Two-echelon fresh product supply chain with different transportation modes

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Abstract
The fresh product supply chain suffers from the quantity loss and quality loss due to its perishability in long-distance transportation, which affect the health of customers and the sustainable development of supply chain. Using low-cost normal temperature transportation or high-cost cold chain transportation has become a problem for transportation enterprises. This paper aims to investigate the impact of different transportation modes on the supply chain performance. The operation strategies of the supply chain are analyzed under three situations: no coordination contract, wholesale price contract, and revenue-sharing contract. Taking Zhanhua winter jujube as an example, the correctness of theoretical analysis is verified. The main findings are as follows. Supply chain participants, including consumers, can benefit from cold chain transportation. That the cost of cold chain transportation is below the threshold is the basic condition to use cold chain transportation. The retailer has the incentive to encourage the supplier to use cold chain transportation by increasing the wholesale price, but the wholesale price should be set within a certain range. The supplier has the incentive to use cold chain transportation under the revenue-sharing contract, but the revenue-sharing proportion needs to be within a certain range to ensure the retailer’s profit. The revenue-sharing contract is superior to the wholesale price contract, and wholesale price contract is superior to no coordination contract.

Keywords  Value loss · Cold chain transportation · Fresh product supply chain · Wholesale price contract · Revenue-sharing contract

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1 Introduction

As we all know, fresh products are more prone to corruption than ordinary products. With the rapid development of e-commerce and logistics, human’s material life is no longer limited to a certain area, but globalization. People’s food, including fresh products such as fruits and vegetables, may come from places of origin thousands of kilometers away. For example, oranges exported from Guangxi, China to Brunei. Cherries from Chile and mangosteen from Thailand are deeply loved by Chinese people. In the process of transportation and storage, these products will not only face the decrease of freshness, which will lead to the decline of customer satisfaction, but also be thrown away because of deterioration, resulting in the loss of quantity. According to the data from "Sustainable Consumption and Production", the twelfth goal of Sustainable Development Goals of United Nations, one third of food products—1.3 billion tons, worth $1 trillion—end up rotting in the dustbins of consumers and retailers each year, or deteriorating due to improper transportation and harvesting every year. One of the specific goal of "Sustainable Consumption and Production" is to halve per capita food waste in the global retail and consumption stages by 2030, and to reduce food losses in production and supply (including post-harvest). This process requires the participation of many parties, including business, consumers, policy makers, researchers, scientists, retailers, media, and development partners. The COVID-19 pandemic reinforces the imperative to improve resource efficiency and promote sustainable lifestyles. Humans should develop strategies to do more and better with less.

In recent years, people’s attention to life and health makes their requirements for fresh and green foods increasing day by day. The freshness seriously affects the market demand of products. Therefore, the adoption of technical means to improve the freshness of fresh products has become an important event affecting the sustainable development of the supply chain and the national economy and people’s livelihood. In fact, the loss of fresh products in circulation in China is much greater than that in other countries (Yang et al., 2017; Yu & Xiao, 2017). The main reason is the gap of modern logistics facilities. With the improvement of consumers’ safety awareness, significant progress has been made in the development of cold chain transportation (Mercier et al., 2017). Cold chain transportation provides cold storage conditions for fresh products. It is understood that if the cold chain equipment is used, the freshness-keeping period of fresh products will be longer, which verifies the timeliness of the cold chain and helps to extend the shelf life of fresh products. If fresh products are transported and stored at proper temperature, the loss of quantity and quality can be greatly reduced.

However, cold chain transportation has high requirements for logistics enterprises. Enterprises not only need to configure specific refrigeration and control systems, refrigeration vehicles and storage equipment, but also require high power consumption and skills of employees. Therefore, the cost of cold chain transportation is higher than that of normal temperature transportation. Especially for some small and medium-sized enterprises, the cost of cold chain logistics is unbearable. When the supply chain chooses different transportation modes, not only the quality and quantity of fresh products are different, but also the decisions such as the ordering quantity (Bai et al., 2016) and pricing (Banerjee & Agrawal, 2017; Widodo et al., 2018) change accordingly. Use cold chain transportation to ensure the freshness of fresh products or use normal temperature transportation to avoid the cost of cold chain transportation? This is the problem that most enterprises need to face.

Based on the above concerns, this paper aims to solve the following problems by using Stackelberg game and backward induction method (Qiu et al., 2020).
(1) How different transportation modes affect the quantity and quality of fresh products from the supplier to consumers?
(2) What strategies can coordinate supply chain participants to reduce the value loss of fresh products? How to apply these coordination strategies?
(3) What are the conditions for the supplier to choose different transportation modes under different coordination strategies?
(4) How to encourage the supply chain participants to use cold chain transportation to maximize the profit of the whole supply chain?

To address the above problems, we will investigate the impact of different transportation modes on the supply chain. First, a two-echelon fresh product supply chain composed of a supplier and a retailer is established. In the supply chain, the supplier is responsible for the transportation service and has two choices of transportation modes which are normal temperature transportation and cold chain transportation. Second, the value losses of different transportation modes the supplier chooses under three situations are analyzed and compared, respectively. The three situations are no coordination contract, wholesale price contract, and revenue-sharing contract. Finally, Zhanhua winter jujube was taken as an actual case for numerical analysis. Through theoretical analysis and case verification, several conclusions are drawn, and some managerial insights are put forward.

To sum up, this paper contributes to the existing research in four aspects.

(1) Because using normal temperature transportation or cold chain transportation affects the quantity and quality of fresh products, the impacts of different transportation modes on the supply chain members are analyzed.
(2) The supply chain contract is established from two aspects: freshness and quantity loss. The impacts of value loss of the normal temperature transportation and cold chain transportation on supply chain under three situations of no coordination contract, wholesale price contract, and revenue-sharing contract are compared, respectively.
(3) The conditions for the supplier to use cold chain transportation under different coordination strategies are obtained.
(4) Put forward the profit concession measures under different coordination contracts to encourage the supplier to use cold chain transportation, and provide decision-making guidance for supply chain managers.

The rest of this paper is organized as follows. Section 2 gives the literature review and summarizes the literature gap and the contributions of this paper. In Sect. 3, the problem description and assumptions are given. The impacts of value loss on fresh product supply chain under the three situations of no coordination contract, wholesale price contract and revenue-sharing contract are analyzed in Sect. 4, respectively. The model results are verified by a practical case in Sect. 5. Discussion and some managerial insights are put forward in Sect. 6. Finally, Sect. 7 draws conclusions and proposes some future research directions.

2 Literature review

There are lots of documents about fresh product supply chain, including pricing, inventory strategy, coordination strategy and so on. This paper considers the choice of different transportation modes in fresh product supply chain under different contracts. Therefore, the studies related to this paper can be divided into two categories: (1) decision-making of fresh product supply chain, (2) coordination contract of fresh product supply chain.
2.1 Decision-making of fresh product supply chain

In view of the perishability of fresh products, many scholars have discussed how to carry out the optimal production (Leung & Ng, 2007; Liu et al., 2015; Zhang et al., 2018) or replenishment strategy (Chakraborty et al., 2018; Huang, 2013; Jaggi et al., 2019; Kiil et al., 2018). Among them, many papers have considered the quantity loss or quality loss in the decision-making process of supply chain (Wu et al., 2018; Yu & Xiao, 2017). Quantity loss was assumed to be constant in the models developed by Hwang and Hahn (2000) and Bai et al. (2016) for deteriorating goods. However, functions were used to express the relationship between quantity loss or quality loss and other factors such as time, which is closer to reality. For example, Herbon et al. (2014) defined quality loss as a quadratic function of time and emphasized the impact of freshness on consumer utility.

