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Received: September 06, 2023; Accepted: November 06, 2023

Supply chain coordination with inventory risk allocation

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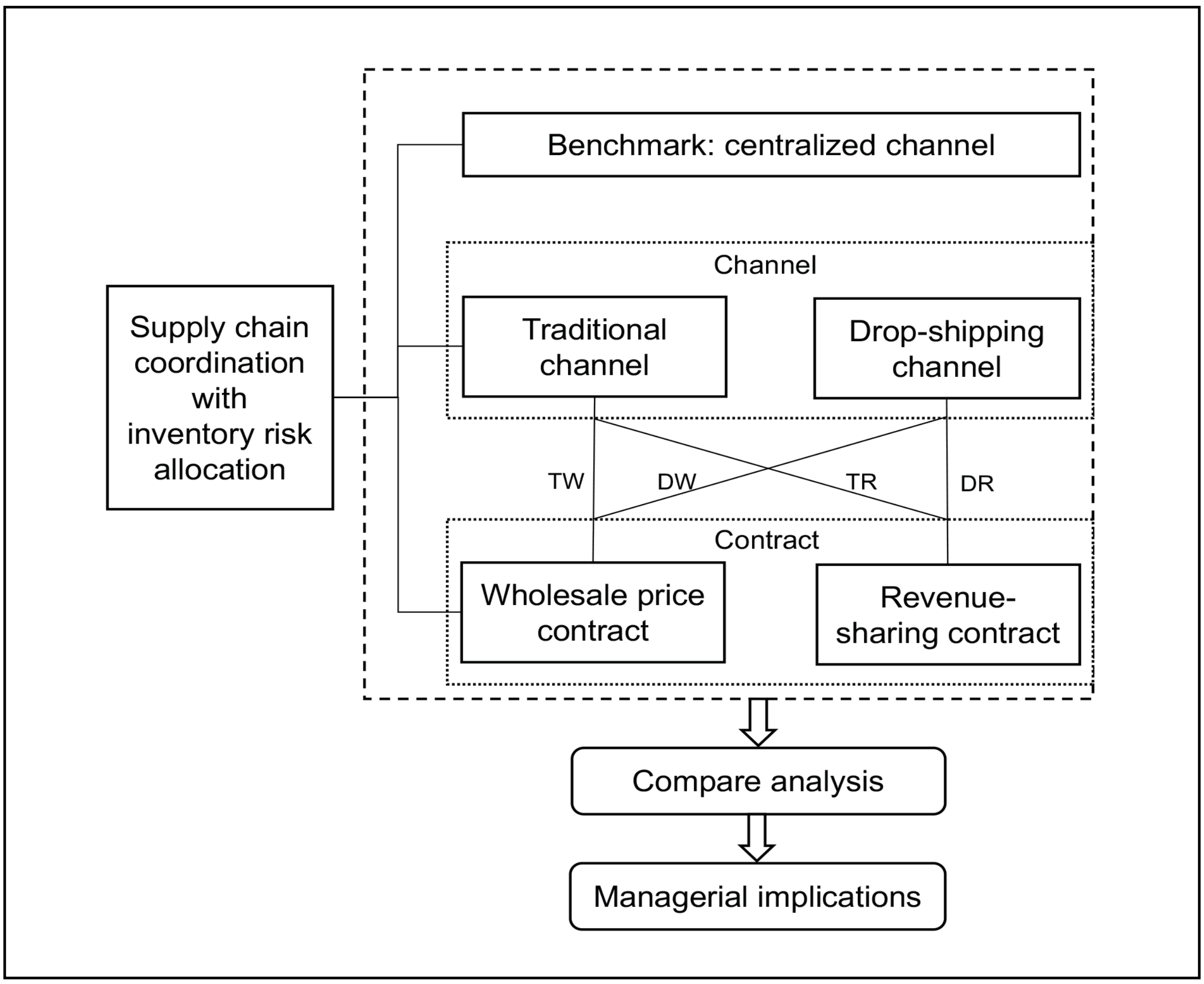
Graphical abstract



The research framework of supply chain coordination.

Public summary

- The study explores the supply chain coordination and product quality problems with different inventory risk allocations.
- The revenue-sharing contract can coordinate both the traditional and drop-shipping channels, but the retailer and manufacturer have distinct preferences.
- The product quality exhibits varying performance across different channels and contracts.

Citation: Wu Q Y, Xie S. Supply chain coordination with inventory risk allocation. *JUSTC*, **2024**, 54(8): 0806. DOI: 10.52396/JUSTC-2023-0134

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Cite This: *JUSTC*, **2024**, 54(8): 0806 (15pp)   Read Online   Supporting Information

Abstract: Unlike the traditional decentralized channel, the drop-shipping channel entails a retailer relaying consumers' orders to the manufacturer, which proceeds to stock the orders and directly ship them to the consumers. This study explores supply chain coordination and product quality in drop-shipping and traditional channels. Specifically, we analyze the performance of both channels under wholesale price and revenue-sharing contracts. Our study yields several key findings. First, the revenue-sharing contract can coordinate both traditional and drop-shipping channels, effectively increasing supply chain performance. Second, given the channel structure, the retailer prefers the wholesale price contract, whereas the manufacturer prefers the revenue-sharing contract. Third, product quality is higher in the drop-shipping channel when demand uncertainty is high. Finally, the implementation of the revenue-sharing contract increases product quality in the traditional channel, whereas it keeps product quality unchanged in the drop-shipping channel.

Keywords: supply chain coordination; product quality; contract; inventory risk allocation

CLC number: **Document code:** A

1 Introduction

With the rise of e-commerce and online retailing, drop shipping has emerged as a popular channel for selling products. In this channel, the retailer relays customer orders directly to the manufacturer, which then handles stock management and product shipping for end consumers[1]. In contrast to the traditional channel, in which the retailer purchases products at a wholesale price and then sells them to consumers at a retail price, the drop-shipping channel offers a strategic advantage by significantly mitigating inventory-related risks because the retailer does not need to pre-purchase products. Studies have underscored the efficacy of this approach, revealing that integrating drop shipping into store operations can yield a remarkable 31.2% reduction in inventory levels. Conversely, the non-implementation of this option could lead to a 9% decrease in anticipated profits[2]. This advantage in inventory risk allocation substantially contributes to the improved performance of the drop-shipping channel. Consequently, approximately 27% of online retailers have transitioned to a drop shipping business model as their primary method of fulfilling customers' orders[3]. In addition, the global drop-shipping market was valued at 225.99 billion dollars in 2022 and is expected to maintain robust growth, with a projected compound annual growth rate of 23.4% from 2023 to 2030[4].

Although the drop-shipping channel holds significant popularity and importance and has been widely used and studied in both practice and theory, most related studies have focused on comparisons with other channels (such as the traditional channel). Consequently, this channel structure has not received sufficient attention from the perspective of supply chain coordination. The absence of coordination often leads to suboptimal performance as supply chain members prioritize their individual interests[5]. However, conventional studies of supply chain coordination are based on traditional channels. For supply chain members, different channel structures and contract types can have varying impacts on profits owing to variations in cost allocation, risk distribution, market reach, and so on. Given the growing importance of the drop-shipping channel, it is crucial to explore its performance from the perspective of supply chain coordination. Therefore, our key research objective is to investigate supply chain coordination by considering different contracts in drop-shipping and traditional channels.

In terms of contracts, we consider wholesale price and revenue-sharing contracts. In particular, the wholesale price contract is widely adopted in supply chains. However, it is prone to the double marginalization problem, which can be efficiently coordinated through a revenue-sharing contract[5]. Over the last two decades, the revenue-sharing contract has gained attention as a way to align the interests of supply chain members. For example, massive distribution platforms such as the Apple App Store and Google Play use uniform revenue-sharing contracts to engage all developers whose apps they sell; with Amazon, the seller pays a certain percentage of the selling price and a fixed fee[6]. Therefore, in this study, we focus on the impact of wholesale price and revenue-sharing contracts on supply chain members' decisions and performance in traditional and drop-shipping channels. In particular, the following questions are put forward:

(i) Whether the revenue-sharing contract can achieve supply chain coordination in traditional and drop-shipping channels?

(ii) Given such channel structures, what contracts do the manufacturer and retailer prefer?

(iii) How does product quality differ between the traditional and drop-shipping channels? What is the effect of employing a revenue-sharing contract on product quality?

To address these questions, we consider a supply chain consisting of a manufacturer and a retailer, where the channel structure encompasses the traditional and drop-shipping channels. In the traditional channel, the manufacturer determines the product quality and wholesale price while the retailer decides the order quantity and retail price. In the drop-shipping channel, inventory risks are transferred from the retailer to the manufacturer, with the retailer not having to make order quantity decisions. Regarding the contract, we utilize the wholesale price contract as a guide for studying the revenue-sharing contract. The main results are summarized as follows.

First, we find that the revenue-sharing contract is effective in achieving supply chain coordination in traditional and drop-shipping channels as it leads to increased profits for the entire supply chain. Under a revenue-sharing contract, the manufacturer reduces its wholesale price after receiving part of the retailer's revenue. Consequently, the retail price decreases, resulting in an increase in product demand. Increased demand, in turn, increases the profitability of the entire supply chain.

