfaq R, Raja U (2018). Evaluation of order fulfillment options in retail supply chains. Decision Sciences, 49(3): 487–521

Ivanov D (2020). 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: 101922

Jin M, Li G, Cheng T C E (2018). Buy online and pick up in-store: Design of the service area. European Journal of Operational Research, 268(2): 613–623

Kong R, Luo L, Chen L, Keblis M (2020). The effects of BOPS implementation under different pricing strategies in omnichannel retailing. Transportation Research Part E: Logistics and Transportation Review, 141: 102014

Kumar M, Basu P, Avittathur B (2018). Pricing and sourcing strategies for competing retailers in supply chains under disruption risk. European Journal of Operational Research, 265(2): 533–543

Li G, Li L, Zhou Y, Guan X (2017). Capacity restoration in a decentralized assembly system with supply disruption risks. International Transactions in Operational Research, 24(4): 763–782

Li G, Liu M, Bian Y, Sethi S P (2020). Guarding against disruption risk by contracting under information asymmetry. Decision Sciences, 51(6): 1521–1559

Li G, Liu M, Zheng H (2022). Subsidization or diversification? Mitigating supply disruption with manufacturer information sharing. Omega, 112: 102670

Li M, Zhang X, Dan B (2021). Cooperative advertising and pricing in an O2O supply chain with buy-online-and-pick-up-in-store. International Transactions in Operational Research, 28(4): 2033–2054

Li Y, Xu L, Choi T M, Govindan K (2014). Optimal advance-selling strategy for fashionable products with opportunistic consumers returns. IEEE Transactions on Systems, Man, and Cybernetics: Systems, 44(7): 938–952

Lin X, Zhou Y W, Hou R (2021). Impact of a “buy-online-and-pickup-in-store” channel on price and quality decisions in a supply chain. European Journal of Operational Research, 294(3): 922–935

Liu Z, Li M, Zhai X (2022). Managing supply chain disruption threat via a strategy combining pricing and self-protection. International Journal of Production Economics, 247: 108452

Lücker F, Chopra S, Seifert R W (2021). Mitigating product shortage due to disruptions in multi-stage supply chains. Production and Operations Management, 30(4): 941–964

Lücker F, Seifert R W, Biçer I (2019). Roles of inventory and reserve capacity in mitigating supply chain disruption risk. International Journal of Production Research, 57(4): 1238–1249

Mahajan K, Tomar S (2021). COVID-19 and supply chain disruption: Evidence from food markets in India. American Journal of Agricultural Economics, 103(1): 35–52

Mahar S, Wright P D (2017). In-store pickup and returns for a dual channel retailer. IEEE Transactions on Engineering Management, 64(4): 491–504

Mandal P, Basu P, Saha K (2021). Forays into omnichannel: An online retailer’s strategies for managing product returns. European Journal of Operational Research, 292(2): 633–651

Modgil S, Singh R K, Hannibal C (2022). Artificial intelligence for supply chain resilience: Learning from COVID-19. International Journal of Logistics Management, 33(4): 1246–1268

Moosavi J, Fathollahi-Fard A M, Dulebenets M A (2022). Supply chain disruption during the COVID-19 pandemic: Recognizing potential disruption management strategies. International Journal of Disaster Risk Reduction, 75: 102983

Nageswaran L, Cho S H, Scheller-Wolf A (2020). Consumer return policies in omnichannel operations. Management Science, 66(12): 5558–5575

Naghshineh B, Carvalho H (2022). The implications of additive manufacturing technology adoption for supply chain resilience: A systematic search and review. International Journal of Production Economics, 247: 108387

Pang Z, Xiao W, Zhao X (2021). Preorder price guarantee in e-commerce. Manufacturing & Service Operations Management, 23(1): 123–138

Park J, Dayarian I, Montreuil B (2021). Showcasing optimization in omnichannel retailing. European Journal of Operational Research, 294(3): 895–905

Parlar M, Berkin D (1991). Future supply uncertainty in EOQ models. Naval Research Logistics, 38(1): 107–121

Qi L, Lee K (2015). Supply chain risk mitigations with expedited shipping. Omega, 57: 98–113

Qi X, Bard J F, Yu G (2004). Supply chain coordination with demand disruptions. Omega, 32(4): 301–312

Queiroz M M, Telles R, Bonilla S H (2019). Blockchain and supply chain management integration: A systematic review of the literature. Supply Chain Management, 25(2): 241–254

Remko V H (2020). Research opportunities for a more resilient post-COVID-19 supply chain: Closing the gap between research findings and industry practice. International Journal of Operations & Production Management, 40(4): 341–355

Roggio A (2017). Ship-from-store fulfillment a must for brick-and-click retailers. Online Report

Saha K, Bhattacharya S (2021). Buy online and pick up in-store: Implications for the store inventory. European Journal of Operational Research, 294(3): 906–921

Saleheen F, Habib M M (2022). Global supply chain disruption management post COVID-19. American Journal of Industrial and Business Management, 12(3): 376–389

Serkan Akturk M, Ketzenberg M, Heim G R (2018). Assessing impacts of introducing ship-to-store service on sales and returns in omnichannel retailing: A data analytics study. Journal of Operations Management, 61(1): 15–45

Shao X F (2012). Demand-side reactive strategies for supply disruptions in a multiple-product system. International Journal of Production Economics, 136(1): 241–252

Shekarian M, Mellat Parast M (2021). An Integrative approach to supply chain disruption risk and resilience management: A literature review. International Journal of Logistics Research and Applications, 24(5): 427–455

Tomlin B (2006). On the value of mitigation and contingency strategies for managing supply chain disruption risks. Management Science, 52(5): 639–657

Tomlin B, Wang Y (2005). On the value of mix flexibility and dual sourcing in unreliable newsvendor networks. Manufacturing & Service Operations Management, 7(1): 37–57

van Hoek R, Lacity M (2020). How the pandemic is pushing blockchain forward. Harvard Business Review, 27

Wang Y, Gilland W, Tomlin B (2010). Mitigating supply risk: Dual sourcing or process improvement? Manufacturing & Service Operations Management, 12(3): 489–510

Wu T, Blackhurst J, O'Grady P (2007). Methodology for supply chain disruption analysis. International Journal of Production Research, 45(7): 1665–1682

Xu Q, Shao Z, He Y (2021). Effect of the buy-online-and-pickup-in-store option on pricing and ordering decisions during online shopping carnivals. International Transactions in Operational Research, 28(5): 2496–2517

Yan S, Hua Z, Bian Y (2020). Does retailer benefit from implementing "online-to-store" channel in a competitive market? IEEE Transactions on Engineering Management, 67(2): 496–512

Yang D, Qi E, Li Y (2015). Quick response and supply chain structure with strategic consumers. Omega, 52: 1–14

Yang D, Zhang X (2020). Quick response and omnichannel retail operations with the ship-to-store program. International Transactions in Operational Research, 27(6): 3007–3030

Yoon J, Talluri S, Rosales C (2020). Procurement decisions and information sharing under multi-tier disruption risk in a supply chain. International Journal of Production Research, 58(5): 1362–1383

Zhang S, Zhang J (2020). Agency selling or reselling: E-tailer information sharing with supplier offline entry. European Journal of Operational Research, 280(1): 134–151