Controlling the quality loss and quantity loss brought by fresh product wastage has attracted the attention of scholars and researchers in recent years. It is natural to keep products fresh to control the loss of quantity or quality. Some papers analyzed the equilibrium pricing and service level of supply chain for deteriorating products based on freshness-keeping technology investment (Dye & Yang, 2016; Dye et al., 2018; Ma et al., 2019b; Wang & Zhao, 2021). On this basis, some scholars developed optimal management strategies for superior and inferior products (Chen et al., 2021; Huang et al., 2019) or considered the pre-sale strategies (Zhang et al., 2020). However, the aforementioned studies only considered the changes of the quantity or quality of fresh products, and lacked the research on the changes of both.

Unlike the above, there are related papers that consider both the quantity loss and quality loss of deteriorating products. Most studies used cold chain transportation as a kind of freshness-keeping service to reduce losses (Aiello et al., 2012; Cai et al., 2013; Mercier et al., 2017; Yu & Xiao, 2017). They focused on the storage or replenishment strategies (Hsu et al., 2010; Lee & Dye, 2012) or pricing and freshness-keeping cost input strategies (Cai et al., 2010; Chang et al., 2016; Yu et al., 2020; Zhang & Wang, 2020) of supply chains that retailers invest in freshness-keeping costs. However, retailers are usually only responsible for keeping products fresh during storage rather than during transportation. It is usual for the third-party logistics service provider (TPLSP) or the supplier to provide freshness-keeping services during transportation (Feng et al., 2021; Liu et al., 2021; Ma et al., 2020; Qiu et al., 2020; Song & He, 2019; Wu et al., 2015; Yan et al., 2020b). Further, Zhang et al. (2015) and Moon et al. (2020) considered the interests of the supply chain of deteriorating goods when both the manufacturer and the retailer invested in freshness-keeping efforts. Wang et al. (2020) discussed the game structure between the retailer and the farmer when the farmer invests more in the production of green fresh products and the retailer invests in the packaging and cold chain transportation. From the above studies, it can be found that whoever provides freshness-keeping service can greatly improve the market value of products.

Most of the above studies consider the value loss at a certain stage of the supply chain (such as storage or transportation), but this paper comprehensively considers the value loss of the whole fresh product supply chain. Although the efforts to keep products fresh have not been ignored, there is few studies to compare cold chain transportation with normal temperature transportation, while the choice of transportation mode is important for the supply chain. As far as we know, only Lin et al. (2020) discussed the decision of two transportation modes for vaccines, and concerned about the impact of the two inspection methods of the retailer on the decision of the distributor at the end of transportation. Shui et al. (2021) analyzed the balance between insulation packaging cost and shipping cost when choosing nonrefrigerated vehicles or refrigerated vehicles under the community group purchase model.
2.2 Coordination contract of fresh product supply chain

In the literature, the research on supply chain coordination contracts commonly includes buyback contract, quantity discount contract, cost-sharing contract, revenue-sharing contract, wholesale price contract, and so on. Wu (2013) showed that buyback contract can lead to a higher profit than no buyback in both vertical integration and manufacturer's Stackelberg in competitive supply chains. Chen and Bell (2011) proposed an agreement between the manufacturer and the retailer, which includes two buyback prices, and showed that this agreement can achieve perfect supply chain coordination. Compared with a fixed discount, Venegas and Ventura (2018) found that the non-cooperative model can improve the benefits of the participants when the discount is flexible. Because buyback and quantity discount contracts cannot take the characteristics of short life cycle products into account, they are not suitable for fresh product supply chain. Song and He (2019), Yan et al. (2020b) and Feng et al. (2021) found that cost-sharing contract cannot achieve the coordination of the supply chain. Therefore, the wholesale price contract and the revenue-sharing contract are two common coordination contracts used in fresh product supply chain.

The wholesale price contract is a simple and common form of supply chain contracts. When the supply chain is under the decentralized decision-making mode, it can effectively coordinate the supply chain. Cai et al. (2013) and Huang et al. (2019) used the wholesale price contract to coordinate a fresh product supply chain when distributors determine the level of freshness-keeping effort in product transportation. Fang et al. (2020) and Yan et al. (2020a) designed a wholesale price contract to coordinate the fresh product supply chain under the decentralized decision-making mode. Revenue-sharing contract binds the profits of the supplier and the retailer together, which can coordinate the whole supply chain and improve the overall efficiency. There are many papers on coordinating fresh product supply chain that use it (Ma et al., 2019b; Xiao & Xu, 2013; Yang et al., 2014; Zhang et al., 2015; Zheng et al., 2017). For example, Bai et al. (2016) designed a revenue-sharing contract to coordinate the decentralized supply chain for deteriorating items. Yan et al. (2021) proposed a revenue-sharing contract to achieve a win–win situation for the supplier and the retailer in a fresh agricultural product supply chain.

As mentioned above, the wholesale price contract and the revenue-sharing contract can achieve good coordination effect in the fresh product supply chain. Therefore, this study analyzes the impact of different transportation modes under three situations: no coordination contract, wholesale price contract and revenue-sharing contract, respectively.

2.3 Research gap

Considering the various studies, Table 1 lists partial recent and relevant papers, and compares them from five aspects to clearly fill the research gap. Table 1 is structured based on columns including (1) quantity loss, (2) quality loss, (3) value loss procedure, (4) comparison of transportation modes, and (5) coordination contracts.

As shown in Table 1, due to the perishability of fresh products, many scholars have studied the value loss of fresh products over time. In these studies, some documents only considered the quantity or quality loss of fresh products (Chakraborty et al., 2018; Zhang et al., 2020), and some studies considered both quantity loss and quality loss, but only focus on part of the circulation process (Song & He, 2019; Zhang & Wang, 2020). Although Yu and Xiao (2017) focused on the loss of quantity and quality in the whole circulation process, they emphasized the optimal price and service level decisions under different channel leadership and the
impacts of channel leadership on supply chain members. Moreover, they set the demand as a linear function. However, in this paper, we focus on the decision-making behavior of supply chain under different transportation modes and coordination contracts. As a whole, there are obvious differences between this paper and the above studies.