Second, given the channel structure, the retailer prefers the wholesale price contract, whereas the manufacturer prefers the revenue-sharing contract. Although the revenue-sharing contract has the potential to increase the supply chain's performance, it may not always be advantageous for the retailer, especially when the shared revenue is substantial. In particular, the additional supply chain profit generated by increased demand cannot be divided equally between the two firms. The manufacturer obtains a large proportion, leaving the augmented portion for the retailer, such portion is insufficient to fully offset the retailer's losses resulting from the lowered retail price and shared revenue. Hence, the revenue-sharing contract is advantageous for manufacturers but not for the retailer.

Third, we show that product quality may be higher in the drop-shipping channel than in the traditional channel. In the drop-shipping channel, the manufacturer takes the risk of demand uncertainty. To mitigate potential profit fluctuations due to this uncertainty, the manufacturer opts to raise the wholesale price and product quality in the drop-shipping channel.

Finally, we find that adopting the revenue-sharing contract can lead to an increase in product quality in the traditional channel, particularly when demand uncertainty is high. In the case of low demand uncertainty, the manufacturer lacks motivation to enhance product quality. The manufacturer obtains a portion of the retailer's revenue, resulting in a reduction in the wholesale price only. in the case of high demand uncertainty, the manufacturer adopts a strategy of reducing wholesale prices while improving product quality to mitigate the impact of high demand risk on profitability. The costs incurred to improve product quality are counterbalanced by the revenue shared by the retailer. Consequently, under the revenue-sharing contract, product quality could be improved. In the drop-shipping channel, the product quality remains unaffected.

The remainder of this paper is organized as follows. In Section 2, we review the related literature. In Section 3, we present the basic model and notations used in this study and describe the basic concepts of different contracts. In Section 4, we demonstrate two basic cases of the supply chain model are demonstrated, followed by an analysis and comparison of supply chain performance under different contracts. In Section 5, we present a numerical study for obtaining further insights. Finally, in Section 6, we conclude the study. Proofs of all the lemmas, corollaries, and propositions are presented in Supporting Information.

2 Literature review

There are three streams of literature related to our study: inventory risk allocation, supply chain coordination with contracts, and product quality. In the following sections, we briefly review the literature in each stream.

Our study is most relevant to the literature on inventory risk allocation[7–13]. Researchers have paid considerable attention to the allocation of inventory risk among members of the supply chain. For example, Cachon[7] highlights the different types of contracts (i.e., push, pull, and advance-purchase discount contracts) that can be used to allocate inventory risk between suppliers and retailers, and describes how they affect supply chain performance. From the perspective of inventory ownership/stocking decision rights, Netessine and Rudi[8] investigate the traditional, drop-shipping, and dual channels and find that these channels, except the traditional channel, have the potential to be Pareto improvement choices, but the traditional channel does not. Following Netessine and Rudi' s research, many studies have focused on the drop-shipping channel. Shi et al.[10] analyze the choice between the wholesale contract and the drop-shipping contracts for the online retailers and the manufacturers in a dual-channel supply chain. Lei and Xue[12] investigate the manufacturer's contract preference (i.e., drop-shipping or batch ordering) with and without the retailer's demand information sharing. Ma, Zhang, and Chen[13] also pay attention to inventory risk allocation, investigating the manufacturer's and retailer's preferences for the traditional, drop-shipping, and dual channels in the presence of sales effort. However, these studies have not regarded the drop-shipping channel as a separate supply chain structure to understand its coordination problem. Moreover, they have not paid attention to product quality issues in this channel. In the current study, we consider product quality in investigating the channel and contract choices of the manufacturer and retailer and the coordination issues in the drop-shipping channel. Our results show that both the retailer and manufacturer prefer the drop-shipping channel and that the revenue-sharing contract can improve the drop-shipping channel's performance.

Our study also relates to the literature on supply chain coordination with contracts[5, 14–20]. This topic has received considerable attention in recent years. Cachon[5] reviews and extends the supply chain literature focusing on the management of incentive conflicts with contracts. These contracts include wholesale price, buyback, and revenue-sharing contracts. Cachon and Lariviere[15] demonstrate that revenue sharing is

DOI: 10.52396/JUSTC-2023-0134
JUSTC, **2024**, 54(8): 0806

an attractive contract for coordinating the supply chain but they also point out the limitations. As research has progressed, some scholars have considered behavioral factors to explore the performance of different contracts. For instance, Zhang et al.[19] discuss how the presence of loss aversion influences the supplier's contract preference and the choice of contract parameters. Lan et al.[20] explore the effect of inequity aversion on a supply chain with random yield and random demand. However, the focus of these existing studies is mainly on the traditional channel, in which the retailer both owns the inventory and decides on the stocking quantity. Different from the traditional channel setting, Wang, et al.[14] studied revenue sharing under a consignment contract, where a retailer offers to share its revenue with a supplier and the supplier then chooses the delivery quantity and retail price of the product. Similar to Ref. [14], we focus on the drop-shipping channel/contract, which is also different from the traditional channel. Unlike under a consignment contract, the retail price in a drop-shipping contract is decided by the retailer rather than the manufacturer/supplier. Moreover, we consider product quality as an endogenous variable, which has been ignored in the supply chain contract literature. Our findings reveal that product quality in the drop-shipping channel is slightly higher than that in the traditional channel.

Another relevant literature is product quality in supply chains[21–28]. Conventional wisdom holds that product quality is relatively low in decentralized supply chains[21, 22]. However, some studies have pointed out that under certain conditions, the manufacturer may provide higher product quality in a decentralized channel than in a centralized channel. For example, Xu[23] studies the effect of convexity of the marginal revenue function; Shi et al.[25] investigate the effect of the distribution of consumer heterogeneity; and Jerath et al.[27] consider a case with inventory risk. In addition, Ha et al.[26] examine a case in which both channels exist for a single manufacturer and demonstrate how product quality under encroachment may vary. Among existing studies, the works of Jerath, Kim, and Swinney[27] and Wu, Xie, and Ma[28] are most similar to ours. Specifically, they develop a stylized model to study the interplay between quality, inventory, pricing, and vertical channel interactions, highlighting the role of product quality and its interaction with demand uncertainty and inventory choice. However, the quality design is rarely discussed in the context of the drop-shipping channel and revenue-sharing contract. Our findings indicate that implementing a revenue-sharing contract has the potential to enhance product quality in the traditional channel. However, such a contract does not lead to any change in product quality in the drop-shipping channel.

3 The model

We explore the supply chain coordination problem in the presence of inventory risk allocation by considering a supply chain sc involving a manufacturer m selling its products through a retailer r. Based on different inventory risk allocations, there are two supply chain structures: the traditional channel and the drop-shipping channel. In the traditional channel, the retailer procures the product from the manufacturer and ships it to consumers. In the drop-shipping channel, the retailer accepts consumer orders and relays them to the manufacturer, which then ships the products directly to consumers. In this channel, we assume that the manufacturer can implement just-in-time (JIT) manufacturing. In other words, the manufacturer can produce on demand upon receiving an order from the retailer. This assumption is well-founded because JIT manufacturing has been practiced since the 1960s[29].

In this study, we endogenize product quality to explore the supply chain coordination problem. It is assumed that the manufacturer incurs a constant marginal production cost, represented by kq^2, where k denotes the quality investment efficiency. Additionally, the two channels share the same marginal operating cost. Without loss of generality, we normalize these costs to zero.

For a product with quality q, the consumer's net utility is $\theta q - p$, where θ is the consumer's willingness to pay and p is the retail price. Consumers are heterogeneous in terms of their willingness to pay, and we assume that θ follows a uniform distribution, that is, $\theta \sim U[0,1]$. Therefore, $1-p/q$ of consumers experience non-negative utility and are willing to purchase the product. Market size is denoted by N, and the potential demand is given by $d=(1-p/q)\cdot N$. Both the retailer and the manufacturer face uncertain demand. We assume that N takes on two values: $N_L = 1-\delta$ and $N_H = 1+\delta$, where $0<\delta<1$. The parameter δ indicates the degree of demand uncertainty[30]. Thus, the market faces two potential demand states: low demand $d_L = (1-p/q)(1-\delta)$ and high demand $d_H = (1-p/q)(1+\delta)$. For brevity, we assume that the two demand states occur with equal probabilities.

Regarding contract choice, we analyze the performance of the wholesale price and revenue-sharing contracts in the supply chain. Under a wholesale price contract, the manufacturer charges the retailer w per unit purchased. Under a revenue-sharing contract, the manufacturer charges w per unit purchased plus the retailer gives the manufacturer a percentage ϕ of its revenue[5,14,15,31]. For brevity, the revenue sharing ratio ϕ is assumed to be exogenous in the model. This assumption is reasonable because determining the optimal revenue-sharing rate is beyond the scope of this study. Although a wholesale price contract is not typically considered a coordinating contract, it is worth studying because of its common occurrence in practice. Moreover, we can better compare the profitability of different channels and contracts.

We develop a multistage game for each channel structure and derive the firms' optimal decisions and profits. Based on profits, we consider how the manufacturer and retailer choose the channel and whether the supply chain can be coordinated by a revenue-sharing contract. As the revenue-sharing percentage is exogenous, the game sequence for the revenue-sharing contracts in both channels aligns with that of the wholesale price contract.

In the traditional channel, the game sequence is as follows. The manufacturer first determines product quality q and then sells the products to the retailer at a wholesale price w. Next, the retailer orders quantity Q before the realization of the potential market size N. Once the market size N is realized, the retailer sets the retail price p. Finally, consumers make their

DOI: 10.52396/JUSTC-2023-0134
JUSTC, **2024**, 54(8): 0806

purchase decisions.