This paper is closely related to Lin et al. (2020), Shui et al. (2021) and Yan et al. (2020b), which discussed the decision-making of supply chain under different transportation modes. However, Lin et al. (2020) and Shui et al. (2021) only considered the quality loss of products in the transportation process, did not consider the quantity loss in the transportation process, nor consider the value loss in the storage process, let alone the coordination of the supply chain. Moreover, Lin et al. (2020) focused on the impact of the retailer’s inspection strategy

### Table 1 Comparison between this paper and related papers

| Authors (year)      | Quantity loss | Quality loss | Value loss procedure | Comparison of transportation modes | Coordination contracts |
|---------------------|---------------|--------------|----------------------|-----------------------------------|-----------------------|
| Yang and Tang (2019)| –             | ✓            | Storage              | –                                 | –                     |
| Zhang et al. (2020) | –             | ✓            | Transportation       | –                                 | –                     |
| Liu et al. (2021)   | –             | ✓            | Transportation       | –                                 | ✓                     |
| Feng et al. (2021)  | –             | ✓            | Transportation       | –                                 | ✓                     |
| Lin et al. (2020)   | –             | ✓            | Transportation       | ✓                                 | –                     |
| Shui et al. (2021)  | –             | ✓            | Transportation       | ✓                                 | –                     |
| Chakraborty et al. (2018) | ✓     | –            | Storage              | –                                 | –                     |
| Huang et al. (2019) | ✓             | –            | Transportation       | –                                 | ✓                     |
| Yan et al. (2020a)  | ✓             | –            | Transportation       | –                                 | ✓                     |
| Song and He (2019)  | ✓             | ✓            | Transportation       | –                                 | ✓                     |
| Zhang and Wang (2020)| ✓       | ✓            | Storage              | –                                 | –                     |
| Yu et al. (2020)    | ✓             | ✓            | Transportation       | –                                 | –                     |
| Ma et al. (2020)    | ✓             | ✓            | Transportation       | –                                 | ✓                     |
| Qiu et al. (2020)   | ✓             | ✓            | Transportation       | –                                 | ✓                     |
| Yu and Xiao (2017)  | ✓             | ✓            | Transportation       | –                                 | –                     |
| Yan et al. (2020b)  | ✓             | ✓            | Transportation       | ✓                                 | ✓                     |
| **This paper**      | ✓             | ✓            | Transportation       | ✓                                 | ✓                     |
at the end of transportation on the distributor’s transportation modes decision-making. Shui et al. (2021) designed a heuristic algorithm to solve the decision-making of transportation modes. In this paper, Stackelberg game is used to study the decision-making of supply chain with different transportation modes under different contracts. Thus, their research contents and methods are quite different from this paper. Yan et al. (2020b) focused on the formation mechanism of market demand and the equilibrium decision of supply chain resulting from the quantity loss and quality loss of fresh products affecting customer utility. However, our demand function is related to the price and the freshness of products, which is the essential difference. Furthermore, the contracts used to coordinate the supply chain are different. They used revenue-sharing contract and cost-sharing contract, while we use wholesale price contract and revenue-sharing contract.

As far as we know, this paper contributes to the literature from four respects. First, the quantity loss and quality loss of fresh products in the whole processes of transportation and storage are considered. Second, the conditions for choosing different transportation modes are discussed. Third, the impacts of different transportation modes on supply chain members are analyzed. Fourth, the decision-making problems under three situations: with no coordinated contract, wholesale price contract and revenue-sharing contract are explored. These are the supplement and extension of the existing research.

3 Problem description and assumptions

In this paper, a two-echelon fresh product supply chain is composed of a supplier, a retailer and consumers, in which the supplier is the leader of the Stackelberg game and the retailer is the follower. The structure is illustrated in Fig. 1.

In this supply chain, there are two transportation modes for the supplier to ship the fresh products to the market, namely cold chain transportation and normal temperature transportation. The cold chain transportation can improve the freshness of fresh products, thereby reducing the loss of quantity and quality, but the supplier must pay the corresponding cost. There is no additional freshness-keeping cost during normal temperature transportation, but the supplier is responsible for the deterioration of the fresh products during long-distance transportation. In the meanwhile, the storage cost borne by the retailer will be affected. As the leader, the supplier first sets the wholesale price according to the transportation mode it chooses and the value loss. Then the retailer determines the retail price according to the freshness of products when they arrive at the market. Because the storage cost varies with the freshness of products, the retailer has the incentive to encourage the supplier to use cold chain transportation.

Specifically, Table 2 summarizes the parameters and decision variables used in this paper. Market demand is influenced by product price and freshness, the following multiplicative demand form is adopted, which is commonly used in the literature (Chernonog & Avinadav,
Table 2 Symbols and description

| Symbols | Description |
|---------|-------------|
| Subscript \(i\) | \(i = s, t\) represents normal temperature or cold chain transportation, respectively |
| \(cm\) | Supplier’s unit production cost |
| \(ci\) | Transportation cost of per unit product under different transportation modes; \(c_t > c_s\) |
| \(m_i\) | Rate of quantity loss, \(m_t < m_s\) |
| \(t\) | Sales period of products, \(t \in [0, T]\) |
| \(\theta_i(t)\) | Freshness of products at time \(t\) |
| \(T\) | Duration of the sales period |
| \(g(\theta)\) | Impact of freshness on demand |
| \(A\) | Potential market demand |
| \(K\) | Price sensitivity, \(K > 1\) |
| \(I_i\) | Impact of freshness over the whole sales period |
| \(\tau_i\) | Average time a unit product spends on the shelf before being sold |
| \(h\) | Storage cost per unit on the shelf |
| \(w_i\) | Wholesale price per unit product |
| \(p_i\) | Retail price per unit product |
| \(D(p, \theta)\) | Demand function |
| \(Q_i\) | Ordering quantity |
| \(\beta\) | Revenue-sharing proportion |
| \(\Pi_{ri}, \Pi_{si}, \Pi_{Ti}\) | Profit of the retailer, the supplier and the whole supply chain in the decentralized supply chain |
| * | Optimal result |
| Superscript "1" | Decision under wholesale price contract |
| Superscript "2" | Decision under revenue-sharing contract |

\[D(p, \theta) = Ap^{-K} g(\theta(t))\]

The decline of the product’s freshness means the reduction of perceived value from the perspective of customers. Accordingly, \(g(\theta(t))\) is an increasing function of \(\theta(t)\). \(\theta(t)\) decreases with \(t\), and \(\theta(t) \in (0, 1)\). The supplier is responsible for the quality loss, so it should produce and transport adequate quantity \(\frac{Q}{m_i}\) to the market. Suppose \(I = \int_0^T g(\theta)dt\) is the impact of freshness on demand during the whole sales period. \(T\) is the duration of the sales period. We assume that \(T\) is shorter than the shelf life of the product, so the product will not perish during the sales period, which means there is no quantity loss during the sales period. However, the quality loss always exists in the supply chain. When the quality loss reaches a certain degree, the quantity loss is bound to occur. Let \(\tau = \int_0^T \frac{g(\theta)dt}{\int_0^T g(\theta)dt}\) be the average time a unit spends on the shelf before it is sold. The storage cost borne by the retailer is \(h \tau Q\).
The assumptions in the model are as follows.

1. The residual value of the fresh products is assumed to be 0. Wang et al. (2004) showed that this assumption is reasonable for fresh products.
2. In the sales cycle $T$, all fresh products can be sold out (Yan et al., 2020b), and the potential consumer market demand $A$ is the market scale, so it is a constant.
3. The supplier and the retailer are risk neutral and pursue their own profit maximization. This is a common assumption (Hua et al., 2011; Qi et al., 2018; Sun, 2013).

4 Impact of value loss

4.1 Impact of value loss with no coordination contract

4.1.1 Value loss with no coordination contract

According to Sect. 3, the market demand for the fresh products at time $t$ is

$$D_i(p, \theta_i(t)) = AP_i^{-K} g(\theta_i(t))$$

(1)

Therefore, during the sales period $T$, the total order quantity is

$$Q_i = \int_0^T D_i(p, \theta_i(t)) dt = \int_0^T AP_i^{-K} g(\theta_i(t)) dt$$

(2)

The retailer’s profit is

$$\prod_{ri} = (p_i - w_i - h \tau_i) Q_i = AP_i^{-K} (p_i - w_i - h \tau_i) I_i$$

(3)

When $\frac{\partial^2 \prod_{ri}}{\partial p_i^2} < 0$, it means that the retailer has the maximum profit when $\frac{\partial \prod_{ri}}{\partial p_i} = 0$. We can obtain the reaction function of $p_i$ with respect to $w_i$, that is, $p_i^*(w_i) = \frac{K(w_i + h \tau_i)}{K - 1}$.

The supplier’s profit is

$$\prod_{si} = w_i Q_i - (c_m + c_i) \frac{Q_i}{m_i} = AP_i^{-K} \left( w_i - \frac{c_m + c_i}{m_i} \right) I_i$$

(4)

By substituting $P_i^*(w_i)$ into Eq. 4, the supplier’s optimal profit can be obtained. Because $\frac{\partial^2 \prod_{si}}{\partial w_i^2} < 0$, the optimal value of $w_i$ exits. Let $\frac{\partial \prod_{si}}{\partial w_i} = 0$, the optimal $w_i^*$ can be calculated. $p_i^*$ can also be calculated accordingly. The results are shown in Lemma 1.

**Lemma 1** For any realized transportation cost $c_i$, the quantity loss $m_i$ and the average time spent on the shelf $\tau_i$, the supplier’s optimal wholesale price is $w_i^* = \frac{m_i h \tau_i + K(c_m + c_i)}{(K - 1)m_i}$, and the optimal retail price is $p_i^* = \left( \frac{K}{K - 1} \right)^2 \frac{c_m + c_i + m_i h \tau_i}{m_i}$.}

According to Lemma 1, the wholesale price and the retail price increase with the increase of the transportation cost $c_i$ and the average shelf time $\tau_i$. When the transportation cost borne by the supplier is higher, a higher wholesale price should be set to balance its profit. Correspondingly, consumers must pay more for products. From the expressions of $w_i^*$ and $p_i^*$, we can find that the longer the average time spent on the shelf, the higher the wholesale
price and the retail price are. When \( \frac{\partial w_i}{\partial m_i} < 0 \) and \( \frac{\partial p_i}{\partial m_i} < 0 \), the products suffer more quantity loss, the prices set by the supplier and the retailer are higher.

By substituting the optimal prices into Eqs. 3 and 4, we obtain the optimal profits of the retailer and the supplier in the decentralized supply chain, as shown in Eqs. 5 and 6.

\[
\prod_{ri}^{*} = A I_i K^{1 - 2k} K^{1 - K} \left[ \frac{m_i}{cm + c_i + m_i h \tau_i} \right]^{K-1}
\]

\[
\prod_{si}^{*} = A I_i \left( \frac{K}{K - 1} \right)^{-2k} \left( \frac{1}{K - 1} \right) \left( \frac{m_i}{cm + c_i + m_i h \tau_i} \right)^{K-1}
\]

We can find \( \prod_{ri}^{*} = \prod_{si}^{*} = \frac{K}{K - 1} \) in two transportation modes with no coordination contract. The profit ratio of two supply chain participants is related to price sensitivity. Since \( K > K - 1 \), the retailer’s profit is higher than the supplier’s profit.

The profit of the whole fresh product supply chain is the retailer’s profit plus the supplier’s profit, that is

\[
\prod_{Ti}^{*} = A I_i (2K - 1) \left[ \frac{(K - 1)^2 m_i}{cm + c_i + m_i h \tau_i} \right]^{K-1}
\]

### 4.1.2 Comparative analysis of two transportation modes

We can obtain Theorem 1 by comparing the optimal retail price, wholesale price and profits of the supply chain members under cold chain transportation mode and normal temperature transportation mode.

**Theorem 1**

1. When \( m_t (cm + c_s) - m_s (cm + c_t) < \frac{h (\tau_t - \tau_s)}{K} \), \( w_t > w_s \).
2. When \( m_t (cm + c_s) - m_s (cm + c_t) < m_t m_s h (\tau_t - \tau_s) \) is satisfied, \( p_t > p_s \), \( \prod_{ri}^{*} > \prod_{si}^{*} \), and \( \prod_{st}^{*} > \prod_{ss}^{*} \).

Theorem 1 shows that the wholesale price, the retail price and profits of the supplier and the retailer under cold chain transportation mode are higher than those under normal temperature transportation mode when \( m_t (cm + c_s) - m_s (cm + c_t) < \min \{ \frac{h (\tau_t - \tau_s)}{K}, m_t m_s h (\tau_t - \tau_s) \} \).

**Theorem 2** When \( c_s < c_t < c_T \), the retailer can make more profit when the supplier uses cold chain transportation in the decentralized supply chain. \( c_T \) is the threshold of cold chain transportation cost.

When \( \prod_{st}^{*} = \prod_{ss}^{*} \), we can get \( c_T = \left( \frac{h (\tau_t - \tau_s)}{K} \right) \left( \frac{1}{m_t} \right) m_t (cm + c_s + m_s h \tau_s) - c_m - m_t h \tau_s \). The supplier will use cold chain transportation when \( c_s < c_t < c_T \). In this case, the retailer also benefits from this mode. Therefore, when the cold chain transportation cost is within a certain range, all the supply chain participants can get more profits without any incentive scheme. The retailer has the motivation to encourage the supplier to use cold chain transportation. The threshold of cold chain transportation cost is related to the production cost, quantity loss, normal temperature transportation cost, price sensitivity, and the impact of freshness on demand.
4.2 Impact of value loss with wholesale price contract

Regardless of the transportation mode, the supplier and the retailer sign a wholesale price contract before shipping fresh products. After the supplier decides the wholesale price $w$, the retailer orders $Q_i$ products. Then, the supplier produces and transports $Q_i m_i$ to the retailer. After the contract is signed, the retailer must accept the products even if the freshness of the products is low when they reach the market.

4.2.1 Value loss with wholesale price contract

The profits of supply chain members with wholesale price contract are the same as those of supply chain members with no coordination contract when $w = w_t = w_s$. According to wholesale price contract, the wholesale price $w$ is agreed upon by the supplier and the retailer at the beginning of the contract. Regardless of the transportation mode, the transactions must be carried out in accordance with the wholesale price. The profits of the supply chain are

$$\prod_{ri} = (p_i - w - h t_i) Q_i = \int_0^T (p_i - w - h t_i) A P_i^{-K} g(\theta_i(t)) dt = \frac{A I_i}{K} \left(\frac{K - 1}{w + h t_i}\right)^{K-1},$$

(8)

$$\prod_{si} = w Q_i - (c_m + c_i) \frac{Q_i}{m_i} = A I_i \frac{w m_i - (c_m + c_i)}{m_i} \left[\frac{K(w + h t_i)}{K - 1}\right]^{-K},$$

(9)

$$\prod_{ti} = \frac{A I_i (w_i + m_i h t_i + w_i m_i - c_m - c_i)}{K} \left[\frac{K - 1}{w_i + h t_i}\right]^{K-1}.$$  

(10)

4.2.2 Comparative analysis of two transportation modes

**Theorem 3** When $c_s \leq c_t \leq C_T$, the supplier’s profit under cold chain transportation mode is higher than that under normal temperature transportation mode.

**Proof** $\prod_{st}^{1} - \prod_{ss}^{1} = A I_i \frac{w m_i - (c_m + c_i)}{m_i} \left[\frac{K(w + h t_i)}{K - 1}\right]^{-K} - A I_s \frac{w m_s - (c_m + c_i)}{m_s} \left[\frac{K(w + h t_s)}{K - 1}\right]^{-K}$.