In the drop-shipping channel, the game sequence is as follows: The manufacturer first determines product quality q and then charges a wholesale price w to the retailer. After the realization of the market size N, the retailer sets the sale price p. Subsequently, consumers make purchase decisions, and accordingly, the retailer forwards the order request to the manufacturer.

We use $i \in \{T, D\}$ to denote the channel structures, where T and D represent the traditional and drop-shipping channels, respectively; and $j \in \{W, R\}$ to denote the contract types, where W and R are the wholesale price and revenue-sharing contracts, respectively. For example, π_r^{ij} represents the profit in channel type i with contract type j. The profit function of each channel with different contracts is described in detail in subsequent sections.

Traditional channel with wholesale price contract (Model TW)

The retailer's profit function is given by

$$\pi_r^{TW} = p \cdot E\min\{Q, d\} - Qw, \tag{1}$$

where Q and d denote the order quantity and product demand and w is the wholesale price.

The manufacturer's profit function is given by

$$\pi_m^{TW} = (w - kq^2) \cdot Q, \tag{2}$$

where kq^2 is the production cost, which is assumed to be a convex function of quality q.

Traditional channel with revenue-sharing contract (Model TR)

The retailer's profit function is given by

$$\pi_r^{TR} = \phi p \cdot d - Qw, \tag{3}$$

where ϕ denotes the retailer's share of the revenue generated from each unit. The wholesale price contract is a special case of the revenue-sharing contract with $\phi = 1$. We assume that the same revenue share applies to all units. Thus, the manufacturer's share is $1 - \phi$, and the manufacturer's profit function is given by

$$\pi_m^{TR} = (w - kq^2)Q + (1 - \phi)p \cdot d. \tag{4}$$

Drop-shipping channel with wholesale price contract (Model DW)

The retailer's profit function is given by

$$\pi_r^{DW} = (p - w) \cdot d, \tag{5}$$

and the manufacturer's profit function is given by

$$\pi_m^{DW} = (w - kq^2) \cdot d. \tag{6}$$

Drop-shipping channel with revenue-sharing contract (Model DR)

The retailer's profit function is given by

$$\pi_r^{DR} = (\phi p - w) \cdot d, \tag{7}$$

and the manufacturer's profit function is given by

$$\pi_m^{DR} = (w - kq^2)d + (1 - \phi)p \cdot d. \tag{8}$$

The supply chain's profit function is given by

$$\pi_{sc} = \pi_r + \pi_m. \tag{9}$$

The notations are summarized in Table 1.

4 Analysis

First, we consider a centralized supply chain as a benchmark. Subsequently, we analyze the performance of decentralized supply chains, including traditional and drop-shipping channels, under both the wholesale price and revenue-sharing contracts. Finally, we compare the supply chain performance under different supply chain structures and contracts to assess the effectiveness of the revenue-sharing contract in coordinating the supply chain and identifying the optimal channel and contract for both the manufacturer and retailer.

4.1 Benchmark model

In the benchmark model, we assume a centralized supply chain in which the manufacturer produces and directly sells the product to consumers, thus eliminating the need for a retailer. In this case, double marginalization is avoided, resulting in optimal supply chain efficiency. In the centralized case, the supply chain's profit function is given by

$$\pi_{sc} = (p - kq^2) \cdot d.$$

The optimal decisions are

$$q_{sc}^* = \frac{1}{3k}, \quad p_{sc}^* = \frac{2}{9k}.$$

4.2 Wholesale price contract

First, we consider that the manufacturer and retailer use the traditional wholesale price contract to collaborate in the traditional channel. Through backward induction, we obtain the optimal decisions for the retailer and manufacturer. The results are summarized in Lemma 1.

Lemma 1. In the traditional channel with a wholesale price contract:

(a) When demand uncertainty is low (i.e., $0 < \delta < \frac{3}{4}$), the

Table 1. Summary of notations.

Symbol	Description	Symbol	Description
q	Product quality	π	Firm's profit
w	Wholesale price	r	Retailer
p	Retail price	m	Manufacturer
d	Demand of the market	sc	Supply chain
N	Potential market size	T	Traditional channel
Q	Retailer's order quantity	D	Drop-shipping channel
δ	Demand uncertainty	W	wholesale price contract
ϕ	Retailer's share of revenue	R	Revenue-sharing contract
k	Quality investment efficiency	CS	Consumer surplus
θ	Consumer's willingness to pay	SW	Social welfare

DOI: 10.52396/JUSTC-2023-0134
JUSTC, **2024**, 54(8): 0806

manufacturer's optimal decisions are $q^* = \frac{1}{3k}$ and $w^* = \frac{2}{9k}$. The retailer's optimal decisions are $Q^* = \frac{1-\delta^2}{6}$ and

$$p^* = \begin{cases} \frac{5-\delta}{18k}, & N = 1-\delta; \\ \frac{5+\delta}{18k}, & N = 1+\delta. \end{cases}$$

(b) When demand uncertainty is high (i.e., $\frac{3}{4} < \delta < 1$), the manufacturer's optimal decisions are $q^* = \frac{1}{6k}$ and $w^* = \frac{1}{18k}$. The retailer's optimal decisions are $Q^* = \frac{1+\delta}{6}$ and

$$p^* = \begin{cases} \frac{1}{12k}, & N = 1-\delta; \\ \frac{5}{36k}, & N = 1+\delta. \end{cases}$$

From Lemma 1, we can see that in the traditional channel, the optimal retail prices, order quantities, wholesale price, and product quality are conditional on δ. In the traditional channel, product quality and wholesale price are lower under high demand uncertainty than under low demand uncertainty. Meanwhile, order quantity is higher under high demand uncertainty than under low demand uncertainty.

To avoid inventory risk, the retailer generally orders less when demand uncertainty is high and orders more when demand uncertainty is low. However, the results change when manufacturer decisions are considered. When demand uncertainty is low, the manufacturer tends to set a high product quality and wholesale price, which leads the retailer to order a low quantity. When demand uncertainty is high, the manufacturer tends to set a low product quality and wholesale price to encourage the retailer to order more products. The inference is in line with the work of Jerath, Kim, and Swinney's work[27], who also observed a decline in quality with an increase in demand uncertainty.

Second, we assume that the manufacturer and retailer use the traditional wholesale price contract to collaborate in the drop-shipping channel. In the drop-shipping channel, inventory risk and demand uncertainty risk are shifted from the retailer to the manufacturer. Thus, the retailer no longer needs to decide on the order quantity. Instead, it forwards consumer orders to the manufacturer, which then delivers the products directly to consumers. In the drop-shipping channel, the optimal decisions for the retailer and manufacturer are as follows:

Lemma 2. In the drop-shipping channel with a wholesale price contract, the optimal product quality is $q^* = \frac{1}{3k}$, the wholesale price is $w^* = \frac{2}{9k}$, and the retail price is $p^* = \frac{5}{18k}$.

Lemma 1 and Lemma 2 provide the optimal decisions in different channels with a wholesale price contract. By comparing the retail prices in the two channels, we obtain the following results.

Corollary 1. The retail price in the traditional channel is higher than that in the drop-shipping channel if $0 < \delta \leqslant \frac{3}{4}$ and $N = 1+\delta$.

According to Corollary 1, when the potential market is large and demand uncertainty is low, the retailer sets a higher retail price in the traditional channel than in the drop-shipping channel. Otherwise, the retail price in the drop-shipping channel would be higher. In particular, the manufacturer produces a high-quality product at a high wholesale price when demand uncertainty is low, resulting in a lower profit margin for the retailer. In this condition, if the potential market is sizeable, the retailer is inclined to set a higher retail price to optimize its profit. Conversely, in a market with limited potential, the retailer may lower its retail price to retain customers. When demand uncertainty is high, the manufacturer offers low product quality at a low wholesale price, leading the retailer to set a low retail price.

We denote $\Delta = p^* - w^*$ to explore the double marginalization problem in different channels.

Corollary 2. With a wholesale price contract, the drop-shipping channel has a lower double marginalization problem compared with the traditional channel when demand uncertainty is high, i.e., $\Delta^{TW} > \Delta^{DW}$.

Corollary 2 illustrates that the drop-shipping channel can alleviate the double marginalization problem that arises in the traditional channel because the markup in the drop-shipping channel is lower than that in the traditional channel. However, it is important to note that relative to the centralized channel, the drop-shipping channel does not entirely eliminate the issue as markups still exist within the supply chain.

Proposition 1. The product quality in the drop-shipping channel is weakly higher than that in the traditional channel.

From Proposition 1, we can see that when demand uncertainty is high, the product quality in the drop-shipping channel is higher than that in the traditional channel. This conclusion is supported by Lei and Xue[12].

This difference arises from the manufacturer's distinct risk-bearing roles in each channel. Specifically, in the drop-shipping channel, demand uncertainty is borne by the manufacturer. To mitigate the influence of demand uncertainty on profit, the manufacturer chooses to increase the wholesale price and product quality to compensate for the possible losses caused by demand uncertainty. However, in the traditional channel, demand uncertainty is borne by the retailer. Consequently, the manufacturer is inclined to decrease product quality and wholesale price, motivating the retailer to place larger orders. Lemma 1 indicates that when demand uncertainty is high, the manufacturer tends to reduce product quality and wholesale price, prompting the retailer to increase the order quantity. Therefore, we can conclude that the product quality in the drop-shipping channel is not always lower than that in the traditional channel.

Table 2. The consumer surplus and social welfare under the wholesale price contract.

	Traditional		Drop-shipping
	$0 < \delta \leqslant \frac{3}{4}$	$\frac{3}{4} < \delta < 1$	
CS	$\frac{1}{216k}$	$\frac{1}{108k}$	$\frac{1}{216k}$
SW	$\frac{7-6\delta^2}{216k}$	$\frac{8-3\delta}{216k}$	$\frac{7}{216k}$

DOI: 10.52396/JUSTC-2023-0134
JUSTC, **2024**, 54(8): 0806

Corollary 3. Consumer surplus and social welfare under the wholesale price contract are presented in Table 2.

Lemma 1 shows that in the case of high demand uncertainty, the traditional channel has lower product quality. Nevertheless, the consumer surplus surpasses that of the drop-shipping channel. This phenomenon occurs because lower quality drives down wholesale and retail prices, causing more consumers to purchase the product. Consequently, consumer surplus increases. In terms of social welfare, the drop-shipping channel outperforms the traditional channel because of higher profits within the supply chain, which leads to higher social welfare in the drop-shipping channel.

By comparing the profits of the manufacturer and retailer in the two channels, we present the preferred channels for both parties.

Proposition 2. With a wholesale price contract, the profit in the traditional channel is lower than that in the drop-shipping channel regardless of the value of δ.

As Proposition 2 shows, the drop-shipping channel can be the better choice because of the benefits of risk pooling and low double marginalization. This conclusion aligns with the work of Netessine and Rudi[8], which implies that the drop-shipping channel has the potential to be Pareto-improvement, but the traditional channel does not.

4.3 Revenue-sharing contract

In this section, we assume that the manufacturer and retailer use the revenue-sharing contract for collaboration. First, we analyze the traditional channel. We summarize the optimal decisions in Lemma 3.

Lemma 3. In the traditional channel with a revenue-sharing contract,

(a) when demand uncertainty is low (i.e., $0 < \delta < \hat{\delta}$)①, the manufacturer's optimal decisions are $q^* = \frac{1}{3k}$ and $w^* = \frac{\phi + 3\phi^2}{9k + 9k\phi}$. The retailer's optimal decisions are $Q^* = \frac{1-\delta^2}{3+3\phi}$ and

$$p^* = \begin{cases} \dfrac{2-\delta+3\phi}{9k+9k\phi}, & N = 1-\delta; \\ \dfrac{2+\delta+3\phi}{9k+9k\phi}, & N = 1+\delta; \end{cases}$$

(b) when demand uncertainty is high (i.e., $\hat{\delta} < \delta < 1$), the manufacturer's optimal decisions are $q^* = \frac{2k+2k\delta-A}{6(k^2+k^2\delta)}$② and $w^* = \frac{\phi(k(1+\delta)(2+3\phi)-A)(2k(1+\delta)-A)}{36k^3(1+\delta)^2(1+\phi)}$. The retailer's optimal decisions are $Q^* = \frac{k+k\delta+A}{6k+6k\phi}$ and

$$p^* = \begin{cases} \dfrac{2k(1+\delta)-A}{12k^2(1+\delta)}, & N = 1-\delta; \\ \dfrac{(2k(1+\delta)-A)(k(1+\delta)(5+6\phi)-A)}{36k^3(1+\delta)^2(1+\phi)}, & N = 1+\delta. \end{cases}$$

From Lemma 3, we can confirm that the property of the optimal decisions in Lemma 1 remains valid when using a revenue-sharing contract. However, the revenue-sharing contract affects product quality. We present this finding as Proposition 3.

Proposition 3. In the traditional channel, the use of a revenue-sharing contract can increase product quality under high demand uncertainty.

Proposition 3 implies changes in product quality in the traditional channel under different contracts. The revenue-sharing contract allows the manufacturer to obtain a portion of the retailer's revenue and thereby reduce the wholesale price. Subsequently, the retailer increases the order quantity and reduces the retail price. When demand uncertainty is low, the manufacturer has no incentive to enhance quality. However, when demand uncertainty is high, the manufacturer reduces the wholesale price and improves product quality to mitigate the influence of high demand risk on profit. The cost of quality improvement is compensated for by the revenue shared by the retailer. Therefore, under the revenue-sharing contract, product quality has the potential to be improved.

Corollary 4. Consumer surplus and social welfare under the revenue-sharing contract are presented in Table 3.

According to Proposition 3, the revenue-sharing contract evidently enhances product quality while reducing prices under high demand uncertainty. As the supply chain's profit is also higher under the revenue-sharing contract, both consumer surplus and social welfare are higher than those under the wholesale price contract.

By comparing supply chain performance in the traditional channel with different contracts, the following proposition can be drawn:

Proposition 4. In the traditional channel with wholesale price and revenue-sharing contracts, the following holds: $\pi_r^{TW} > \pi_r^{TR}$, $\pi_m^{TW} < \pi_m^{TR}$, and $\pi_{sc}^{TW} < \pi_{sc}^{TR}$.

From Proposition 4, we find that the revenue-sharing contract can coordinate the traditional channel by improving the supply chain's performance.

Next, we compare the supply chain's performance in the traditional channel with a revenue-sharing contract and that in the drop-shipping channel with a wholesale price contract. We conclude with Proposition 5.

Proposition 5. In the traditional channel with a revenue-sharing contract and the drop-shipping channel with a wholesale price contract,

(a) in the case of $0 < \delta < \hat{\delta}$: (i) $\pi_r^{TR} < \pi_r^{DW}$; (ii) when $0 < \phi < 1 - 2\delta^2$, $\pi_m^{TR} > \pi_m^{DW}$; otherwise, $\pi_m^{TR} < \pi_m^{DW}$; (iii) when $0 < \phi < \frac{1}{3}(1-4\delta^2) + \frac{2}{3}\sqrt{1-5\delta^2+4\delta^4}$, $\pi_{sc}^{TR} > \pi_{sc}^{DW}$; otherwise, $\pi_{sc}^{TR} < \pi_{sc}^{DW}$;

(b) in the case of $\hat{\delta} < \delta < 1$: (i) $\pi_r^{TR} < \pi_r^{DW}$, $\pi_{sc}^{TR} < \pi_{sc}^{DW}$; (ii) when $0 < \phi < \hat{\phi}$①, $\pi_m^{TR} > \pi_m^{DW}$; otherwise, $\pi_m^{TR} < \pi_m^{DW}$.

Fig. 1 provides a clear depiction of Proposition 5. As the retailer prefers the drop-shipping channel with a wholesale price contract, we show only the preferred mode for the manufacturer and the supply chain in Fig. 1.

For the retailer, choosing the traditional channel with a revenue-sharing contract is not a favorable decision. On the one hand, the retailer faces higher risks in the traditional channel

① The value of $\hat{\delta}$ can be found in the appendix.
② The value of A can be found in the appendix.

① The value of $\hat{\phi}$ can be found in the appendix.

DOI: 10.52396/JUSTC-2023-0134
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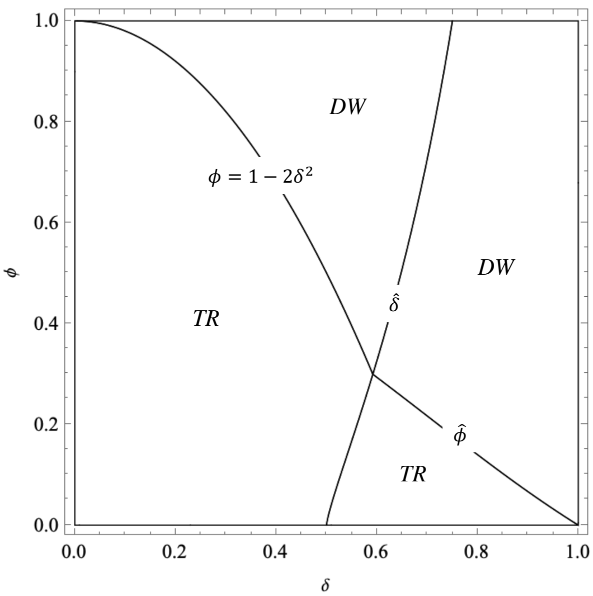
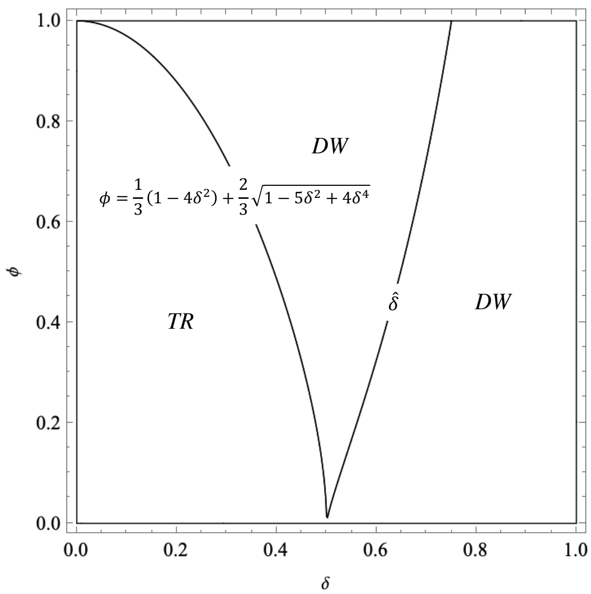
Table 3. The consumer surplus and social welfare under the revenue-sharing contract.