When $\prod_{st}^{1} = \prod_{ss}^{1}$, the cost parameter $c_T^{S} = (w m_i - c_m) - \frac{m_i}{m_s} \left(\frac{w + h t_i}{w + h t_s}\right)^{-K} (w m_s - c_m - c_s)$. If $c_s \leq c_t < C_T^{S}$, $\prod_{st}^{1} > \prod_{ss}^{1}$; if $C_T^{S} < c_s \leq c_t$, $\prod_{st}^{1} < \prod_{ss}^{1}$.

When the cost of cold chain transportation is within a certain range, the supplier can be guaranteed to obtain more profit by choosing cold chain transportation. For the retailer, cold chain transportation can make more profit, so the retailer encourages the supplier to use cold chain transportation by allowing the supplier to increase the wholesale price. However, the wholesale price must be within a certain range to ensure that the profits of the supplier and the retailer under cold chain transportation mode are greater than those under normal temperature transportation mode before the wholesale price rises. As showed in Theorems 4 and 5.

**Theorem 4** The supplier uses cold chain transportation when $c_m + c_s < w_T^{S} < w$. Otherwise, the supplier uses normal temperature transportation. $w_T^{S}$ is the lower limit of the wholesale price.
Theorem 5 Under the wholesale price contract, there is an upper limit of wholesale price 
\[
\bar{w} = \left( \frac{t}{T} \right)^{\frac{1}{K-1}} (w + h \tau_i) - h \tau_i \text{ acceptable to the retailer.}
\]

Proof When the supplier increases the wholesale price to \( \bar{w} \), the retailer’s profit is always greater than the supplier’s profit. Therefore, the retailer shares between the supplier and the retailer. According to the discussion of no coordination contract, the proportion can be negotiated based on the actual situation, which deepens the trust. Revenue-sharing contract is a scheme to redistribute profits among supply chain members.

4.3 Impact of value loss with revenue-sharing contract

4.3.1 Value loss with revenue-sharing contract

Revenue-sharing contract is a scheme to redistribute profits among supply chain members. The proportion can be negotiated based on the actual situation, which deepens the trust between the supplier and the retailer. According to the discussion of no coordination contract, the retailer’s profit is always greater than the supplier’s profit. Therefore, the retailer shares 1 – \( \beta \) of its revenue to the supplier to obtain higher quality products.

The retailer’s profit under the revenue-sharing contract is

\[
\prod_{ri}^1 = (\beta p_i - w_i - h \tau_i) A p_i^{-K} I_i
\]  

(11)

The supplier’s profit is

\[
\prod_{si}^1 = \left[ w_i + (1 - \beta) p_i - \frac{c_m + c_i}{m_i} \right] A p_i^{-K} I_i
\]  

(12)

Then the optimal decisions of the supply chain can be calculated as follows:

\[
w_i^2 = \frac{m_i h \tau_i (K^2 \beta - K^2 + K - \beta) + K \beta (K - 1) (c_m + c_i)}{m_i (K - 1) (K - \beta)}
\]

\[
P_i^2 = \frac{K^2 \beta (m_i h \tau_i + c_m + c_i)}{m_i (K - \beta) (K - 1)}
\]

\[
\prod_{ri}^1 = \left[ \frac{\beta}{m_i (K - \beta) (K - 1)} \right]^{1-K} K^{1-2K} \beta^2 A I_i (m_i h \tau_i + (K \beta - K + 1) (c_m + c_i)) (m_i h \tau_i + c_m + c_i)^{-K}
\]

\[
\prod_{si}^1 = A I_i \beta^{-K} K^{-2K} (2 K^2 \beta - K^2 \beta^2 - K^2 + K - \beta) \left[ \frac{m_i h \tau_i + c_m + c_i}{m_i (K - \beta) (K - 1)} \right]^{1-K}
\]
4.3.2 Comparative analysis of two transportation modes

**Theorem 6** The retailer’s profit increases if the supplier uses cold chain transportation when \( c_s < c_t \leq C^R_T \), where \( C^R_T \) is the threshold of transportation cost, which meets \( \prod_{r_i}^2 = \prod_{r_s}^2 \).

When \( \prod_{r_s}^2 < \prod_{r_i}^2 \) and \( c_s \leq c_t \leq C^R_T \), the retailer’s profit increases when the supplier uses cold chain transportation. Therefore, the retailer wants the supplier to choose cold chain transportation mode. The retailer transfers a reasonable profit to the supplier by reducing the revenue-sharing proportion. The incentive scheme encourages the supplier to use cold chain transportation to ensure the freshness of products. However, the retailer should ensure that the profit under cold chain transportation mode is still greater than that under normal temperature transportation mode before transferring profit. Therefore, there is a lower limit of the revenue-sharing proportion. Like the proof of Theorem 4, Theorem 7 can also be obtained.

**Theorem 7** A proper portion of the retailer’s profit \( \hat{\beta} \leq \beta \leq 1 \) should be transferred to the supplier, to encourage the supplier to use cold chain transportation. \( \hat{\beta} \) is the lower limit of revenue-sharing proportion, which satisfies \( \prod_{r_i}^2 - \prod_{r_s}^2 = 0 \), namely

\[
\frac{I_t}{I_s} = \left( \frac{m_i}{m_s} \right) \left( \frac{1 - K}{1 - K} \right) \left( \frac{m_i h_{r_i} + c_m + c_l}{m_i h_{r_s} + c_m + c_l} \right) = \frac{m_i h_{r_i} + (K \hat{\beta} - K + 1)(c_m + c_l)}{m_i h_{r_s} + (K \hat{\beta} - K + 1)(c_m + c_l)}.
\]

If the supplier does not choose cold chain transportation mode under the revenue-sharing contract, the retailer will have to transfer a portion of the profit to the supplier by increasing the revenue-sharing proportion to encourage the supplier to use cold chain transportation. The amount of transferred profit should ensure that the retailer’s profit under cold chain transportation mode is higher than that under normal temperature transportation mode before transferring profit.

**Theorem 8** Under the revenue-sharing contract, the revenue-sharing proportion has an upper limit \( \bar{\beta} \), that is, the acceptable upper limit of the retailer, which satisfies \( \prod_{r_i}^2 = \prod_{r_s}^2 \). \( \prod_{r_i}^2 \) is the retailer’s profit after the revenue-sharing proportion is increased to \( \bar{\beta} \).

5 Case analysis

Zhanhua winter jujube is a unique fruit in Shandong, China. Because of its delicacy and nutrition, it is loved by consumers. Under normal temperature and natural conditions, Zhanhua winter jujube is easy to deteriorate, which affects its freshness and quantity. However, the cost of cold chain transportation is relatively high. The supplier often faces the problem of using normal temperature transportation or cold chain transportation. To help the supplier make the most economical choice, a two-echelon supply chain consisting of a fresh food e-commerce company A and its supplier B is taken as an example in this section.