	Traditional		Drop-shipping
	$0<\delta\leqslant\hat{\delta}$	$\hat{\delta}<\delta<1$	
CS	$\dfrac{1}{54k(1+\phi)^2}$	$\dfrac{(2k(1+\delta)-A)((4+3\phi)A+F)}{864k^3(1+\delta)^2(1+\phi)^2}$	$\dfrac{1}{54k(1+\phi)^2}$
SW	$\dfrac{3+4\phi-2\delta^2(1+2\phi)}{54k(1+\phi)^2}$	$\dfrac{(2k(1+\delta)-A)((8+11\phi+\delta(4+8\phi))A+G)}{864k^3(1+\delta)^2(1+\phi)^2}$	$\dfrac{3+4\phi}{54k(1+\phi)^2}$



(a) For manufacturer



(b) For supply chain

Fig. 1. Preferred mode for the manufacturer and supply chain.

than in the drop-shipping channel. On the other hand, the retailer must share a part of the profit with the manufacturer. Therefore, demand growth resulting from revenue sharing cannot compensate for the retailer's profit. Thus, the retailer prefers the drop-shipping channel regardless of the size of δ.

As for the manufacturer, the preference depends on the revenue sharing percentage ϕ. If the revenue shared by the retailer is large enough (i.e., ϕ is small), the manufacturer is more inclined to choose the traditional channel with the revenue-sharing contract. Specifically, the shared revenue outweighs the profit loss resulting from the wholesale price reduction. Conversely, if the revenue shared by the retailer is not large enough (i.e., ϕ is large) to compensate for the profit loss caused by wholesale price reduction, the manufacturer tends to choose the drop-shipping channel.

While both the retailer and manufacturer have the same conditions under different demand uncertainties, this is not true for the supply chain. In the case of low demand uncertainty, if the retailer shares more profits, the demand growth resulting from price reductions can effectively improve supply chain profitability. Conversely, if the retailer shares fewer gains, the limited demand growth resulting from limited price reductions cannot effectively improve supply chain profitability. In the case of high demand uncertainty, demand growth from price reductions makes it difficult to compensate for supply chain profitability owing to the high risk, regardless of the amount of revenue shared by the retailer.

Second, we consider the drop-shipping channel with a revenue-sharing contract. The results are summarized as follows.

Lemma 4. In the drop-shipping channel with a revenue-sharing contract, the optimal product quality, wholesale price, and retail price are $q^*=\dfrac{1}{3k}$, $w^*=\dfrac{\phi+3\phi^2}{9k+9k\phi}$, and $p^*=\dfrac{2+3\phi}{9k+9k\phi}$, respectively.

Based on Lemma 4, wholesale and retail prices evidently decrease while product quality remains unchanged after implementing the revenue-sharing contract in the drop-shipping channel. To calculate the markup in different channels with a revenue-sharing contract, we derive Corollary 5.

Corollary 5. With a revenue-sharing contract, the traditional channel has a lower double marginalization problem than the drop-shipping channel when demand uncertainty is high, i.e., $\Delta^{TR}<\Delta^{DR}$.

Although the revenue-sharing contract reduces the retail and wholesale prices in both channels, the reduced part of the retail price in the traditional channel is larger than that in the drop-shipping channel (i.e., $p^{TW}-p^{TR}>p^{DW}-p^{DR}$) while and the reduced part of the wholesale price in the traditional channel is smaller than that in the drop-shipping channel (i.e., $w^{TW}-w^{TR}<w^{DW}-w^{DR}$). Therefore, the markup in the drop-shipping channel is higher than that in the traditional channel with a revenue-sharing contract (i.e., $\Delta^{TR}<\Delta^{DR}$).

By comparing the profits under different contracts in the drop-shipping channel, we derive the following proposition.

Proposition 6. In the drop-shipping channel with whole-

DOI: 10.52396/JUSTC-2023-0134
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sale price and revenue-sharing contracts, $\pi_r^{DW} > \pi_r^{DR}$, $\pi_m^{DW} < \pi_m^{DR}$, $\pi_{sc}^{DW} < \pi_{sc}^{DR}$.

Proposition 6 indicates that the revenue-sharing contract can coordinate the drop-shipping channel by improving supply chain performance. In the drop-shipping channel, the manufacturer's profit increases with the revenue-sharing contract while the retailer's profit decreases as it shares a part of the revenue with the manufacturer. Although revenue sharing leads to a decrease in the wholesale price, the retail price also decreases. The resulting increase in demand cannot compensate for the loss of profits for these two components of the retailer, but it benefits the manufacturer and the supply chain. In other words, the revenue-sharing contract can effectively coordinate the drop-shipping supply chain.

By comparing profits with a revenue-sharing contract in the drop-shipping channel and profits with a wholesale price contract in the traditional channel, we arrive at the following proposition:

Proposition 7. In the traditional channel with a wholesale price contract and the drop-shipping channel with a revenue-sharing contract,

(a) in the case of $0 < \delta < \frac{3}{4}$: (i) $\pi_m^{DR} > \pi_m^{TW}$, $\pi_{sc}^{DR} > \pi_{sc}^{TW}$; (ii) when $0 < \phi < \frac{1-\delta}{1+\delta}$, $\pi_r^{DR} < \pi_r^{TW}$; otherwise, $\pi_r^{DR} > \pi_r^{TW}$;

(*b*) in the case of $\frac{3}{4} < \delta < 1$: (i) $\pi_m^{DR} > \pi_m^{TW}$, $\pi_{sc}^{DR} > \pi_{sc}^{TW}$; (ii) when $0 < \phi < \frac{1-4\delta}{-5+4\delta} - 2\sqrt{2}\sqrt{\frac{-3+4\delta}{(-5+4\delta)^2}}$, $\pi_r^{DR} < \pi_r^{TW}$; otherwise, $\pi_r^{DR} > \pi_r^{TW}$.

From Proposition 7, we can see that the manufacturer and supply chain prefer the drop-shipping channel with a revenue-sharing contract while the retailer's preference depends on the revenue-sharing percentage ϕ. Fig. 2 illustrates the retailer's preferred choice.

When the revenue-sharing percentage is large (i.e., $\frac{1-\delta}{1+\delta} < \phi < 1$ or $\frac{1-4\delta}{-5+4\delta} - 2\sqrt{2}\sqrt{\frac{-3+4\delta}{(-5+4\delta)^2}} < \phi < 1$), the firms and supply chain benefit more from adopting the revenue-sharing contract in the drop-shipping channel than from adopting the wholesale price contract in the traditional channel. Although the revenue-sharing contract is less favorable for the retailer, sharing only a small portion of the revenue enables the retailer to benefit from demand growth and risk transfer while losing part of the revenue, leading to increased profits. By contrast, if the retailer shares a large portion of its revenue with the manufacturer, the benefits from demand growth and risk transfer will not offset the losses incurred from the shared revenue. For the manufacturer and supply chain, regardless of δ and ϕ, the increase in demand and marginal profits resulting from the revenue-sharing contract is always favorable.

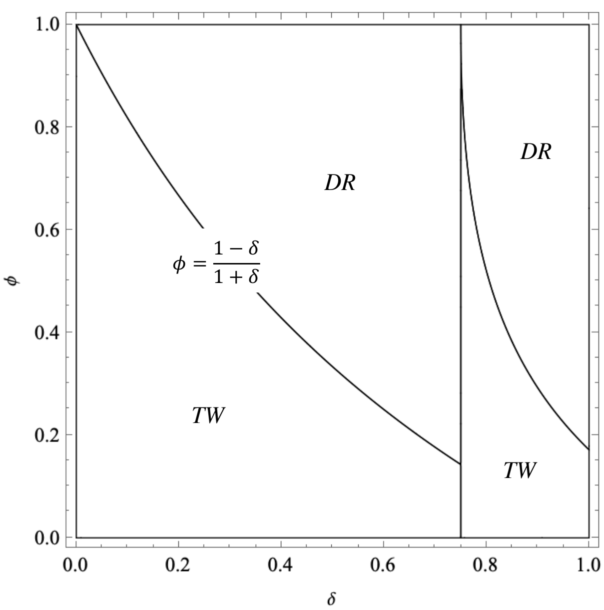

Fig. 2. Preferred mode for the retailer.

Finally, we compare the profits in different channels with a revenue-sharing contract. The following propositions can be drawn:

Proposition 8. Under a revenue-sharing contract, the profit in the traditional channel is lower than that in the drop-shipping channel.

The adoption of a revenue-sharing contract yields the same results as the adoption of a wholesale price contract in terms of channel choice. Recalling Proposition 7, we observe that the retailer's profit is higher in the traditional channel using a wholesale price contract than in the drop-shipping channel using a revenue-sharing contract when the revenue sharing percentage is low (i.e., ϕ is small). This advantage arises primarily because the retailer under a wholesale price contract does not need to share its revenue with the manufacturer. Once the traditional channel adopts a revenue-sharing contract, this slight advantage disappears, causing the retailer to shift to the drop-shipping channel. Consequently, under a revenue-sharing contract, the profit in the traditional channel is lower than that in the drop-shipping channel.

5 Numerical study

In this section, we conduct numerical experiments to investigate how changes in market conditions impact supply chain performance and coordination, aiming to explore some managerial insights. We compare the profits of the supply chain under the four modes (i.e., TW, DW, TR, and DR). Then, we calculate the ratio of profits to benchmark (π_{scb}) under each mode to compare channel coordination efficiencies, as shown in Table 4 and Table 5.

Table 4 presents the outcomes for the traditional and drop-shipping channels under a wholesale price contract. First, the supply chain's profit decreases with the quality investment efficiency parameter (i.e., k). It is intuitive that the supply chain performs better when the quality investment efficiency is higher (i.e., k is smaller). In addition, in the traditional channel, when demand uncertainty is high, the supply chain gains less profit, and the coordination level is relatively low. As indicated in Lemma 1, when demand uncertainty is low (i.e., $\delta \le \frac{3}{4}$), the retailer places smaller orders to minimize inventory risks, resulting in suboptimal supply chain performance. Conversely, under high demand uncertainty (i.e., $\delta > \frac{3}{4}$), the manufacturer reduces the product quality and wholesale price

DOI: 10.52396/JUSTC-2023-0134
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Table 4. Numerical examples for the both channels under wholesale price contract

	TW			DW
	$\delta = 0.2$	$\delta = 0.5$	$\delta = 0.8$	
$k = 0.5$				
π_{sc}	0.0533	0.0417	0.0333	0.0556
π_{sc}/π_{scb}	72.00%	56.25%	45.00%	75.00%
$k = 1$				
π_{sc}	0.0267	0.0208	0.0167	0.0278
π_{sc}/π_{scb}	72.00%	56.25%	45.00%	75.00%
$k = 2$				
π_{sc}	0.0133	0.0104	0.0083	0.0139
π_{sc}/π_{scb}	72.00%	56.25%	45.00%	75.00%

Table 5. Numerical examples for the both channels under revenue-sharing contract

	$k = 0.5$				$k = 1$			
	TR			DR	TR			DR
	$\delta = 0.2$	$\delta = 0.5$	$\delta = 0.8$		$\delta = 0.2$	$\delta = 0.5$	$\delta = 0.8$	
$\phi = 0.1$								
π_{sc}	0.0705	0.0551	0.0421	0.0735	0.0353	0.0275	0.0211	0.0367
π_{sc}/π_{scb}	95.21%	74.38%	35.70%	99.17%	95.21%	74.38%	35.70%	99.17%
$\phi = 0.3$								
π_{sc}	0.0673	0.0526	0.0407	0.0701	0.0337	0.0263	0.0203	0.0351
π_{sc}/π_{scb}	90.89%	71.01%	34.08%	94.67%	90.89%	71.01%	34.08%	94.67%
$\phi = 0.5$								
π_{sc}	0.0632	0.0494	0.0387	0.0658	0.0316	0.0247	0.0193	0.0329
π_{sc}/π_{scb}	85.33%	66.67%	32.00%	88.89%	85.33%	66.67%	32.00%	88.89%

to encourage the retailer to order more. Notably, the analysis reveals that under the wholesale price contract, the drop-shipping channel outperforms the traditional channel. Corollary 2 indicates that the drop-shipping channel can alleviate the double marginalization problem, naturally leading to better supply chain performance.

Our analysis continues by comparing the profits and coordination levels under the revenue-sharing contract for both channels, as presented in Table 5. Consistent with the outcomes observed under the wholesale contract, the supply chain performs more effectively with higher quality investment efficiency. Additionally, in both channels, the supply chain's profit decreases as the retailer's share of revenue per unit (ϕ) increases. For instance, as demonstrated in Lemma 3 (a), when ϕ is higher, the manufacturer's share of revenue decreases, prompting the manufacturer to set a higher wholesale price to maximize profits. Consequently, the retailer orders a smaller quantity, which deviates from the outcome of the benchmark, resulting in less favorable supply chain performance. However, it is worth noting that overall, the level of channel coordination under the revenue-sharing contracts surpasses that under the wholesale price contract.

6 Conclusions

In recent years, the drop-shipping channel has gained popularity owing to the growth of e-commerce and online retail. Contrary to the traditional channel, the drop-shipping channel eliminates the retailer's need to stock inventory, thus allowing the retailer to direct demand to the manufacturer, which subsequently delivers products directly to consumers. Although the drop-shipping channel has been studied for decades, limited research has explored the incorporation of product quality and supply chain contracts. Motivated by this research gap, we develop a model to investigate the impact of different types of channels and contracts on product quality and supply chain coordination. Additionally, we examine how the transfer of risk influences the preferred channels of the manufacturer and retailer. Our investigation has several significant implications, which are summarized as follows.

First, we observe that the revenue-sharing contract can effectively increase the supply chain's profit; hence, it can achieve supply chain coordination in traditional and drop-shipping channels. Under this contract, the manufacturer reduces its wholesale price because it can receive a portion of the retailer's revenue. This condition, in turn, leads to a reduction in retail price and an increase in product demand. Subsequently, the increased demand increases the overall profitability of the entire supply chain.

Second, given the channel structure, the retailer favors the wholesale price contract while the manufacturer leans toward the revenue-sharing contract. Despite the revenue-sharing contract's potential to increase supply chain performance, it may not consistently favor the retailer, especially when the revenue shared with the manufacturer is substantial. Specifically, the extra supply chain profit generated by the increased demand cannot be divided fairly between the two firms. The manufacturer takes a large share, leaving an insufficient augmented portion for the retailer to fully compensate for the losses incurred owing to the reduced retail price and shared revenue. Consequently, the revenue-sharing contract proves advantageous for the manufacturer but less so for the retailer.

Third, we find that under high demand uncertainty, the drop-shipping channel has higher product quality because the manufacturer takes on the risk of demand uncertainty and adopts a strategy to cope with demand fluctuations by increasing the wholesale price and product quality. Conversely, in the traditional channel, the retailer primarily bears the burden of demand uncertainty. As a result, the manufacturer is motivated to decrease product quality and influence the retailer to place larger orders.

Our last observation concerns the changes in product quality under the revenue-sharing contract. In the traditional channel, the use of revenue-sharing contracts can improve product quality under high demand uncertainty. With low demand uncertainty, the manufacturer receives a portion of the revenue from the retailer, resulting in only a lower wholesale price. Consequently, the retailer has an incentive to increase its order quantity and lower its retail price. Under this condition, the manufacturer lacks incentives to improve product quality because of the low demand risk. When demand uncertainty is high, the manufacturer mitigates the impact of high demand risk on profitability by lowering the wholesale price while improving product quality. The cost of improving product quality is offset by the revenue shared by the retailer. Thus, product quality could improve under the revenue-sharing contract. By contrast, in the drop-shipping channel, product quality is not affected.

Overall, these findings provide valuable insights into supply chain management and decision-making processes. For example, supply chain managers can leverage these insights to develop informed channel and contract strategies, fostering better coordination and overall performance and ultimately benefiting the industry. Firms can make strategic decisions regarding product quality, wholesale price, retail price, and order quantity to enhance profits. Moreover, the research outcomes empower consumers to discern the quality differences between traditional and drop-shipping channels, enabling them to make informed purchase decisions.

Although this study fills a gap in the existing literature by addressing supply chain coordination and product quality problems in the drop-shipping channel, it also has some limitations. First, the assumption of an equal probability of high and low demand in the market may not align with reality because the manufacturer and retailer often possess predictive capabilities regarding market conditions. Consequently, the probability of high and low demand may not be equal, potentially influencing the optimal decisions in response to varying demand conditions. Second, the study normalizes costs other than production costs to zero, disregarding the significance of shipping costs as a distinguishing factor between traditional and drop-shipping channels. In the traditional channel, the retailer bears the shipping cost, whereas in the drop-shipping channel, the manufacturer takes this responsibility. This difference in cost allocation could potentially impact research outcomes. Finally, real-world practices often involve firms that predominantly use the traditional channel, with the drop-shipping channel serving as a backup option. Future research could explore how this dual channel structure affects firms' decisions and overall supply chain performance.

Supporting information

The supporting information for this article can be found online at http://doi.org/10.52396/JUSTC-2023-0134. It includes proofs of all the lemmas, corollaries, and propositions.

Acknowledgements

The authors are grateful to the anonymous referees for their valuable comments and constructive suggestions. This work was supported by the Key Fund Project for Youth Innovation of USTC (WK2040000042).

Conflict of interest

The authors declare that they have no conflict of interest.

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Supporting Information of JUSTC-2023-0134

S.1 Proof of Lemma 1

In the traditional channel with a wholesale price contract, since the retailer orders the product before demand realization, it suffers from demand uncertainty. The profit function of the retailer is

$$\pi_r^{TW} = p \cdot E\min\{Q, d\} - Qw,$$

and the profit function of the manufacturer is

$$\pi_m^{TW} = (w - kq^2) \cdot Q.$$

Note that when $d \geqslant Q$, the profit function of the retailer is $\pi_r^{TW} = (p - w) \cdot Q$. The retailer would set $Q = d$ to ensure profit maximization, which is included in the case $d \leqslant Q$. Thus, we focus on analyzing the case of $d \leqslant Q$.