According to the sales data, the monthly market demand for Zhanhua winter jujube is about 700000 kg. Under normal circumstances, when the unit price of Zhanhua winter jujube...
rises by about 10%, the purchase volume of consumers will be reduced by about 22%. Therefore, the price elasticity of Zhanhua winter jujube is 2.2. The production cost is about 5 yuan/kg, and the storage cost per unit on the shelf is 1 yuan/kg. The transportation price is generally 3 yuan/kg under normal temperature and 5 yuan/kg under cold chain. Under normal temperature, fresh Zhanhua winter jujube can stay on the shelf for 8 days. If the supplier uses cold chain transportation, Zhanhua winter jujube will be sold faster with a shelf life of 4 days. The transportation time from the place of origin to warehouse A is about 2 days, and the quantity loss rate is 0.3 during normal temperature transportation. Under the condition of cold chain transportation at 3 °C-5 °C, the freshness-keeping rate of Zhanhua winter jujube can reach 80%. The wholesale price contract stipulates that the wholesale price is 20 yuan/kg, and the revenue-sharing contract stipulates that the revenue-sharing proportion is 0.9. As a result, the relevant parameters are set in Table 3.

5.1 Decisions with no coordination contract

By substituting the parameters into the relevant equations in Sect. 4.1, the decision variables and profits under different transportation modes are obtained, and the results are shown in Table 4.

The threshold of cold chain transportation cost is 5.97. When \( ct \leq 5.97 \), B uses cold chain transportation; otherwise, B uses normal temperature transportation. When \( ct = 5 \), B uses cold chain transportation even without any incentive mechanism. As shown in Table 4, the profits of both the retailer and the supplier increase. The wholesale price and the retail price under cold chain transportation mode are lower than those under normal temperature transportation mode, which verifies that every supply chain participant, even the consumer, benefits from cold chain transportation. Therefore, A expects B to provide cold chain transportation service. This is consistent with theoretical analysis of Theorems 1 and 2.

5.2 Decisions under wholesale price contract

By substituting the parameters in Table 1 into the equations in Sect. 4.2, when the wholesale price contract stipulates that \( w = 20 \), the threshold of cold chain transportation cost is 6.12. The cold chain transportation cost of supplier B is 5 which is within this range, so cold chain transportation can be used. This proves that Theorem 3 is effective in practice.
In addition, the lower limit of wholesale price can be concluded as 15.59. Figure 2a indicates the relationship between the wholesale price and the supplier’s profit under different transportation modes with wholesale price contract. When the wholesale price is greater than 15.59, the supplier’s profit will be higher under cold chain transportation mode. As illustrated in Fig. 2b, the retailer’s profit is always higher if the supplier uses cold chain transportation. This is consistent with Theorem 4. Under the wholesale price contract, when the contractual wholesale price is greater than the threshold, the supplier can be encouraged to use cold chain transportation by raising the wholesale price.

When the wholesale price contract stipulates that $w = 20$, other parameters remain unchanged. We investigate the upper limit of wholesale price $w$ acceptable to the retailer with the wholesale price contract, where $w = \sigma w = 20\sigma$, which means that the upper limit of wholesale price acceptable to the retailer is $\sigma$ times of the previous wholesale price. In this case, the retailer allows the supplier to charge $\sigma$ times higher than the original wholesale price to ensure cold chain transportation. As shown in Fig. 3, when $\sigma < 1.98$, the retailer’s profit under cold chain transportation mode is higher than that under normal temperature transportation mode. If outside this range, the retailer does not encourage the supplier to provide cold chain service. Therefore, the upper limit of the wholesale price is 1.98 times the original price. This is consistent with the analysis of Theorem 5.

5.3 Decisions with revenue-sharing contract

From Fig. 4, as the retailer gradually shares more profit with the supplier, the change trend of its own profit and the supplier’s profit is the same, increasing first and then decreasing. Based on the theory, with the increase of revenue-sharing proportion $\beta$, the retail price and the wholesale price will increase, and the market demand will correspondingly decrease. When the revenue-sharing proportion is small, the loss of demand reduction is less than the profit increase caused by the rise of the retail price and the wholesale price, resulting in the increase of the profits of the retailer and the supplier. When the revenue-sharing proportion is large, the opposite is true, so the profits of the retailer and the supplier decrease.
As shown in Fig. 4a, if the revenue-sharing proportion is greater than the threshold, the supplier’s profit under cold chain transportation mode is always higher than that under normal temperature transportation mode. Therefore, the supplier is motivated to use cold chain transportation with the revenue-sharing contract. From Fig. 4b, the retailer’s profit under normal temperature transportation mode is greater than that under cold chain transportation mode when $\beta$ is less than the threshold $\hat{\beta}$ with the revenue-sharing contract; otherwise, the profit under cold chain transportation mode is greater than that under normal temperature transportation mode. In this case, to ensure that the retailer’s profit is higher, the revenue-sharing proportion needs to be greater than the threshold $\hat{\beta}$. Figure 4b intuitively shows the management implication of Theorem 7.
Now let the retailer transfer 10% of the revenue to the supplier, and other parameters remain unchanged. $\beta$ denotes the transferred profit amount of the retailer, where $\beta = \lambda \beta = 0.9 \lambda$. The relationship between the retailer’s profit and the amount of transferred profit is shown in Fig. 5.

As can be seen from Fig. 5, when $\beta \geq 0.959 \beta$, the profit of cold chain transportation after profit transfer is higher than that of normal temperature transportation before profit transfer. Thus, $0.959 \beta \leq \beta$ is acceptable to the retailer.

As can be seen from Table 5, regardless of the existence of coordination contract, the profits of both supply chain members and the total profits of the whole supply chain under the cold chain transportation mode are higher than those under the normal temperature transportation mode. By comparing these three situations, the profits of both supply chain members with coordination contract are higher than those with no coordination contract, and the total profits of the whole supply chain are correspondingly higher. In the case of coordination contract, the profits of supply chain members and the total profits of the whole supply chain with the revenue-sharing contract are higher than those with the wholesale price contract. Therefore, the supply chain with coordination contract is better than the supply chain with no coordination contract, and the revenue-sharing contract can better coordinate the fresh product supply chain than the wholesale price contract.

6 Discussion and managerial insights

Through the above analysis, this paper draws many conclusions. There are some similarities and differences between these conclusions and existing relevant literature.
Table 5 Comparison of profits under three situations

| Transportation mode | No coordination contract | Wholesale price contract | Revenue-sharing contract |
|---------------------|--------------------------|--------------------------|-------------------------|
|                     | $\Pi_s^*$                | $\Pi_r^*$                | $\Pi_T^*$               | $\Pi_s^1$          | $\Pi_r^1$          | $\Pi_T^1$          | $\Pi_s^2$          | $\Pi_r^2$          | $\Pi_T^2$          |
| Normal temperature  | 2304.39                  | 4224.71                  | 6529.10                 | 2071.58            | 5639.30            | 7710.88            | 3335.96            | 4594.45            | 7930.41            |
| Cold chain          | 2523.17                  | 4625.81                  | 7148.98                 | 2290.00            | 6106.67            | 8396.67            | 3652.68            | 4815.37            | 8468.05            |
(1) Cold chain transportation is beneficial to the fresh product supply chain, which is similar to the conclusion of Yan et al. (2020b). Cold chain transportation can not only improve the freshness of products and reduce resource waste, but also improve human food safety. For the supply chain, cold chain transportation can improve the profits of participants under certain situations. In the situation with no coordination contract, Yan et al. (2020b) found that there are two thresholds of cold chain transportation cost for the supplier using cold chain transportation. Different from them, the threshold of cold chain transportation cost has only one upper limit in our model.