We first derive the best response of the retailer's order quantity. By rewriting the demand function, we can express p as $p = q(1 - \frac{d}{N})$. Plugging the price into the retailer's profit function, we can know that the optimal demand is $d^* = \frac{N}{2}$. Recall that we assume the two demand states occur with equal probabilities (i.e., $P(N_L) = P(N_H) = \frac{1}{2}$). Thus, we get the following analysis.

(1) For the case of $Q \leqslant \frac{N_L}{2}$, we have that $d = Q$ no matter under what demand status. The expected profit of the retailer is $E(\pi_r^{TW}) = \frac{1}{2}\left(1 - \frac{Q}{1-\delta}\right)qQ + \frac{1}{2}\left(1 - \frac{Q}{1+\delta}\right)qQ - wQ$. By optimizing the expected profit function, we derive the optimal unconstrained order quantity is $Q = \frac{(q-w)(1-\delta)^2}{2q}$. Considering the condition of $Q \leqslant \frac{1-\delta}{2}$, we obtained that when $0 < w < \frac{q\delta}{1+\delta}$, $Q = \frac{1-\delta}{2}$, and the retailer's profit is $E(\pi_r^{TW}) = \frac{(1-\delta)(q + 2q\delta - 2w(1+\delta))}{4(1+\delta)}$; otherwise, $Q = \frac{(q-w)(1-\delta)^2}{2q}$, and the retailer's

profit is $E(\pi_r^{TW})=\frac{(q-w)^2(1-\delta)(1+\delta)}{4q}$.

(2) For the case of $\frac{N_L}{2}<Q\leqslant\frac{N_H}{2}$, the demand function is $d=\frac{N_L}{2}$ when facing a low demand. When facing a high demand, the demand function is $d=Q$. The expected profit of the retailer is $E(\pi_r^{TW})=\frac{(1-\delta)}{8}q+\frac{1}{2}\left(1-\frac{Q}{1+\delta}\right)qQ-wQ$. By optimizing the expected profit function, we derive the optimal unconstrained order quantity is $Q=\frac{(q-2w)(1+\delta)}{2q}$. Considering the condition of $\frac{N_L}{2}<Q\leqslant\frac{N_H}{2}$, we obtained that when $0<w<\frac{q\delta}{1+\delta}$, $Q=\frac{(q-2w)(1+\delta)}{2q}$, and the retailer's profit is $E(\pi_r^{TW})=\frac{(q^2-2qw(1+\delta)+2w^2(1+\delta))}{4q}$; otherwise, $Q=\frac{1-\delta}{2}$, and the retailer's profit is $E(\pi_r^{TW})=\frac{(1-\delta)(q+2q\delta-2w(1+\delta))}{4(1+\delta)}$.

(3) For the case of $Q>\frac{N_H}{2}$, the demand function is $d=\frac{N_L}{2}$ when facing a low demand. When facing a high demand, the demand function is $d=\frac{N_H}{2}$. Under this condition, the expected retailer's profit decreases with Q. As a result, the optimal order quantity is $Q=\frac{1+\delta}{2}$ and the profit of retailer is $E(\pi_r^{TW})=\frac{1}{4}(q-2w(1+\delta))$.

Comparing the retailer's profit, we find that when $w\geq\frac{q\delta}{1+\delta}$, case (1) is better for the retailer; and if $0<w<\frac{q\delta}{1+\delta}$, case (2) is better for the retailer.

Plugging the retailer's response into the manufacturer's profit, we find:

(1) When $w\geq\frac{q\delta}{1+\delta}$, $Q=\frac{(q-w)(1-\delta)^2}{2q}$. The optimal wholesale price charged by the manufacturer is $w=\frac{1}{2}q(1+kq)$, which is within the constraint. The manufacturer's profit is $E(\pi_m^{TW})=\frac{1}{8}q(1-kq)^2(1-\delta)^2$. When $w=\frac{q\delta}{1+\delta}$, the manufacturer's profit is $E(\pi_m^{TW})=\frac{q(1-\delta)(\delta-kq(1+\delta))}{2(1+\delta)}$.

(2) When $0<w<\frac{q\delta}{1+\delta}$, $Q=\frac{(q-2w)(1+\delta)}{2q}$. The optimal unconstrained wholesale price charged by the manufacturer is $w=\frac{1}{4}q(1+2kq)$. Considering the constraint, we derive that if $\frac{1}{3}<\delta<1$ and $0<q<\frac{-1+3\delta}{2k+2k\delta}$, $w=\frac{1}{4}q(1+2kq)$, and the manufacturer's profit is $E(\pi_m^{TW})=\frac{1}{16}q(1-2kq)^2(1+\delta)$. Otherwise, $w=\frac{q\delta}{1+\delta}$, the manufacturer's profit is $E(\pi_m^{TW})=\frac{q(1-\delta)(\delta-kq(1+\delta))}{2(1+\delta)}$.

Comparing the manufacturer's profit, we find that when $0<q<-\sqrt{\frac{(1-\delta)}{k^2(1+\delta)^2}}\left(\frac{1}{\sqrt{2}}\right)+\frac{\delta}{k(1+\delta)}$, case (2) is better for the manufacturer; otherwise, case (1) is better for the manufacturer.

Plugging the manufacturer's wholesale price into its profit, we find:

(1) When $q>-\sqrt{\frac{(1-\delta)}{k^2(1+\delta)^2}}\left(\frac{1}{\sqrt{2}}\right)+\frac{\delta}{k(1+\delta)}$ and the manufacturer's profit is $E(\pi_m^{TW})=\frac{1}{8}q(1-kq)^2(1-\delta)^2$. The optimal unconstrained quality decided by the manufacturer is $q=\frac{1}{3k}$. Considering the constraint, we derive that if $0<\delta<\frac{7}{8}$, $q=\frac{1}{3k}$, and the manufacturer's profit is $E(\pi_m^{TW})=\frac{(1-\delta^2)}{54k}$. If $\delta>\frac{7}{8}$, the manufacturer's profit is $E(\pi_m^{TW})=\frac{1}{8}q(1-kq)^2(1-\delta)^2$ with $q=-\sqrt{\frac{(1-\delta)}{k^2(1+\delta)^2}}\left(\frac{1}{\sqrt{2}}\right)+\frac{\delta}{k(1+\delta)}$.

(2) When $0<q<-\sqrt{\frac{(1-\delta)}{k^2(1+\delta)^2}}\left(\frac{1}{\sqrt{2}}\right)+\frac{\delta}{k(1+\delta)}$, the manufacturer's profit is $E(\pi_m^{TW})=\frac{1}{16}q(1-2kq)^2(1+\delta)$. The optimal unconstrained quality decided by the manufacturer is $q=\frac{1}{6k}$. Considering the constraint, we derive that if $\frac{17}{25}<\delta<1$, the manufacturer's profit is $E(\pi_m^{TW})=\frac{1+\delta}{216k}$. If $0<\delta<\frac{17}{25}$, the manufacturer's profit is $E(\pi_m^{TW})=\frac{1}{16}q(1-2kq)^2(1+\delta)$ with $q=-\sqrt{\frac{(1-\delta)}{k^2(1+\delta)^2}}\left(\frac{1}{\sqrt{2}}\right)+\frac{\delta}{k(1+\delta)}$.

Comparing the manufacturer's profit, we derive that when $0<\delta\leqslant\frac{3}{4}$, $q^*=\frac{1}{3k}$, $E(\pi_m^{TW})=\frac{(1-\delta^2)}{54k}$. When $\frac{3}{4}<\delta<1$, $q^*=\frac{1}{6k}$, $E(\pi_m^{TW})=\frac{1+\delta}{216k}$.

Thus, we have all the optimal decisions:

When $0<\delta\leqslant\frac{3}{4}$,

$$q^*=\frac{1}{3k},\quad w^*=\frac{2}{9k},\quad Q^*=\frac{1-\delta^2}{6},\quad p^*=\begin{cases}\frac{5-\delta}{18k}, & N=1-\delta;\\ \frac{5+\delta}{18k}, & N=1+\delta.\end{cases}$$

DOI: 10.52396/JUSTC-2023-0134
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When $\frac{3}{4} < \delta < 1$,

$$q^* = \frac{1}{6k}, \quad w^* = \frac{1}{18k}, \quad Q^* = \frac{1+\delta}{6}, \quad p^* = \begin{cases} \frac{1}{12k}, & N = 1-\delta; \\ \frac{5}{36k}, & N = 1+\delta. \end{cases}$$

By substituting the optimal decisions back to the profit functions, we have:

When $0 < \delta \leqslant \frac{3}{4}$,

$$E(\pi_m^{TW}) = \frac{1-\delta^2}{54k}, \quad E(\pi_r^{TW}) = \frac{1-\delta^2}{108k}, \quad E(\pi_{sc}^{TW}) = \frac{1-\delta^2}{36k}.$$

When $\frac{3}{4} < \delta < 1$,

$$E(\pi_m^{TW}) = \frac{1+\delta}{216k}, \quad E(\pi_r^{TW}) = \frac{5-4\delta}{216k}, \quad E(\pi_{sc}^{TW}) = \frac{2-\delta}{72k}.$$

S.2 Proof of Lemma 2

In the drop-shipping channel with a wholesale price contract, the manufacturer suffers from demand uncertainty. Thus, the profit functions of the retailer and the manufacturer are

$$\pi_r^{DW} = (p-w)\cdot d, \quad \pi_m^{DW} = (w-kq^2)\cdot d,$$

respectively. We first derive the best response of the retailer's retail price. The retailer's expected profit is $E(\pi_r^{DW}) = \frac{1}{2}\left(1-\frac{p}{q}\right)(p-w)(1-\delta) + \frac{1}{2}\left(1-\frac{p}{q}\right)(p-w)(1+\delta)$. By optimizing the retailer's profit, we get the optimal retail price is $p = \frac{w+q}{2}$. Considering the condition of $d > 0$, we obtain that $p < q$ and $w < q$.