(2) In the situation with no coordination contract, we find that $\frac{\prod_{i=1}^{K} \pi_i}{\prod_{i=1}^{K} \pi_i} = \frac{K}{K-1}$ under two transportation modes. The profit ratio of two supply chain participants is related to price sensitivity, and the retailer's profit is higher than the supplier's profit. This is contrary to the view of Yan et al. (2020b), that is, regardless of other factors, the supplier's profit is always twice the retailer's profit.

(3) Whether the supplier uses cold chain transportation depends on the cost of cold chain transportation. This is similar to the conclusion of Lin et al. (2020). The supplier will provide cold chain service only when the cost is lower than the threshold.

(4) Wang and Zhao (2021) found that the supplier can be encouraged to invest in cold chain service with the increase of profits, which is consistent with this paper. Increasing the supplier’s profit by investing in cold chain service will greatly stimulate the supplier to provide cold chain service.

(5) Xiao and Xu (2013) confirmed that the revenue-sharing contract can coordinate the fresh product supply chains. They discussed the coordination of supply chain when the revenue-sharing proportion is in two large ranges. However, the model in this paper obtains the specific value range of revenue-sharing proportion.

(6) This paper finds that by formulating the wholesale price contract, the retailer encourages the supplier to use cold chain transportation by increasing the wholesale price, but the wholesale price should be within a certain range. Unlike Yan et al. (2020a), the manufacturer sacrifices the wholesale price to induce the retailer to increase the order quantity. Although both papers use wholesale price contract to coordinate the supply chain, their starting points are different.

According to the above analyses, the following management suggestions and improvement strategies are put forward to help the participants of the fresh product supply chain in which the supplier should bear the transportation cost to maximize profit.

(1) The fresh product supply chain should use cold chain transportation to reduce food waste and improve customer satisfaction.

(2) The supplier should evaluate the cost of cold chain transportation before choosing the transportation mode. It is advantageous only when the cost is below a certain value.

(3) Cold chain transportation can increase the profits of the supplier and the retailer, and the whole supply chain can benefit whether there is a coordination contract or not.

(4) The wholesale price contract and the revenue-sharing contract can coordinate the supply chain, so that the profits of supply chain members with coordination contract are higher than those with no coordination contract. However, the wholesale price or the revenue-sharing proportion should be set within a certain range when the supplier uses cold chain transportation.

(5) Revenue-sharing contract is superior to wholesale price contract, and wholesale price contract is superior to no coordination contract.

(6) As a follower of the supply chain with the wholesale price contract, the retailer has the incentive to encourage the supplier to provide cold chain service.
(7) With the revenue-sharing contract, the supplier has the incentive to use cold chain transportation.

### 7 Conclusions

When the supplier uses normal temperature transportation, the fresh products will cause quantity loss and quality loss, resulting in lower profits and customer satisfaction for supply chain members. The transportation mode also has a great impact on the retailer, which has always been ignored in the previous literature. However, when the supplier uses cold chain transportation, there will be a game among supply chain members due to the high cost of cold chain. This paper identifies the impact of two transportation modes on the performance of a two-echelon fresh product supply chain, and analyzes the value loss of the two transportation modes under three situations: no coordination contract, wholesale price contract and revenue-sharing contract. The following conclusions can be drawn.

(1) The wholesale price and the retail price increase with the increase of the transportation cost and the average shelf time. The higher the transportation cost borne by the supplier, the higher the wholesale price and the retail price.

(2) The retailer is motivated to encourage the supplier to use cold chain transportation because it can benefit from cold chain transportation.

(3) The supplier uses cold chain transportation only when the cost is lower than the threshold $C_T$, which can maximize its own interests. $C_T$ is related to the production cost, quantity losses, normal temperature transportation cost, price sensitivity, and the impact of freshness on demand.

(4) With the wholesale price contract, there are two conditions for the supplier to use cold chain transportation. First, the cost of cold chain transportation is required to be lower than the threshold $C_T$. Second, the wholesale price must be within the specific range of $w_T^S < w < w$. In this way, both the supplier and the retailer can make more profits than under normal transportation mode.

(5) With the revenue-sharing contract, when the cost of cold chain transportation is below the threshold $C_T^R$, the supplier will use cold chain transportation. To protect the benefit of both participants, the revenue-sharing proportion should satisfy $\hat{\beta} < \beta < \bar{\beta}$.

(6) The profits of both supply chain members and the total profits of the whole supply chain under the cold chain transportation mode are higher than those under the normal temperature transportation mode.

(7) The profits of supply chain members with coordination contract are higher than those with no coordination contract. The revenue-sharing contract can better coordinate the fresh product supply chain than the wholesale price contract.

Although the conclusions of this paper put forward the conditions and coordination mechanism for supply chain members to promote the supplier to use cold chain transportation, which can provide guidance for supply chain enterprises to better coordinate the supply chain and improve the quality of fresh products, there are still some limitations. This paper considers the supply chain composed of a supplier and a retailer. However, there are many more complex supply chain structures in real life, such as the structure of multiple suppliers and multiple retailers, suppliers or retailers opening online channels, the TPLSP providing cold chain service. In addition, this paper assumes that both the supplier and the retailer are risk neutral. Although this is a general assumption, it does not apply to every member of the
supply chain. In fact, many supply chain members are risk averse. Finally, as the leader of Stackelberg game, the supplier takes priority to decision-making in this paper, but the retailer may be the leader in the supply chain, in which many large retailers participate. Based on the above limitations, more topics can be considered in future research.

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Declarations

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

References

Aiello, G., La Scalia, G., & Micale, R. (2012). Simulation analysis of cold chain performance based on time-temperature data. Production Planning & Control, 23(6), 468–476. https://doi.org/10.1080/09537287.2011.564219

Bai, Q. G., Xu, X. H., Xu, J. T., & Wang, D. (2016). Coordinating a supply chain for deteriorating items with multi-factor-dependent demand over a finite planning horizon. Applied Mathematical Modelling, 40(21–22), 9342–9363. https://doi.org/10.1016/j.apm.2016.06.021

Banerjee, S., & Agrawal, S. (2017). Inventory model for deteriorating items with freshness and price dependent demand: optimal discounting and ordering policies. Applied Mathematical Modelling, 52, 53–64. https://doi.org/10.1016/j.apm.2017.07.020

Cai, X. Q., Chen, J., Xiao, Y. B., & Xu, X. L. (2010). Optimization and coordination of fresh product supply chains with freshness-keeping effort. Production and Operations Management, 19(3), 261–278. https://doi.org/10.1111/j.1937-5956.2009.01096.x

Cai, X. Q., Chen, J., Xiao, Y. B., Xu, X. L., & Yu, G. (2013). Fresh-product supply chain management with logistics outsourcing. Omega-International Journal of Management Science, 41(4), 752–765. https://doi.org/10.1016/j.omega.2012.09.004

Chakraborty, D., Jana, D. K., & Roy, T. K. (2018). Two-warehouse partial backlogging inventory model with ramp type demand rate, three-parameter Weibull distribution deterioration under inflation and permissible delay in payments. Computers & Industrial Engineering, 123, 157–179. https://doi.org/10.1016/j.cie.2018.06.022

Chang, X., Li, J., Rodriguze, D., & Su, Q. (2016). Agent-based simulation of pricing strategy for agriproducts considering customer preference. International Journal of Production Research, 54(13), 3777–3795. https://doi.org/10.1080/00207543.2015.1120901

Chen, J., & Bell, P. C. (2011). Coordinating a decentralized supply chain with customer returns and price-dependent stochastic demand using a buyback policy. European Journal of Operational Research, 212(2), 293–300. https://doi.org/10.1016/j.ejor.2011.01.036

Chen, J., Tian, Z. W., & Huang, W. (2021). Optimal ordering and pricing policies in managing perishable products with quality deterioration. International Journal of Production Research, 59(15), 4472–4494. https://doi.org/10.1080/00207543.2020.1766715

Chernonog, T., & Avinadav, T. (2019). Pricing and advertising in a supply chain of perishable products under asymmetric information. International Journal of Production Economics, 209, 249–264. https://doi.org/10.1016/j.ijpe.2017.10.002

Dye, C. Y., & Yang, C. T. (2016). Optimal dynamic pricing and preservation technology investment for deteriorating products with reference price effects. Omega-International Journal of Management Science, 62, 52–67. https://doi.org/10.1016/j.omega.2015.08.009

Dye, C. Y., Yang, C. T., & Wu, C. C. (2018). Joint dynamic pricing and preservation technology investment for an integrated supply chain with reference price effects. Journal of the Operational Research Society, 69(6), 811–824. https://doi.org/10.1057/s41274-017-0247-y

Fang, X., Wang, R., Yuan, F. J., Gong, Y., Cai, J. R., & Wang, Y. L. (2020). Modelling and simulation of fresh-product supply chain considering random circulation losses. International Journal of Simulation Modelling, 19(1), 169–177. https://doi.org/10.2507/IJSIMM19-1-C05

Feng, Y. G., Hu, Y., & He, L. (2021). Research on coordination of fresh agricultural product supply chain considering fresh-keeping effort level under retailer risk avoidance. Discrete Dynamics in Nature and Society. https://doi.org/10.1155/2021/5527215
Shui, W. B., Zhao, H. M., & Li, M. X. (2021). Integrated thermal insulation packing and vehicle routing for perishable products in community group purchase. *Discrete Dynamics in Nature and Society*. https://doi.org/10.1155/2021/6673555

Song, Z. L., & He, S. W. (2019). Contract coordination of new fresh produce three-layer supply chain. *Industrial Management & Data Systems, 119*(1), 148–169. https://doi.org/10.1108/IMDS-12-2017-0559

Sun, G. H. (2013). Research on the fresh agricultural product supply chain coordination with supply disruptions. *Discrete Dynamics in Nature and Society*. https://doi.org/10.1155/2013/416790

Venegas, B. B., & Ventura, J. A. (2018). A two-stage supply chain coordination mechanism considering price sensitive demand and quantity discounts. *European Journal of Operational Research, 264*(2), 524–533. https://doi.org/10.1016/j.ejor.2017.06.030

Wang, Y. Z., Jiang, L., & Shen, Z. J. (2004). Channel performance under consignment contract with revenue sharing. *Management Science, 50*(1), 34–47. https://www.jstor.org/stable/30046167.

Wang, G. L., Ding, P. Q., Chen, H. R., & Mu, J. (2020). Green fresh product cost sharing contracts considering freshness-keeping effort. *Soft Computing, 24*, 2671–2691. https://doi.org/10.1007/s00500-019-03828-4

Wang, M., & Zhao, L. D. (2021). Cold chain investment and pricing decisions in a fresh food supply chain. *International Transactions in Operational Research, 28*(2), 1074–1097. https://doi.org/10.10111/jitor.12564

Widodo, E., Prihadianto, R. D., & Hartanto, D. (2018). Multi period pricing for managing local fruit supply chain. *MATEC Web of Conferences, 154*, 1049.

Wu, D. S. (2013). Coordination of competing supply chains with news-vendor and buyback contract. *International Journal of Production Economics, 144*(1), 1–13. https://doi.org/10.1016/j.ijpe.2011.11.032

Wu, J., Teng, J. T., & Skouri, K. (2018). Optimal inventory policies for deteriorating items with trapezoidal-type demand patterns and maximum lifetimes under upstream and downstream trade credits. *Annals of Operations Research, 264*(1–2), 459–476. https://doi.org/10.1007/s10479-017-2673-2

Wu, Q., Mu, Y., & Feng, Y. (2015). Coordinating contracts for fresh product outsourcing logistics channels with power structures. *International Journal of Production Economics, 160*, 94–105. https://doi.org/10.1016/j.ijpe.2014.10.007

Xiao, T. J., & Xu, T. T. (2013). Coordinating price and service level decisions for a supply chain with deteriorating item under vendor managed inventory. *International Journal of Production Economics, 145*(2), 743–752. https://doi.org/10.1016/j.ijpe.2013.06.004

Yan, B., Chen, X. X., Cai, C. Y., & Guan, S. Y. (2020a). Supply chain coordination of fresh agricultural products based on consumer behavior. *Computers and Operations Research*. https://doi.org/10.1016/j.cor.2020.105038

Yan, B., Fan, J., Cai, C. Y., & Fang, J. (2020b). Supply chain coordination of fresh agri-products based on value loss. *Operations Management Research, 13*(3–4), 185–196. https://doi.org/10.1007/s12063-020-00162-z

Yan, B., Fan, J., & Wu, J. W. (2021). Channel choice and coordination of fresh agricultural product supply chain. *RAIRO-Operations Research, 55*(2), 679–699. https://doi.org/10.1051/ro/20201014

Yang, L., Tang, R. H., & Chen, K. B. (2017). Call, put and bidirectional option contracts in agricultural supply chains with sales effort. *Applied Mathematical Modelling, 47*, 1–16. https://doi.org/10.1016/j.apm.2017.03.002

Yu, Y. L., & Xiao, T. J. (2017). Pricing and cold-chain service level decisions in a fresh agri-products supply chain with logistics outsourcing. *Computers & Industrial Engineering, 111*, 56–66. https://doi.org/10.1016/j.cie.2017.07.001

Yu, Y. L., Xiao, T. J., & Feng, Z. W. (2020). Price and cold-chain service decisions versus integration in a fresh agri-product supply chain with competing retailers. *Annals of Operations Research, 287*(1), 465–493. https://doi.org/10.1007/s10479-019-03368-y

Zhang, H. Y., Xu, H. Y., & Pu, X. J. (2020). Comparisons of pre-sale strategies for a fresh agri-product supply chain with service effort. *Agriculture, 10*(8), 324. https://doi.org/10.3390/10080324

Zhang, J. X., Liu, G. W., Zhang, Q., & Bai, Z. Y. (2015). Coordinating a supply chain for deteriorating items with a revenue sharing and cooperative investment contract. *Omega-International Journal of Management Science, 56*, 37–49. https://doi.org/10.1016/j.omega.2015.03.004

Zhang, T., Choi, T. M., & Zhu, X. (2018). Optimal green product’s pricing and level of sustainability in supply chains: effects of information and coordination. *Annals of Operations Research*. https://doi.org/10.1007/s10479-018-3084-8
Zhang, Y. J., & Wang, Z. (2020). Joint ordering, pricing, and freshness-keeping policy for perishable products: single-period deterministic case. IEEE Transactions on Automation Science and Engineering, 17(4), 1868–1882. https://doi.org/10.1109/TASE.2020.2980027
Zheng, Q., Ieromonachou, P., Fan, T. J., & Zhou, L. (2017). Supply chain contracting coordination for fresh products with fresh-keeping effort. Industrial Management & Data Systems, 117(3), 538–559. https://doi.org/10.1108/IMDS-04-2016-0139

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