To calculate the manufacturer's profit, we use the expected demand and expected price. Thus, the manufacturer's profit is $E(\pi_m^{DW}) = \frac{(w-kq^2)(q-w)}{2q}$. Then we have the optimal unconstrained wholesale price is $w = \frac{q(1+kq)}{2}$. Considering the condition of $w < q$, we obtain that $q < \frac{1}{k}$. Plugging the wholesale price into the manufacturer's profit function, we find that the optimal unconstrained quality of the manufacturer is $q = \frac{1}{3k}$ or $q = \frac{1}{k}$. Since $q = \frac{1}{k}$ does not meet the condition above, thus, in the drop-shipping channel, the optimal retail price is $p^* = \frac{5}{18k}$, the wholesale price is $w^* = \frac{2}{9k}$, the quality is $q^* = \frac{1}{3k}$.

By substituting the optimal decisions back to the profit functions, we obtain the supply chain's expected profits are

$$E(\pi_m^{DW}) = \frac{1}{54k}, \quad E(\pi_r^{DW}) = \frac{1}{108k}, \quad E(\pi_{sc}^{DW}) = \frac{1}{36k}.$$

S.3 Proof of Corollary 1

The result is easy to find from Lemma 1 and Lemma 2. Therefore, we omit the demonstration here.

S.4 Proof of Corollary 2

With a wholesale price contract, in the traditional channel, when demand uncertainty is low, $\Delta^{TW} = \frac{1}{18k}$; when demand uncertainty is high, $\Delta^{TW} = \frac{3}{18k}$. In the drop-shipping channel, the markup is $\Delta^{DW} = \frac{1}{18k}$. It is easy to find that the markup in the traditional channel is higher than that in the drop-shipping channel when demand uncertainty is high.

S.5 Proof of Proposition 1

The result is easy to find from Lemma 1 and Lemma 2. Therefore, we omit the demonstration here.

S.6 Proof of Corollary 3

The consumer surplus is $CS = \int_\theta^1 (\theta q - p) d\theta$ and the social welfare is $SW = CS + \pi_{sc}$. According to the model, we have the consumer surplus and social welfare under the wholesale price contract.

S.7 Proof of Proposition 2

The result is easy to find from Lemma 1 and Lemma 2. Therefore, we omit the demonstration here.

S.8 Proof of Lemma 3

DOI: 10.52396/JUSTC-2023-0134
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By replacing the profit function in Lemma 1, the optimal decisions in the traditional channel with a revenue-sharing contract are readily accessible. Therefore, we omit the optimal decision-making proof process here and give the results in the following.

In the traditional channel with a revenue-sharing contract, when $0<\delta<\hat{\delta}$, the optimal decisions are

$$q^*=\frac{1}{3k},\quad w^*=\frac{\phi+3\phi^2}{9k+9k\phi},\quad Q^*=\frac{1-\delta^2}{3+3\phi},$$

$$p^*=\begin{cases}\dfrac{2-\delta+3\phi}{9k+9k\phi}, & N=1-\delta;\\ \dfrac{2+\delta+3\phi}{9k+9k\phi}, & N=1+\delta;\end{cases}$$

where $\hat{\delta}$ corresponds to the unique δ-value satisfying $0<\delta<1$ for solving the formula $\frac{k^3(-2+6\delta-8\delta^3+9\phi^2-9\delta^2\phi^2)(1+\delta)-(-k^2(1+\delta)(2-3\phi^2+\delta(-4+3\phi^2)))^{3/2}}{216k^4(1+\delta)^2(1+\phi)}=0$.

When $\hat{\delta}<\delta<1$, the optimal decisions are

$$q^*=\frac{2k+2k\delta-A}{6(k^2+k^2\delta)},\quad w^*=\frac{\phi(k(1+\delta)(2+3\phi)-A)(2k(1+\delta)-A)}{36k^3(1+\delta)^2(1+\phi)},\quad Q^*=\frac{k+k\delta+A}{6k+6k\phi},$$

$$p^*=\begin{cases}\dfrac{2k(1+\delta)-A}{12k^2(1+\delta)}, & N=1-\delta;\\ \dfrac{(2k(1+\delta)-A)(k(1+\delta)(5+6\phi)-A)}{36k^3(1+\delta)^2(1+\phi)}, & N=1+\delta.\end{cases}$$

By substituting the optimal decisions back to the profit functions, we have: When $0<\delta<\hat{\delta}$,

$$E(\pi_m^{TR})=\frac{1-\delta^2}{27k+27k\phi},\quad E(\pi_r^{TR})=\frac{(1-\delta^2)\phi}{27k(1+\phi)^2},\quad E(\pi_{sc}^{TR})=\frac{(1-\delta^2)(1+2\phi)}{27k(1+\phi)^2}.$$

When $\hat{\delta}<\delta<1$,

$$E(\pi_m^{TR})=\frac{(2k(1+\delta)-A)(A+B)}{216k^3(1+\delta)(1+\phi)},$$

$$E(\pi_r^{TR})=\frac{\phi(2k(1+\delta)-A)(A+C)}{216k^3(1+\delta)(1+\phi)^2},$$

$$E(\pi_{sc}^{TR})=\frac{(2k(1+\delta)-A)((1+2\phi)A+E)}{216k^3(1+\delta)(1+\phi)^2},$$

where $A=\sqrt{-k^2(1+\delta)(2-3\phi^2+\delta(-4+3\phi^2))}$, $B=k(4-3\phi^2+\delta(-2+3\phi^2))$, $C=k(4+9\phi+6\phi^2-\delta(2+9\phi+6\phi^2))$, $E=k(4+8\phi+6\phi^2+3\phi^3-\delta(2+4\phi+6\phi^2+3\phi^3))$.

S.9 Proof of Proposition 3

The result is easy to find from Lemma 1 and Lemma 3. Therefore, we omit the demonstration here.

S.10 Proof of Corollary 4

The proof is the same with proof of Corollary 3. In Corollary 4, the value of $F=k(7+12\phi+6\phi^2+\delta(10+12\phi+3\phi^2))$ and $G=k(23+44\phi+30\phi^2+12\phi^3+\delta(18+28\phi+3\phi^2)-4\delta^2(2+4\phi+6\phi^2+3\phi^3))$.

S.11 Proof of Proposition 4

The result is easy to find from Lemma 1 and Lemma 3. Therefore, we omit the demonstration here.

S.12 Proof of Proposition 5

The result is easy to find from Lemma 2 and Lemma 3. Therefore, we omit the demonstration here.

In Proposition 5, the value of $\hat{\phi}$ corresponds to the unique ϕ-value satisfying $0<\phi<1$ for solving $\frac{(-2+3\phi^2+\delta(4-3\phi^2))A+k(1+\delta)(14+4\phi-9\phi^2+\delta(-8+9\phi^2))}{216k^2(1+\delta)(1+\phi)}=0$.

S.13 Proof of Lemma 4

By replacing the profit function in Lemma 2, the optimal decisions in the drop-shipping channel with a revenue-sharing contract are readily accessible. Therefore, we omit the optimal decision-making proof process here and give the results in the following:

DOI: 10.52396/JUSTC-2023-0134
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$$q^* = \frac{1}{3k}, \quad w^* = \frac{\phi + 3\phi^2}{9k + 9k\phi}, \quad p^* = \frac{2 + 3\phi}{9k + 9k\phi}.$$

By substituting the optimal decisions back to the profit functions, we obtain the supply chain's expected profits:

$$E(\pi_m^{DR}) = \frac{1}{27k + 27k\phi}, \quad E(\pi_r^{DR}) = \frac{\phi}{27k(1+\phi)^2}, \quad E(\pi_{sc}^{DR}) = \frac{1 + 2\phi}{27k(1+\phi)^2}.$$

S.14 Proof of Corollary 5

With a revenue-sharing contract, in the traditional channel, when demand uncertainty is low, $\Delta^{TR} = \frac{2 + 2\phi - 3\phi^2}{9k + 9k\phi}$; when demand uncertainty is high, $\Delta^{TR} = \frac{(2k(1+\delta) - A)(k(1+\delta)(8 + 5\phi - 6\phi^2) - (1 - 2\phi)A)}{72k^3(1+\delta)^2(1+\phi)}$. In the drop-shipping channel, the markup is $\Delta^{DR} = \frac{2 + 2\phi - 3\phi^2}{9k + 9k\phi}$. By comparing the markup in different channels, we find that the markup in the traditional channel is lower than that in the drop-shipping channel when demand uncertainty is high.

S.15 Proof of Proposition 6

The result is easy to find from Lemma 2 and Lemma 4. Therefore, we omit the demonstration here.

S.16 Proof of Proposition 7

The result is easy to find from Lemma 1 and Lemma 4. Therefore, we omit the demonstration here.

S.17 Proof of Proposition 8

The result is easy to find from Lemma 3 and Lemma 4. Therefore, we omit the demonstration here.

DOI: 10.52396/JUSTC-2023-0134
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